Real-time 3D Graphic Augmentation of Therapeutic Music Sessions for People on the Autism Spectrum

John Joseph McGowan

Submitted in partial fulfilment of the requirements of Edinburgh Napier University for the degree of Doctor of Philosophy

October 2018

Declaration

I, John McGowan, declare that the work contained within this thesis has not been submitted for any other degree or professional qualification.

Furthermore, the thesis is the result of the student's own independent work.

Published material associated with the thesis is detailed within the section on Associate Publications.

Signed: [redacted]

Date: 12th October 2019

Abstract

This thesis looks at the requirements analysis, design, development and evaluation of an application, *CymaSense*, as a means of improving the communicative behaviours of autistic participants through therapeutic music sessions, via the addition of a visual modality. Autism spectrum condition (ASC) is a lifelong neurodevelopmental disorder that can affect people in a number of ways, commonly through difficulties in communication. Interactive audio-visual feedback can be an effective way to enhance music therapy for people on the autism spectrum. A multi-sensory approach encourages musical engagement within clients, increasing levels of communication and social interaction beyond the sessions.

Cymatics describes a resultant visualised geometry of vibration through a variety of mediums, typically through salt on a brass plate or via water. The research reported in this thesis focuses on how an interactive audio-visual application, based on Cymatics, might improve communication for people on the autism spectrum.

A requirements analysis was conducted through interviews with four therapeutic music practitioners, aimed at identifying working practices with autistic clients. *CymaSense* was designed for autistic users in exploring effective audio-visual feedback, and to develop meaningful cross-modal mappings of musical practitioner-client communication. *CymaSense* mappings were tested by 17 high functioning autistic participants, and by 30 neurotypical participants. The application was then trialled as a multimodal intervention for eight participants with autism, over a 12-week series of therapeutic music sessions. The study captured the experiences of the users and identified behavioural changes as a result, including information on how *CymaSense* could be developed further. This dissertation contributes evidence that multimodal applications can be used within therapeutic music sessions as a tool to increase communicative behaviours for autistic participants.

Acknowledgements

I would like to thank my supervisory team for their enduring and gracious support throughout this project. My Director of Studies Dr Grégory Leplâtre for his guidance and sensibilities, Dr Iain McGregor for his attention to detail and patience, and Dr Imed Romdhani for his advice and enthusiasm. Thanks to the team at Edinburgh Napier University and the Institute for Informatics and Digital Innovation (IIDI) who provided the opportunity and resources for this research, as well as to my fellow PhD students with whom I have shared this journey.

Thanks to David McCluskey, Ewan Sinclair, Bal Cooke, Sensatronic Lab, and the staff at TouchBase Centre for their organisational capabilities, patience and enthusiasm for the project.

Love and thanks to my family, in particular to my Dad Joe, who made so many things possible. Finally, all my love and thanks to my partner Jo for supporting me throughout my entire career, for the sacrifices she has made, and the subsequent changes we have made together.

Associated Publications

McGowan, J., Leplâtre, G., and McGregor, I. (2017). *CymaSense*: A Real-Time 3D Cymatics- Based Sound Visualisation Tool. DIS '17 Companion: Proceedings of the 2017 ACM Conference Companion Publication on Designing Interactive Systems, Edinburgh (DIS 2017).
http://doi.org/10.1145/3064857.3079159

McGowan, J., Leplâtre, G., and McGregor, I. (2017). Exploring Musical Creativity through Interactive Cymatics. HCI '17: Proceedings of the 31st British Computer Society Human Computer Interaction Conference, Sunderland (BHCI 2017).
http://dx.doi.org/10.14236/ewic/HCI2017.67

McGowan, J., Leplâtre, G., and McGregor, I. (2017). *CymaSense*: A Novel Audio-Visual Therapeutic Tool for People on the Autism Spectrum. ASSETS '17: Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility, Baltimore (ASSETS 17).
https://doi.org/10.1145/3132525.3132539

Table of Contents

Index of Figures

Index of Tables

1 Introduction

The research described in this thesis is concerned with audio-visual interaction within a musical environment for people on the autism spectrum. More specifically, it presents an interactive prototype application that enables the visualisation of sound in real time, based on 3D models of Cymatic shapes. Cymatics describes a technique that studies the resultant geometry of sound vibrated through a variety of mediums. This research uses the principles of Cymatics within an application to encourage communication.

1.1 Background

Autism Spectrum Condition (ASC), also known as Autism Spectrum Disorder (ASD), is a lifelong neurodevelopmental disorder that affects how people see the world and interact with others (Baron-Cohen et al., 2009). A 2014 study by the Centres for Disease Control (Preis *et al.*, 2015) found that the condition affects one child in every 68, and has encouraged health professionals to consider ASC as a critical and urgent public health concern. Research has shown that autism is a strongly genetic condition, however, its genetic or biological signature has not yet been identified (Pellicano *et al.*, 2013). As theories regarding its cause are highly debated, there is no known cure, and the condition provides lifelong challenges for those who are on the spectrum. Subsequently, there is a need for evidence-based treatment methods for the development of functional skills. People on the autism spectrum share the following features in their diagnosis, which include: difficulties in social communication and interaction; problems in the use of language and verbal communication; limited and stereotypical behavioural patterns; problems in perceptual processing; inhibited use of their imagination (DePape *et al.*, 2012; Paxton and Estay, 2007; Neale *et al.*, 2002; Parés *et al.*, 2005).

The characteristics of autism are interrelated, thus making it more difficult to address individual challenges on a wider basis. Communication and social skills are required for relationships, independence, and vocation, which subsequently affect the emotional status of the individual (LaGasse, 2014). The National Research Council's Guidelines for Educating children with ASC stated that appropriate social interactions may be some of the most difficult and important lessons a child with autism spectrum conditions will learn (Lord and McGee, 2001). The authors highlighted that educational objectives should include social skills to enhance participation in family, school, and community activities.

From a historical perspective, recognised interventions are largely behavioural based, with applied behavioural analysis (ABA) being the most effective and widely used (Green and Ricciardi, 2015). Some critics, however, have pointed out that ABA relies heavily on responding to auditory stimuli and vocalising responses, which can be difficult for many people on the autism spectrum. In addition, it can be restrictive to the individual's freedom of expression (Bredek *et al.*, 2014).

Music therapy has been around since the 1940s and provides a non-verbal means of communication with autistic clients (Reschke-Hernández, 2011). However, due to the disparate nature of the evidence, academia has still not entirely recognised it as a viable source of therapy for people on the autism spectrum (Green and Ricciardi, 2015). This is largely due to the lack of randomised controlled trials that can be run with groups of autistic people, the nature of the spectrum condition being that no two groups or individuals have the same abilities or requirements. Nonetheless, case studies continue to back the validity and success of music therapy techniques, in particular, the improvisational techniques used by Nordoff and Robbins (Wheeler, 2015). It should be noted that, although sharing commonalities in their approach, a distinction has been made within this thesis between the terms 'music therapy' and 'therapeutic music sessions'. 'Music therapy' is defined as an established psychological intervention delivered by the Health and Care Professions Council (NHS Education for Scotland, 2014), whilst 'therapeutic music sessions' ('music sessions' or 'therapeutic music study') refer to the author's studies run by the music tutor within Sense Scotland (2019). In addition, 'therapeutic music practioners' or 'practitoners' is a general term within this thesis referring to the facilitators of the music sessions.

Therapeutic music practitioners continue to embrace technology within their practice to stimulate the senses of autistic clients. A range of technology from simple iPad apps through to sophisticated music production tools are available and in use within practices (Hourcade *et al.*, 2013). Computers have been shown to provide a certain amount of predictability and stability for people on the autism spectrum, providing an attractive environment due to the lack of human contact and stress involved in reading emotional cues from faces (Golan and Baron-Cohen, 2006).

Representation of music has taken many forms over time, from musical structure represented as notation, through to random algorithmic visualisations based on the amplitude of an audio signal. One aspect of music visualisation that has not been widely explored in this context is that of Cymatics (section 3.6). Cymatics are physical impressions of music created in mediums such as water (see Figure 1-1 below) or through particulate material on a brass plate (Jenny, 1968). As such, they could be considered as analogues of music. Could audio-visual mapping of Cymatic shapes be used to encourage play within a therapeutic environment for people on the autism spectrum? Use of multi-sensory integrative technology has been shown to encourage interaction and independence for people with ASC through the use of tactile, auditory and visual senses (Schaaf and Miller, 2005; Cappelen and Andersson, 2016). Multi-user play could also encourage social interaction and communication between practitioners and clients, or between groups.

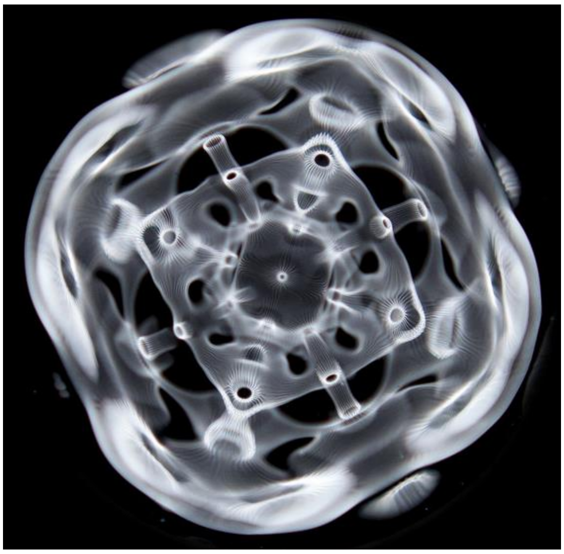


Figure 1-1: Cymatic image of sound vibrated through water (Grant, 2012)

1.2 Research Aim

The aim of this research is to develop and trial a multimodal method that will allow therapeutic music practitioners a novel way to improve communicative behaviours for people on the autism spectrum.

1.3 Research Questions

The main research question and hypothesis related to this thesis is:

> Q: Can augmentation of music sessions with real-time 3D graphics improve therapeutic outcomes for people with autism?
>
> H: Visualisation of sound in therapeutic music practice can increase communicative behaviours for people on the autism spectrum.

In order to fully answer the main research question, three sub-questions have to be addressed:

> Sub-question one (SQ1): How effective is the audio-visual mapping of the developed prototype application (*CymaSense*) for autistic and neurotypical end-users?
>
> SH1: Amplitude to scale, pitch to shape, pitch to colour lightness, and timbre to detail of shape are expected to be effective audio-visual mappings of the prototype application for autistic and neurotypical end-users.
>
> SQ2: What benefits does a shared real-time interactive audio-visual application bring to autistic clients within therapeutic music sessions?
>
> SH2: Increased awareness of sense-of-agency, through visualisation of musical interaction, will increase/improve communicative behaviours for people on the autism spectrum.
>
> SQ3: What are the perceived benefits of the application beyond its use in therapeutic music sessions?

SH3: There will be improvements in the social and musical behaviours of autistic participants, observable by parents, care workers and tutors, following the use of *CymaSense*.

The main research question addresses whether an interactive 3D visual modality within music sessions, can be effective as a therapeutic tool for people on the autism spectrum. Literature on challenges associated with autism, and associated interventions will be reviewed. Practices within music therapy will be examined, as well as visual representation of sound, to establish their combined therapeutic potential.

The three secondary questions will assist in addressing the primary question. Sub-question one seeks to establish whether the designed audio-visual correspondences of the prototype application will be intuitive to both autistic and neurotypical users. Autistic clients and neurotypical practitioners require a shared understanding of musical audio input and visual output of an application to communicate effectively. Cross-modal correspondences are investigated to determine appropriate end-user audio-visual mappings. This question also looks at the requirements of end-users and practitioners, and the efficacy of the application design through small-scale testing of the audio-visual mappings.

Sub-question two addresses the identification of beneficial attributes for autistic clients, and how they may be developed in the use of a shared audio-visual interactive application. Establishing which attributes are important for the development of individuals with ASC are explored, and how use of a collaborative environment can encourage their growth. Assistive technologies are examined to identify their effective characteristics. Through discussion with practitioners, methods and techniques using a prototype application need to be identified and tested. Separate case studies could compare the effectiveness of the process in identifying changes in communicative behaviours.

The third sub-question is concerned with identifying benefits to clients, their families and carers beyond the music sessions. It also aims to establish gains for practitioners through their experience of using a shared novel audio-visual therapeutic application.

If all three sub-questions, and thus the main research question, are successfully addressed, augmentation of music sessions with real-time 3D graphics could be used as an alternative or complimentary audio-visual application within therapeutic music sessions. It may also highlight the potential for alternative forms of multimodal therapy for people on the autism spectrum.

1.4 Dissertation Structure

The dissertation can be broken down into four distinct sections: introduction, literature review, studies and conclusions. Chapter 1 introduces the work, Chapters 2 and 3 incorporate the literature review, and Chapter 4 describes requirements gathering. The *CymaSense* prototype development is illustrated in Chapter 5 and trialled in Chapter 6 through an audio-visual mapping survey. Chapter 7 evaluates the *CymaSense* tool via a 12-week study with autistic participants, while the final chapter (8) draws conclusions and introduces further work.

Chapter 2 defines key terms related to autism spectrum condition, its nature, its known causes and its associated challenges. This literature provides context and a foundation for later studies, illustrating published research that describes how autism can affect individuals in a number of ways. Classifications for the challenges of autism are considered, as are current investment, support and intervention methods. Current methods of intervention for people on the autism spectrum are also examined. In order to create an application that could be used by therapeutic music practitioners it was important to survey current practice. This review focuses on currently established and emerging interventions, and technological approaches used to improve communication and social interaction.

Chapter 3 examines cross-modal correspondences in order to understand the relationship between audio and other sense modalities. In addition, the role of how music is visualised from a theoretical and technological perspective is investigated. This review provides an insight into the approaches used to represent music through analysis, learning and teaching, composition and performance. Visual representation of musical interaction is discussed, as well as the role of Cymatics within the visualisation of sound.

The preliminary requirements analysis reported in Chapter 4 discusses the needs of autistic clients within music therapy, and the relationship of technology within current practice. Interview analysis with two clinical music therapists, one community music therapist, and one music tutor from a charitable organisation is used to identify attributes that could be incorporated within a new prototype application design. Potential ways to improve their methods and the scope for future applications are identified.

Chapter 5 applies the findings of the literature review and interview analysis to a proposed model of interaction for audio-visual synthesis, and the creation of an initial requirements analysis for a prototype application, *CymaSense*. The design of *CymaSense* looks at the needs of end-users relative to musical input and associated visual output. Determination of meaningful audio to visual mappings are discussed and implemented in version one of the application. Associated design and development issues are identified and addressed in version two of the application.

Chapter 6 discusses the first empirical study with *CymaSense*, a mapping survey designed to test the features of *CymaSense* on both a high functioning autistic end-user group, and a neurotypical end-user group. The findings were used to define the audio-visual mappings of *CymaSense* version two, and aid in the development of a subsequent study.

Chapter 7 evaluates the use of *CymaSense* within a 12-week therapeutic music study for eight participants with autism. Quantitative and qualitative methods were employed and the results discussed. The study included observational analysis of a number of musical and non-musical communicative measures within a therapeutic environment. Parents, carers and tutors were asked to complete a questionnaire providing opinions on observable changes in participants' behaviours following the study. Quantitative data analysed from video observation over 12 weeks, indicated that both musical and non-musical communicative behaviours of the majority of the participants had increased in response to use of the intervention. Feedback from the questionnaire and interviews indicated that the application had improved social interaction within the participants.

Chapter 8 includes a summary of the thesis, conclusions, and future work. This chapter also details the strengths and limitations of the research, in addition to the thesis' contributions to the field of multimodal interventions for autism. Future work was identified such as testing alternative user-defined 2D or 3D graphics as a means to visualise sound. The current version of *CymaSense* could be used with other sensory impaired groups to determine its effectiveness in therapeutic scenarios. *CymaSense* allowed visualisation of sound for a variety of inputs, but was found to be computationally expensive. A redesign of the application has been identified to allow use on a wider range of devices and environments.

1.5 Summary

The introduction has provided the background to the research by highlighting some of the issues that people on the autism spectrum have. It has also shown that, although music therapy continues to grow as a positive intervention to improve communication for people with ASC, utilising a multimodal method may widen the appeal and efficacy of therapeutic music sessions for autistic clients. The hypotheses have been presented and the general structure of the dissertation has been outlined. The next chapter discusses the issues associated with autism, current interventions, and methods of evaluation of commonly used interventions, as a basis for the requirements gathering and subsequent design.

2 Autism

The basis of the research conducted for this dissertation falls into three main categories: autism and its challenges; currently available interventions for people on the autism spectrum; and how music is represented from a visual perspective. This chapter describes the general challenges associated within autism spectrum condition (ASC), recognised forms of intervention, as well as less established approaches, specifically music therapy. Also known as autism spectrum disorder (ASD), due to changes to the main diagnostic manuals (American Psychiatric Association, 2013), ASC is now likely to become the most commonly given diagnostic term (G. Kent *et al.*, 2013). However, clinicians will still often use additional terms to help to describe the particular autism profile presented by an individual. It should be noted that many researchers in the past have referred to Asperger's Syndrome (Wing, 1981), a recognised higher functioning end of the autism spectrum. Please refer to Figure 2-1 below for a graphical representation of the extent of the impairment. The figure includes pervasive developmental disorder (PDD), one of several previously separate subtypes of autism that were folded into the single diagnosis of ASC with the publication of the DSM-5 diagnostic manual in 2013 (American Psychiatric Association, 2013).

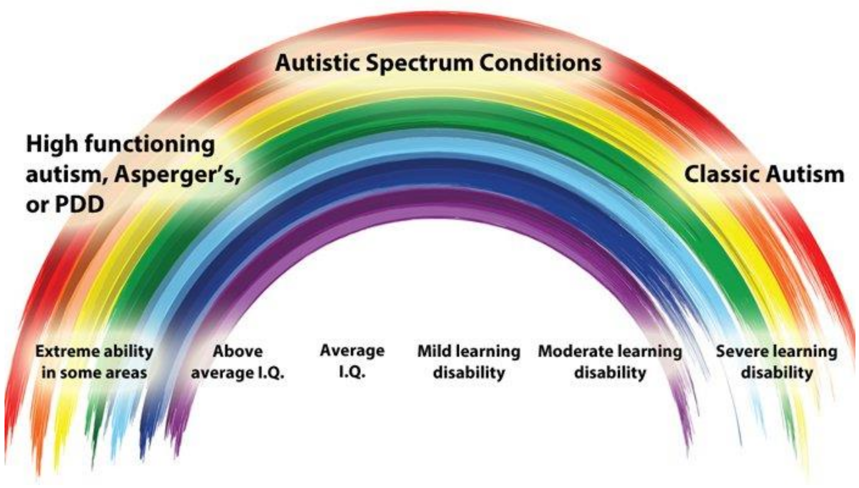


Figure 2-1: Autism Spectrum Conditions (Eden Futures, 2016)

ASC is commonly referred to as consisting of a triad of impairments (see Figure 2-2), which can include problems in communication, social interaction, and imagination, typically described through the activities and interests of an individual (Wing, 1997).

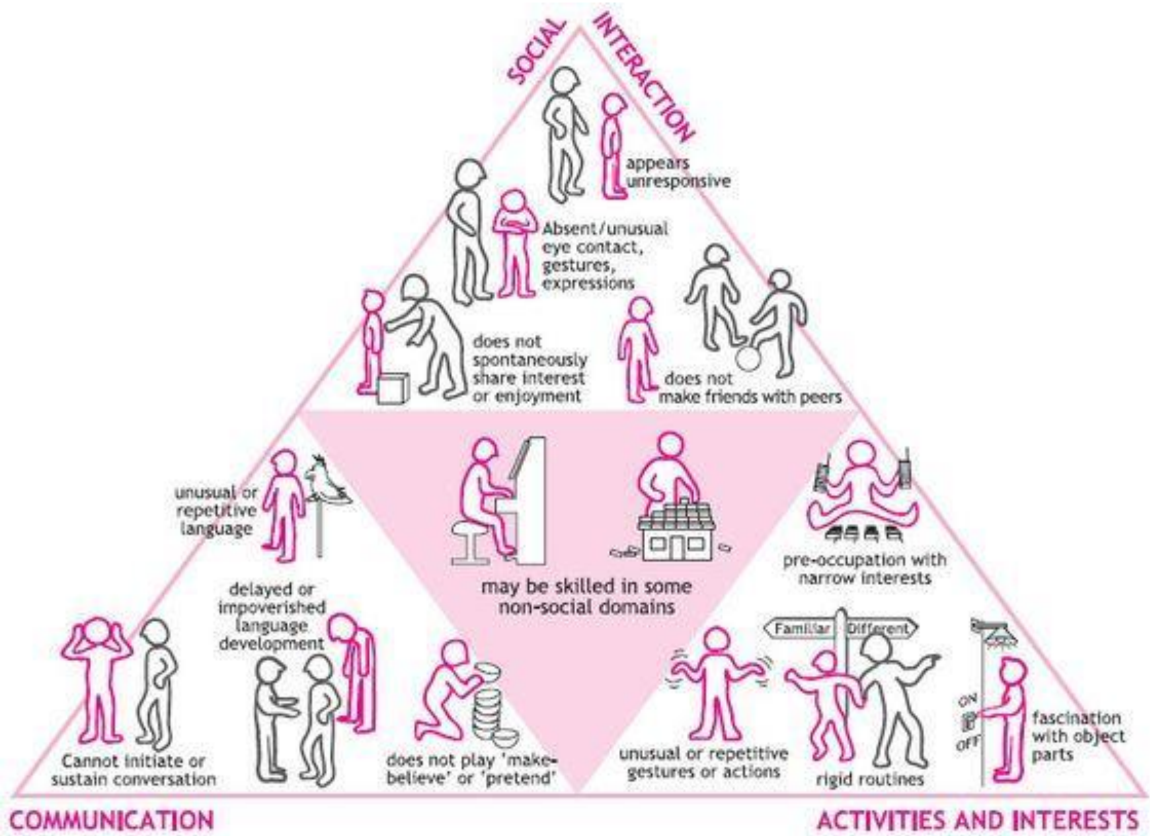


Figure 2-2: The triad of impairments (Autismtopics.org, 2016)

2.1 Challenges

Whilst autism affects both sexes and is a lifelong condition, a simplification of the challenges has been made here for the sake of clarity. Table 2-1 below, represents an overview of the challenges facing both people on the autism spectrum, and for those supporting people with ASC. As many of the challenges are connected, individuals can encounter them to a greater or lesser degree.

Challenges with Autism				Challenges Supporting Autism
Communication	**Social Interaction**	**Agency and Emotional Regulation**	**Cognitive Processing and Sensory Awareness**	**Investment, Support and Technical Intervention**
Verbal --- Eye Contact --- Literal Use of Language --- Misunderstanding Metaphor	Eye Contact --- Turn-Taking --- Facial Expression --- Family Isolation --- On-Line Etiquette and Safety --- Relationships --- Non-Disclosure of Condition --- Social Ignorance of Condition --- Social Isolation	Repetitive Behavioural Patterns --- Mental Isolation --- Depression --- Illness --- Managing Change --- Motivation --- Daily Living Skills --- Anxiety --- Agoraphobia	Hyposensitivity, Hypersensitivity of All Senses --- Use of Imagination --- Poor Hand-Eye Coordination --- Local and Global Processing --- Learning to Learn	Academic Focus on Cognition --- Lack of Applied Solutions for Intervention --- Lack of Support for Adults --- Lack of Consultation of Autistic Users --- Poor HCI --- High Costs

Table 2-1: : Autism and its Challenges (Tager-Flusberg *et al.*, 2013; Robledo *et al.*, 2012; Dennis *et al.*, 2001; Aigen, 2012; Paxton and Estay, 2007; a. Hillier *et al.*, 2012; Bredek *et al.*, 2014; Norwich, 2014; Simpson and Keen, 2011; Putnam and Chong, 2008)

2.1.1 Communication

Speech and language impairments have been regarded as one of the most significant deficits relating to autism (Tager-Flusberg *et al.*, 2013). Developments in research have indicated that people with autism have different neural organisation compared to those without. Magnetic resonance imaging studies have identified widespread atypicalities in brain regions involved in social behaviour and other core ASC-related behavioural deficits (Hernandez *et al.*, 2015). They established that the corpus of imaging studies in autism have led to an emerging model of abnormal developmental connectivity, a dynamic model that accounts for both genetic liability and environmental influences that shape early brain development. Those not affected by a developmental disorder, to a considerably lesser degree, are often referred to as neurotypical (Webster, 2017). Difference in neural organisation can lead to an overload of sensory information and motor regulation difficulties that ultimately can impact daily functioning, including social and communication skills (Robledo *et al.*, 2012). Many studies, which focused on the language of children with ASC, identified aberrant speech features. For example, unusual word choice, pronoun reversal, echolalia, incoherent discourse, unresponsiveness to questions, aberrant prosody, and a lack of drive to communicate (Rapin and Dunn, 2003). Tager-Flusberg (2003) suggested there may a number of subgroups on the autism spectrum that reflect different kinds of language disorder. Tager-Flusberg identified two language phenotypes in those with verbal abilities – children with normal linguistic abilities and those with autism-impaired language similar to the phenotype found in specific language impairment. However, Tager-Flusberg (2003) also commented that a significant number of children never acquire speech, and suggested it is unlikely that all these children remain mute for the same reasons.

Research on written language in high functioning students with ASC, indicated that their written work displayed more variability, was more brief than their neurotypical (NT) counterparts, and less complex (Myles *et al*., 2003). The authors noted that students with ASC produced significantly less legible letters and words than the NT group, and generally, their work suffered more from a qualitative perspective. However, the notion that people on the autism spectrum do not want to communicate might be misguided. Rather, as self-advocates with autism indicate, they have the inability to follow through or tolerate the desired interaction (Goddard and Goddard, 2012; McGinnity and Negri, 2005). Communication deficit in autism can manifest itself through the inability to create and sustain appropriate conversation, use of repetitive language, and problems in using spoken language (Shamsuddin *et al.*, 2012). This may also be expressed as a difficulty in comprehension of metaphorical language, as much of what is verbally communicated can often be taken literally (Dennis *et al.*, 2001). Dependent on the severity of the disorder with each person, studies involving children with ASC have found verbal ability can range from seemingly unaffected to completely non-verbal (Wigram and Gold, 2006).

2.1.2 Social Interaction

Social skills are considered to lie at the heart of individual development (McClelland *et al.*, 2000). A study by Jones and Schwartz (2009), examined communication patterns between high functioning children with autism and their families and typically developing children and their families within traditional dinner time conversation. Jones and Schwartz have shown that children with autism are less likely to initiate interaction in conversation (Figure 2-3), and seemingly become less sympathetic and interested in continuing to interact with whom they have established contact. In addition, people on the autism spectrum commonly have difficulty in understanding facial expressions and other cues that NT people take for granted, thus potentially alienating them further from their peers (Abirached *et al.*, 2011). The self-conscious awareness of their condition combined with increasingly complex issues and apparent inability to do anything about it, hinders childhood development and may increase impairment and distress as they approach adolescence (Tantam, 2003). Subsequently, limitations with social skills and interactions in childhood can have negative consequences including: employability; living independently; developing meaningful social relationships; as well as exacerbation of mental and physical health problems (Strain and Schwartz, 2001). This can ultimately lead to withdrawal and a life of social isolation (Caltabiano, 2010).

Figure 2-3: Problems with social interaction lead to isolation for children with ASC (Autism Link, 2014)

Young adults with autism can face further difficulties because of their attitude towards the condition from a social perspective. A study by Fabri and Andrews (2014) on autistic students' characteristics, revealed that some people on the autism spectrum prefer not to disclose their condition, unless there are clear benefits for them doing so (Davidson and Henderson, 2010). Huws and Jones (2008) identified that some students with ASC reject the 'label' of diagnosis, a term that they use to refer to the negative connotations the effects of labelling may have. Others do not consider autism a deficit, and in the US a third of autistic students do not identify themselves as being disabled (Anderson *et al.*, 2014). Fabri and Andrews (2014) highlight the stigma of the 'broken' student in higher education where the student is perceived as the problem and not the institution, indicating that the focus seems to be on perceived deficiencies rather than strengths. These studies highlight the need for greater understanding of the condition, and more effective integration of those with ASC within educational establishments. Silberman (2019) raised awareness of this by highlighting the positive qualities of autistic individuals, focusing on strengths and unique abilities as a basis for advocating for neurodiversity (Autistic UK, 2019). He defined neurodiversity as naturally occurring cognitive variations with distinctive strengths, rather than as a checklist of symptoms (Silberman, 2019).

2.1.3 Agency and Emotional Regulation

Agency is described as the experience of initiating and controlling one's own actions and producing desired changes in the world via these actions (Zalla and Sperduti, 2015). People on the autism spectrum are said to be unconscious of the amount of control they can exert over their environment and obtain a coherent response, even when it is they themselves who are responsible for changes in their environment (Parés *et al.*, 2005). They have little appreciation of the cause-and-effect a NT person takes for granted, thus increasing a sense of a lack of agency and frustration. This can lead to problems in emotional regulation of that individual. Sensory overload can also lead to repetitive and maladaptive behaviours within children with ASC. Typically this takes the form of gazing at objects for long periods of time, repetitive spinning of toys, rocking of their bodies or hand-flapping, as well as self-injurious, aggressive behaviours and tantrums (Dominick *et al.*, 2007; Hartley *et al.*, 2008). This type of behaviour can reduce opportunities to learn through social interaction and their environment, resulting in a negative impact in their overall development (Richler *et al.*, 2010). For example, someone who is in a constant state of rocking, will not be easy to engage with, or someone with auditory awareness problems might not hear their name being called or respond to their environment (Miller *et al.*, 2007).

The isolating nature of this condition has shown higher rates of anxiety and depression, regardless of intellectual and linguistic abilities (S. Parsons and Mitchell, 2002; Hosseini *et al*., 2015). This has prompted researchers to find solutions to a disorder where relatively little is known concerning its causes (Michaud and Theberge-Turmel, 2002; Bishop et al., 2017). Since the 1960s, substantial research has focused on behavioural analysis approaches, with many adapting Skinner's contributions as a basis for ASC interventions (Ferster, 1964; E. K. Morris *et al.*, 2005). This approach provides some success in terms of treating symptoms, but does not address the core emotional deficits of people with ASC (Paxton and Estay, 2007). Issues of low self-esteem, anxiety and attitudes towards relationships with peers can create additional negative physical and psychological illnesses (Hillier *et al.*, 2012). Communication and relationship development, with individuals lacking in a sense of agency and emotional regulation, requires addressing through appropriate intervention.

2.1.4 Cognitive Processing and Sensory Awareness

Autism is associated with hypersensitivity and/or hyposensitivity of the senses, which in turn can affect the cognitive processes of that individual (DePape *et al.*, 2012; The National Autistic Society, 2016; Morris and Picard, 2009). Abnormal visual, tactile and auditory processing within people with ASC can manifest itself in the way information is processed locally, at the expense of global information. For example, people on the autism spectrum can locate visually embedded figures more easily within complex geometry than NT individuals (Plaisted *et al.*, 1999). Other people have severely abnormal reactions to tactile stimuli, for example, the feeling of sand or uncooked rice on the hands can evoke crying, avoidance, or fear (Bredek *et al.*, 2014). Bredek *et al.*

also highlighted that from an auditory point of view, some children are overly sensitive to auditory stimuli to the point that it interferes with their learning. For example, a blender, a school bell, or a motorcycle driving past, can evoke fear and avoidance responses (see Figure 2-4).

Figure 2-4: Hypersensitivity in autism often leads to children wearing ear protection (Guardian News and Media Limited, 2017)

Alternatively, some people on the autism spectrum demonstrate sensory seeking behaviour, like hand flapping or rocking. Tomchek and Dunn (2007) discovered that over 90% of children with ASC demonstrated behaviour related to poor sensory modulation. If the behaviour is not challenged by caregivers, it may reinforce a stimulus-reaction cycle, whereby the autistic person will not escape the behavioural pattern. It was suggested by Tomchek and Dunn that the key, from the perspective of modifying hypersensitivity to sound, for example, was to gently introduce background noise into the environment whilst encouraging positive coping behaviours (Bredek *et al.*, 2014). DePape *et al.* (2012) noted that people on the autism spectrum have a higher incidence of perfect pitch, which in itself can have advantages as a musician, but disadvantages in speech prosody. She commented that the pure melodic tone of the voice is detected rather than its relative undulating nuances, which can result in a lack of focus on human conversation. These issues can subsequently create difficulties in verbal communication (section 2.1.1).

Other sensory attributes include light sensitivity as another common theme amongst people on the autism spectrum. This can result in nausea, physical pain or panic attacks, which can create restrictions on the potential environments in which they feel comfortable. For example, some children and adults with autism suffer severe reactions to new forms of energy-efficient lighting, commonly within fluorescent lighting (The National Autistic Society, 2016; Grandin, 2009). Consequently, some campaigners have urged the government to continue making traditional forms of lighting available to the small number of people that are affected.

Ludlow *et al.* (2014) hypothesised that colour obsession in autism may be related to hyposensitivity, while colour phobias may be related to hypersensitivity, in the affected regions of colour space (section 2.1.4). In terms of design considerations for software or technology-based solutions for autistic users, a study by Putnam and Chong (2008) suggested that users be allowed to set their own colour. Alessandrini *et al.* (2014) suggested that therapists allowed lower functioning autistic children the ability to choose their own colours and drawing materials for storytelling, as a necessary means of expressing themselves and feeling comfortable.

One of the most recognised deficits in ASC has been noted through pretend play and false belief. This involves non-literal behaviour and perspective taking, for example, pretending something is happening that is not, thus creating and sharing a false belief with a peer (Tarbox and Persicke, 2014). According to Baron-Cohen *et al.* (1985), people with ASC show deficits in attributing and understanding the mental states of themselves with others, and so lack the ability to take another person's perspective. This can lead to problems in communication - for example, in a conversation the speaker and listener need to adopt each other's perspectives to be effective interaction partners (Chin and Bernard-Opitz, 2000). The authors suggest that without this mental ability, people with autism may talk endlessly about a topic that interests only them, assuming that their conversation partner remains interested. There may be a subsequent failure of the autist, to understand that their chosen conversational topic may bore or even irritate the listener, making the communicative exchange one-sided and restricted (Ricks and Wing, 1975). Baron-Cohen *et al.* (1985) term this hypothesis 'theory of mind', while Frith and Leslie have described it as 'mind blindness' (Frith, 1994; Leslie and Frith, 1987). This will be further discussed in section 2.2.

2.1.5 Investment, Support and Technical Intervention

ASC is a lifelong condition, and support for people on the autism spectrum seems to be lacking for the adolescent and adult community, partly due to the rising numbers of people being diagnosed with ASC at the beginning of the 21st century (Hillier *et al.*, 2012; Waterhouse, 2008). It has even been noted that there exists more support for parents of autistic children than for adults on the autism spectrum (Paxton and Estay, 2007; Robertson, 2010; Nicolaidis *et al.*, 2013).

Autistica (2018), a leading autism research UK-based charity, state that just £6.60 is spent on research per autistic person per year, while in comparison, £90 is spent on dementia research per patient per year (Alzheimer's Society, 2018). A report by Norwich *et al.* (2014) stated that almost £21 million was invested in autism research in the UK between 2007 and 2011 across 106 projects, the majority of the projects mostly directed towards children. However, only 11 of these were directly targeted towards adults. Simpson and Keen (2011) agree that there is little research in the 11 to 18 year old age range on the efficacy of music interventions. Only 18% of this funding was targeted towards finding effective services and interventions for people on the autism spectrum and their families, while 56% was focused on cognitive research. These included grants focused on cortical development, social cognition and animal models of autism (Pellicano et al., 2013). Generally, feedback from the Pellicano *et al.* study shows that the causes of autism are creating the most interest as opposed to the ways in which help can be generated for those who need it. Two main problem areas are highlighted. Firstly, the lack of research into applied areas, especially public health and social care, education and sociology. Additionally, the nature of decision-making, whereby autistic people, their family members and practitioners are rarely involved in the decision-making processes that shape the research and applications. Fabri and Andrews (2016) confirm this lack of consultation with young autistic adults people regarding the design of new technology for their use.

In terms of the success of technological interventions, a study by Dawe (2006) found that a surprisingly high percentage of assistive technology devices (35% or more) were purchased, but not successfully adopted. Putnam and Chong (2008) noted that there was very little evidence of useful technology designed with the user goals in mind. A survey aimed at autistic users asked about the effectiveness of software and technology from the user's perspective in terms of meeting their goals, and aligning to their interests and strengths. It found that, while experiences were generally good, only 25% of respondents had tried technology designed for people with cognitive disabilities and only 7% had used technology designed specifically for people with autism. A more recent report by The National Academies of Sciences (2017), found that data on the prevalence of use of the assistive products and technologies, and the extent to which they mitigate the impacts of impairments, were fragmented and limited.

However, other studies also highlighted the positive experience that involvement in a participatory design process can offer the autistic population. Findings from a 2012 study (Benton *et al.*, 2012) revealed that children with ASC were able to successfully participate and collaborate with other autistic children in designing a math-based game. In designing creative spaces for people with ASC, Makhaeva *et al.* (2017) highlighted that the common contradictory misconception between autism and creativity, generated by those outwith autism and therapy, could be overcome. They introduced a theoretical tool known as '*Handlungsspielraum'* (roughly translated as *action*, *play*, *space*) that could be applied to practical projects through subtle interplay and space that allowed meaningful participation. By combining a well-known activity with familiar, but slightly modified elements, Makhaeva *et al.* indicated that autistic participants felt free to appropriate them in original ways. In the *OutsideTheBox* project, the authors' method supported them in systematically developing tailored co-design activities with autistic children to design interactive "smart" objects. For example, based on one participant's desire "to start their day in a good mood" and considering their difficulties getting up in the morning, they developed the idea of a personalised alarm clock, which consists of three components. 1) The alarm clock itself showing the time and providing a mechanism to set an alarm. 2) A pillow that starts shaking once the alarm goes off. 3) A floor mat that is used to turn the alarm off (see Figure 2-5). This is further evidenced in a study by Mora-Guiard *et al.* (2017) where a full-body interaction system, *Lands of Fog*, was co-designed and created by children with ASC and neurotypical children. Results indicated that the system was successful in fostering motivation, socialisation and collaboration. Moreover, the system was positively perceived by both children and school professionals.

Figure 2-5: The alarm clock developed for the *OutsideTheBox* project (right) and several impressions from its development (Frauenberger et al., 2017)

For a more extensive list of challenges and interventions, as defined by the Scottish Government, refer to Table 2-2. The majority of the challenges identified, relate to the development of an autistic individual's communication and improved social interaction, which extends to their families.

ASC Challenge	Current Intervention: including advice, therapeutic interventions and counselling
Understanding the implications	Post diagnostic discussion and counselling Education and information packs for individuals, families/carers Use of visual props if needed Signposting to useful websites and forums
Developing communication	Individualised language therapy assessment Alternative and augmentative communication systems introduced where required Teaching/learning on internet etiquette and supervision
Developing social communication	Targeted social communication programmes delivered either individually or in a group
Relationships	Work to assess the understanding of relationships and promotion of skills to develop relationships including sexuality issues and intimate relationships Access to social groups, friendship circles etc.
Social isolation for ASC individuals	Accessible social groups, befrienders and opportunities Respect the need to be alone at times Acceptance by families that friendships can take many forms
Social isolation for family	Family/ Partner/ Carer support, opportunity for respite Access to autism friendly environments
Learning to learn skills	Functional assessment of the person's cognitive abilities and learning style leading to a planned programme
Predicting and managing change	Timely individual direct work with individuals to teach methods where required Visual supports, timetables, timers, text alerts, choice boards etc.
Behaviour and emotional regulation	Assessing behaviour, recognising triggers and developing and managing the implementation of strategies to help Behaviour support plans, cognitive interventions, psychotherapy or counselling Work with the individual's family/carers, criminal justice, social work, Police Autism Alert card possession
Restricted and repetitive interests and behaviours	Assessment and positive day to day management on an individualised basis Treatment by mental health clinician
Motivation issues	Structured programmes Career guidance, employer/HE/FE support
Sensory Issues	Assessment of difficulties Identification and implementation of strategies Environmental adaptation on an individual basis
Daily living skills	Assessment of core life skills Specific individual programmes Involvement of families/carers in assessment and implementation of new learning
Co-existing conditions (examples)	Epilepsy, dyspraxia, dyslexia, disorders of attention, sensory impairment, anxiety, sleep disorder, addiction, anger management, depression, self-harm, psychosis, personality disorder, OCD, disordered eating patterns etc.

Table 2-2: ASC Challenges and Interventions (Government, 2013)

While there is a large variability in the way autism affects individuals, there are many similarities, including problems in communication, sensory dysfunction, behavioural problems and social interaction, which can lead to other mental and physical health issues (Tager-Flusberg *et al.*, 2013; Schaaf and Miller, 2005; Parés *et al.*, 2005; Parsons and Mitchell, 2002). These challenges continue to be tackled through a number of interventions including traditional behavioural techniques and contemporary technologies. The following section discusses some of the current interventions, focusing on difficulties in communication and social interaction as examples.

2.2 Current Interventions for Autism

Research Autism (2017), a UK-based charity dedicated to the evaluation and review of a wide range of autism-related interventions, provide an overview including: service based; healthcare; behavioural; psychological; medical; and sensory, amongst others. The interventions are rated according to the amount and quality of scientific evidence, which has been published in peer-reviewed journals that supports or does not support the effectiveness of that intervention. Common interventions that concern improving social communication for autistic children are highlighted in Table 2-3.

The United States-based National Autism Center's National Standards Project phase 2 report (NSP2), has updated a number of established interventions for autistic individuals, which include: Behavioural Interventions; Comprehensive Behavioural Treatment for Young Children; Language Training; Naturalistic Teaching Strategies; Parent Training; Schedules; Scripting; Self-Management; and Social Skills packages (Green and Ricciardi, 2015). The phase 1 report did not recognise Social Skills packages as an established intervention (National Autism Center, 2009), whilst Reichow and Volkmar (2010) stated that only video modelling and social skills group interventions had the requisite research to be considered evidence-based treatment interventions. The authors highlighted that there were a number of interventions directed at improving social skills in autistic people; however, they suggested that no conclusive evidence yet exists to demonstrate the efficacy of one over another.

Intervention	Description
Social stories	A short story that describes the salient aspects of a specific social situation that a child may find challenging. They also explain the likely reactions of others in a situation and provide information about appropriate social responses (Delano and Snell, 2006)
Peer-mediated strategies	Normally developing peers are selected and trained to facilitate improved social interaction of children with autism (Laushey and Heflin, 2000)
Video modelling	A teaching method which consists of children viewing models on video, performing specific behaviour for the viewers to imitate (Paterson and Arco, 2007)
Cognitive-behavioural training	Also known as social-behavioural learning, this provides a set of rules to attend to relevant social cues, process and respond appropriately (Bock, 2007)
Pivotal response training	Derived from applied behavioural analysis (ABA), and is play-based and child initiated. Therapist targets “pivotal” areas of a child's development. These include motivation, response to multiple cues, self-management and the initiation of social interactions (Autism Speaks Inc., 2017; Jones and Feeley, 2009).
Theory of mind	Deficits in attributing and understanding the mental states of themselves and others, so lack the ability to take another person’s perspective (Baron-Cohen *et al.*, 1985). An intervention guide was divided into three instruction areas (Howlin *et al.*, 1998): 1. **Emotion:** Activities designed to help children understand the emotions of others 2. **Informational States:** Offers instruction in simple and complex visual perspective taking; understanding that “seeing leads to knowing”; predicting actions based on a person’s knowledge; understanding false-beliefs. 3. **Pretend Play:** Activities to promote the development of play skills from the child’s current level of functioning to pretend play.

Table 2-3: Social Skills Interventions

Behavioural interventions are recognised as the largest established means of intervention by the National Autism Center (Green and Ricciardi, 2015). The purpose of applied behaviour analysis (ABA) is to provide flexibility for children with ASC, not to instil a rote method of learning or routine. Relating to Theory of Mind intervention, play can encourage an improvement in gross and fine motor skills in NT children; however, for people on the autism spectrum it has to be developed further (Baron-Cohen *et al*., 1985). Tarbox and Persicke (2014) suggested that interventions that encourage development of different skills through play are of great importance, as the love of play can encourage flexibility and learning. They commented that during typical childhood development, independent play begins with an exploratory phase, where a child is interested in the properties of an object. Following this is sensorimotor play, where the cause-and-effect of action and reaction is learned. The final phase is manipulative play, where complex actions with familiar objects or toys can produce a pleasurable experience. Tarbox and Persicke also describe interactive play as a means of involving eye contact, facial recognition, emotional recognition and physical contact. Again, many children with ASC do not engage in these types of play interaction behaviour, especially at an early age when it is considered key for development.

Sensory abnormalities differ greatly across people on the autism spectrum. The Center for Autism and Related Learning (CARD) suggest that visual sensory input designed for intervention, may be the most common modality that requires modification in planning treatment for children with ASC (Bredek *et al.*, 2014). Visual modifications refers to the use of textual stimuli (written or typed words), iconic stimuli (pictures or picture representations), or motor responses (such as sign language or gestures) that are used in place of or in conjunction with speech or auditory stimuli. Communication via means other than speech is commonly referred to as augmentative and alternative communication (AAC). These are systems developed for people with autism with little or no language capabilities (Wilkinson and Jagaroo, 2004). Augmentative and alternative communication can supplement or replace spoken and written language in a number of ways, using images or symbols (see Figure 2-6). The picture exchange communication system (PECS) developed by Frost and Bondy (2001) has demonstrated its effectiveness as a means of communication in children with ASC. However, Ganz *et al.* (2012) suggested the approach imposes limitations to the teaching of requesting items. The Frost and Bondy system uses basic behavioural principles and techniques such as shaping, differential reinforcement, and transfer of stimulus control via delay to teach children functional communication using pictures (Charlop-Christy *et al.*, 2002). Typically, the pictures are kept in a notebook and then stuck to a board in the construction of a basic sentence, teaching a child to initiate requests and respond to questions. A number of applications have also appeared for tablet computers, such as *iCan*, where the focus is on replacement of a paper-based system with an electronic one, thereby reducing the workload on caregivers and clients (Tang *et al.*, 2013).

Figure 2-6: An example sports themed Picture Exchange Communication System (Bilingual Speech Therapist, 2016)

A common concern about using non-vocal means of communication is that it may hinder the acquisition of vocal speech. However, this could be considered a misconception, as research has documented that the utilization of AAC promotes the acquisition and use of speech to communicate (Charlop-Christy *et al.*, 2002).

The use of colour as intervention has been used in a number of ways. For example, as a means of reinforcing the organisational needs of an autistic child within a learning environment, a teacher may use coloured 'wait' cards as a visual cue, typically a blank red card (Bredek *et al.*, 2014). The aim is to teach the child to wait before impulsively responding when demonstrating functional communication. A study by Taheri *et al.* (2015) demonstrated that changing colour within the eyes of interactive robots reinforced joint attention skills in autistic children. Serret *et al*. (2014) also used colour within a serious game, *JeStimule*, to teach children with autism social interaction and emotion recognition, through the association of colour with virtual characters.

2.2.1 Music Therapy

Music therapy is considered an effective approach for addressing language and communication skills for children with autism (Kaplan and Steele, 2005; Lim, 2007; LaGasse, 2014). A number of interventions using music have been utilised as people on the autism spectrum often show an interest in music – listening to, playing and creating their own, in the same way that the general population (Hillier *et al.*, 2012). A level of predictability within musical structure offer people on the autism spectrum a channel of communication through which to express themselves, that has resulted in many benefits. Lim states that the inherent structure of music stimuli and intact capacity of pattern perception and production in children with ASC, can have a positive effect on speech production (Lim and Draper, 2011).

For example, therapeutic interventions involving music have shown enhanced social interaction with peers (Kern and Aldridge, 2006a; Wimpory *et al.*, 1995), as well as enhanced peer interactions (Kern and Aldridge, 2006b). They have improved verbal communication (Shore, 2003; Kaplan and Steele, 2005; Lim and Draper, 2011) and social greeting routines (Kern *et al.*, 2007). Music-based interventions have enhanced self-esteem (Shore, 2003), reduced anxiety and improved mood (Trevarthen, 2002; Hillier *et al.*, 2015). They have also increased eye contact (Wimpory *et al.*, 1995; Kim *et al.*, 2008), enhanced cognitive social skills (Ulfarsdottir and Erwin, 1999) and improved joint attention behaviours (LaGasse, 2014; Kalas, 2012; Kim *et al.*, 2008). An autism-based study in 2012 indicated that functional processing systems were more effectively engaged for song than for speech (Lai *et al.*, 2012). These areas coincided with a greater activation of frontal-posterior networks, suggesting that musical stimuli may engage children with ASC more effectively, thus increasing their learning capabilities and providing evidence of music therapy's validity.

As people on the autism spectrum are known to have difficulties in communication and expression of emotions through language, music therapy can provide them with a non-verbal means of interaction (Wigram and Gold, 2006). Meaningful communication, between therapist and client, and exchange of emotional ideas can thus potentially take place across a common communication channel (Erkkilä, 2004).

As Cross (2010) notes, regardless of the differing cultural relationships that exist with music around the world, the fact that we are all human provides the capacity for cultural musical engagement of some kind.

One therapeutic approach, the Orff-Schulwerk Method (Hollander *et al.*, 1974), emphasises the rhythm of speech through the use of song and dance within groups. It could be considered a useful approach to regulating interaction and communication in autistic children (Hosseini *et al.*, 2015). Its basic idea is the integration of the performing arts - music and movement specifically – but also speech and drama. The Orff-Schulwerk Method involves reiterating the part of a child's natural behaviour in which autistic children require assistance. For example, in developing play through imitation, exploration, improvisation and creation (Shamrock, 1997).

Improvisational forms of music therapy have been noted for their potential to provide a meaningful framework that, similar to early mother-infant interaction, encompasses relevant features of social communication. For example, being embedded in a shared history of interaction, having a common focus of attention, turn-taking, as well as musical and emotional attunement (Geretsegger *et al.*, 2012; Gattino *et al.*, 2011; Jinah Kim *et al.*, 2008; Kim *et al.*, 2009).

There are many forms of music therapy; however, according to Wheeler *et al*. (2012), the five main internationally recognised models include the following:

Analytical Music Therapy – this focuses on the use of symbolism in improvised music as a psychological tool to break down barriers in the mind-set of the client (Wheeler, 2015).

The **Behavioural Approach** to Music Therapy uses reinforcement principles to shape behaviour, development and or medical issues, where music is used to accomplish therapeutic aims (Madsen, 1999).

The **Benenzon Model** of Music Therapy draws from psychology, music, philosophy and literature, and focuses on non-verbal communication using an active physical approach, to imitate, reply to and communicate with a client (Benenzon, 2007).

The **Guided Imagery and Music (GIM) model**, also known as the **Bonny Method**, has been used as an intervention for psychosocial disorders and as treatment for depression. It focuses on using music, typically classical, within a directed therapy program in combination with altered states of consciousness to bring about transformation and well-being (Lin *et al.*, 2010).

Nordoff Robbins has been a music therapy based charity since the late 1950s, originally created with the intention of treating children with autism (Trevarthen *et al.*, 1998). Since then, the organisation has developed and includes many other types of disability. Music therapy is seen as a means to bring about change in clients using creative and improvised musical communication. The relational-improvisational music therapy approach used is considered a more dominant and dynamic way to approach healing compared to receptive therapy where someone merely listens to music (Pavlicevic *et al.*, 2013).

Music therapy is designed to reach out to vulnerable people in society, reduce social isolation and improve communication that can result as a consequence of their physical or mental condition (Cross, 2014). Benenzon (1999) agrees that social isolation is a problem that many people deny, non-autistic included, that can lead to other illnesses. Vulnerable people have a variety of needs, and music therapy has been shown to help with the aid of the five internationally recognised forms of therapy. Not all of the successes of music therapy are easy to quantify, however, as they can integrate medical, educational, sociological, psychological and musicological discourses within their practices (Pavlicevic *et al.*, 2013). Consequently, this can lead to many funding bodies asking for longer term objective studies to back up existing case histories (Pavlicevic, 2014). The National Autistic Society (2015) recognises that there is a limited amount of low quality research suggesting the benefits of such. Simpson and Keen (2011) recognise there is limited evidence to back up the efficacy of music interventions, but that more research needs to be conducted, particularly within more naturalistic settings.

Typically, music therapy involves the use of traditional acoustic instruments: the piano, alternative types of percussion, and use of the voice. Few studies, however, have focused on high functioning (HF) people on the autism spectrum, and young adults with ASC, using less traditional music interventions (Hillier *et al.*, 2012). Paxton and Estay (2007) noted that efforts to treat HF people on the autism spectrum may be resisted by the recipients. They commented that behavioural interventions could be seen as being forced upon them, unless a level of understanding can be reached concerning use of the intervention. Goldsmith and Leblanc (2004) commented that people on the autism spectrum are attracted to technology in the same way that NT teenagers are. Furthermore, they highlighted that use of technology in shared spaces for people with ASC, like mobile devices and laptops, will result in having them blend in with society rather than stand out from it. They suggested that this approach would yield positive results for a section of the ASC population currently underrepresented.

Culture, context and resources are important aspects of working with any client in facilitating successful therapy. Music therapy has to reflect their life, thus providing context and meaning. This is evidenced in a study concerning the combination of music therapy with theatre working toward and creating a performance (Brandalise, 2015). An approach by Stige and Aaro (2012), which is supported by Pavlicevic and Ansdell (2009), is known as Community Music Therapy (CoMT). It questions the idea that therapists should always work with their clients in a clinical setting, but rather views music therapy practice as being a more culture-centred and context-sensitive activity. Stige and Aaro describe CoMT as a cross-disciplinary form of therapy and difficult to define. It was only established as an international discourse through articles and books after the year 2000. Table 2-4 presents seven characteristic qualities or features that help define CoMT through the acronym PREPARE.

Name	Description
Participatory	Expertise of participants and therapists are valued
Resource-oriented	To mobilize, create access to, and redistribute social, cultural and material resources, thus enabling the solving of problems in daily life
Ecological	Exploration of systemic perspectives on practice
Performative	Action and performance of relationships
Activist	Recognition of how people’s problems are related to limitations in society, and involves a willingness to act for social change
Reflective	Collaborative attempts to understand the processes, outcomes and implications
Ethics-driven	Human needs and limitations are taken into consideration

Table 2-4: Seven characteristic qualities that help define CoMT (Stige and Aaro, 2012)

Conversely, this approach also provides challenges by introducing a new and unpredictable setting for the autistic clients (Brandalise, 2015). However, Brandalise suggests this risk could help to expand confidence through social interaction and environmental change. He goes on to say that, music therapy does not necessarily have to be a one-to-one sit-down over an instrument. It can be an augmentation of the people on the autism spectrum's interests. For example, creating songs for theatrical performance, or verbally or musically supporting their ideas. Moreover, research by Koegel and Koegel (1995) has shown that peers can be considered as interventional factors for improving social skills in autistic children. CoMT, by its very nature, could therefore provide opportunities for learning social skills such as imitation, turn taking, social reciprocity, joint attention, shared affect, and empathy.

Improved social behaviour has also been noted through group music therapy sessions where the use of a musical object sustained attention to peers (Sussman, 2009), and in an outdoor play-based setting (Kern and Aldridge, 2006b). This lends credence to the concept of an audio-visual intervention in its potential as a tool to facilitate social skills.

Music as a therapeutic approach may not always be best served within a clinical setting. A study by Ruud (2013) highlighted the historical and ritualistic aspects of making music as both a cure and preventative practice that has been superseded by the bio-medical model and the rise of 19th century positivism. Traditions dating back to Pythagoras and the ancient Greeks saw the use of music as a functional means to purify the mind from everyday noise and maintain psychological balance (West, 2000). Ruud (2013) has noted that there are currently two main trends within music therapy: the medical model relying on an evidence-based approach; and a community-based approach operating within an ecological and systematic ideology encouraging therapists to work outside established health institutions (Stige and Aaro, 2011). Each of these trends are dependent on the skills of the music therapist, however, everyday self-help practices like listening to music or playing a musical instrument, can aid individuals independently (Ruud, 2013).

Another approach used primarily for developing communication and social skills in autistic children is known as Musical Interaction (Prevezer *et al.*, 2012). Developed by Sutherland House School (Autism East Midlands, 2018), the aims of their approach include a shared fun experience; engagement of pupils in joint activities with a familiar adult; promotion of eye contact, turn taking, imitation and initiating interaction; expression of emotion through musical play; promotion of self-awareness, choice making, self-esteem and emotional well-being. These aims incorporate many aspects of Community Music Therapy, and as such could be considered a stable foundation in the creation of a useable technology for people with ASC, by augmenting the key goals.

Music Therapy has been listed by Research Autism (2017) as having limited positive experience. Each intervention is rated according to the amount and quality of scientific evidence that has been published in peer-reviewed journals that supports or does not support the effectiveness of that intervention. Similarly, the National Autism Center's National Standards Project phase 2 report only list music therapy as an emerging intervention for children and adults under the age of 22, or as being an unestablished intervention for adults (Green and Ricciardi, 2015). This could be attributed to an area of study where the lack of quantitative evidence does not provide the level of validity other areas take for granted. It is well documented in autism literature that there is limited intervention outcome regarding adults with ASC, and despite broadening the inclusion criteria for the adult literature, only 27 articles (28 studies) met criteria for inclusion in the 2015 review.

However, many instances in research demonstrate that music therapy can have a positive effect on communication in children with autism (Cross *et al.*, 2013; Sundberg *et al.*, 1998). Moreover, the Centre for Autism and Related Disorders (CARD) list the use of music and movement within their applied behaviour analysis (ABA) program to encourage verbalisation and gesturing with peers in a classroom setting (Tarbox and Persicke, 2014). Another study by Lim and Draper (2011) compared applied behavioural analysis verbal behaviour without music (ABA VB), against ABA VB with music, in order to develop speech-language training. The results indicated that music could be a successful stimulus in the enhancement of functional verbal production. A study evaluating the effects of interactive reading materials within an educational setting, proposed that the use of music with other forms of intervention, like visual cues, improved the social skills of autistic students (Carnahan et al., 2008). Results from the study indicated an increase in students' engagement with the use of interactive reading materials in comparison to traditional reading aloud.

In general, the focus of the topic being reported within this subsection is not on the psychological, interpretive and cultural reasons related to why we listen to music. However, some aspects are relevant in connection to the relationships that develop as a result of musical communication between human beings, regardless of their abilities. Music as an interactive process has received little attention in studies - western society in general sees music as a commodity for hedonic consumption (Cross *et al.*, 2013). Cross (2010) suggests that the act of listening to music is in itself an act of communication. Thus, music therapy can be considered a non-verbal act of communication. In a wider context, there is a need to develop hypotheses to be able to examine why music can affect social interaction on a cultural level, and to test the idea of music as therapeutic via quantifiable means. Music seems to be the preferred medium of dealing with difficult situations in a social situation. Cross *et al.* (2013) highlight, for example, that music is commonly chosen before spoken word in situations like funerals, marriages and initiation rites.

Two features of music as communication, relevant in therapeutic terms to those with ASC as defined by Cross *et al.* (2013), are:

Entrainment – this is when the behaviours of two or more people become periodically aligned in time, allowing each participant to anticipate, predict and align their sound-producing behaviours to those of others. Himberg (2006) recognises that regular pulse patterns are important in organising contributions from participants, which he calls 'reciprocal adaptation'. Research into neural activity conducted by Janata and Grafton (2003) suggests that music may be involved in a perception-action cycle rather than a one-way flow of information. Some of the earliest studies to demonstrate coordination of brain activity across interacting individuals explored musical interaction (Lindenberger *et al.*, 2009).

An increasing amount of evidence indicates that when people entrain their behaviours with one another, they experience magnified effects on their memory and attitudes in themselves and towards each other (Miles *et al.*, 2010; Miles *et al.*, 2009). By playing together in time, participants are likely to experience a greater sense of social interaction (Keyfitz and McNeill, 1996). Hosseini *et al.* (2015) also identified that group synchronous movements during rhythmic actions or music-making, as well as unison singing, helped create a state of social cooperation, shared purpose, and a sense of togetherness. This can eventually bring a social connection between individuals. Research by Abrams *et al.* (2013) has shown that even joint music listening can activate similar brain networks across individuals and that these networks share a common time-course of activation. According to LaGasse (2014), the rhythmic and structural components of music stimuli may provide an external cue or anchor to further help people with ASC to organise, predict, and respond to their environment. LaGasse (2014) suggests that this could provide additional time to plan a series of actions required for social interaction.

Floating intentionality - Cross *et al.* (2013) commented that people experience music as though it has intention and meaning, but that this is always particular to an individual. Each participant has their own immediate, but personal experience, which is paradoxical in that they share that experience with another, but the explicit nature of that experience is non-verbal and can be considered subjective. This makes it ideal for situations of social uncertainty, including communication between an autistic person and a therapist within music therapy. It becomes less abstract and more personified, and in the process less universal (Cross, 2010). The reciprocal act of playing music together, when personas are removed, can create a more reliable channel of communication.

Music is described as a non-verbal language that humans subconsciously develop associations with through rhythm, dynamics, pitch, and other attributes. Krumhansl (1992) observed that we seek familiarity within the frequency of certain pitches to provide us with a certain amount of stability – a simple example being the birthday song being sung, indicating a happy occasion. She commented that new dynamic structures are incorporated and integrated into our experience (Krumhansl, 1992), like one of many telephone ringtones, that become part of the background noise of everyday life. Described by Castellano *et al.* (1984) as a process of schematization, studies conducted on music and listeners from a range of cultures and cultural contexts, suggest that we form and reconfigure them continually, regardless of background. Meyer (1956) proposed that our experience of the on-going flow of music, including all non-speech and speech sounds, takes the form of a continual process of expectation formation. Interruption or delay of the realisation of these expectations activates our limbic systems and results in the experience of affect. Confirming this theory, Panksepp and Bernatzky (2002) commented that the emotional response we feel towards music, as human beings, arises from the operation of systems that are evolutionarily designed to ensure preparedness for action. Additionally, a study by Koelsch *et al.* (2006) found that when listening to ‘pleasant’, as opposed to ‘distorted’ music, one of the brain areas found to be strongly activated was the Rolandic operculum. This part of the brain is implicated in planning vocal behaviour, specifically, laryngeal and tongue movement, as though music involuntarily prepares the participant for singing. These studies may highlight the link between music therapy as a useful tool against motor regulation and communication difficulties within autism.

Research has noted that the use of music to regulate stress, enjoy and relax with, is intertwined in the everyday rather than a transcendent pleasure (Bossius and Lilliestam, 2012; DeNora, 2000). Ruud (2013) argued that music therapists typically will have their own ontological views of what music is, and thus their own practices are driven by those views. However, Ruud suggested competing theories as to why music is important should not be the issue. Rather, Small (1999) suggested, that we recognise the listener as integral to any musical experience as much as the composer and the written score or artefact that the performance is recorded on. As Small noted, music must be understood as a practice and a process, as something experienced, rather than as an object. The context and situation, therefore, plays a major role in how the music is perceived and meaning attributed (Ruud, 2013). The physical health and psychological benefits of singing in a choir, for example, have been well documented by Clift *et al.* (2010). Benefits include releasing tension; increasing breathing capacity; maintaining muscular and skeletal systems; enhancing positivity and happiness; increasing self-confidence; and even measurable therapeutic results against depression.

One of the limitations of music therapy is the lack of evidence that it has on the enduring effects on a client's life outside of the clinical or group setting that the sessions take place (Reichow *et al.*, 2011). Clinical music therapy makes attempts to constantly evaluate and review its work with clients in order to facilitate the most effective treatment; however, additional empirical evidence is needed to confirm long term benefits (Hillier *et al*., 2012).

2.2.2 Assistive Technologies

Odom *et al.* (2015) commented that the increase of technology in interventions and teaching strategies that affect the daily lives of individuals with autism is reflected in a large number of studies that have emerged in recent years. The results of a meta-analysis by Grynszpan *et al*. (2014) provide support for the continuing development, evaluation, and clinical usage of technology-based intervention for individuals with autism spectrum disorders. Audio-visual hardware used in therapeutic environments for people on the autism spectrum includes the use of motion sensor technology. SoundBeam (2018) is an invisible electronic keyboard controlled by body movement (Figure 2-7), and can be played without the need for any prior musical knowledge (Villafuerte *et al.*, 2012). As successful as SoundBeam has become over its lifetime, some have questioned its level of usability and cost. Villafuerte *et al*. (2012) pointed out that there is no doubting its accessibility for clients with limited motor skills, however, it requires training to use and is expensive. The Microsoft Kinect (Microsoft Corporation, 2012) has also been used as a motion sensing technology in a number of applications designed for low functioning (LF) people on the autism spectrum, including the *Somantics* suite (Cariad Interactive, 2018b). The *Somantics* applications use touch and gesture as user input, and are discussed in the Software Applications section. The Kinect is less expensive than SoundBeam and has shown adaptability within a number of gestural-based interaction studies (Kuchera-Morin *et al*., 2014; Mora-Guiard *et al*., 2017; Ortega *et al.*, 2015; Zhang *et al.*, 2016).

Figure 2-7: SoundBeam (YouTube, 2015)

SensoryPaint (Ringland *et al*., 2014) is a gestural interactive system designed to encourage body and sensory awareness in children with ASC. The system allows users to 'paint' with coloured balls whilst showing a digital reflection of themselves on the screen before them (Figure 2-8). A camera tracks the movement of the balls and triggers the interactions with sound. The results demonstrated that a large multimodal display, using whole body interactions combined with tangible interactions and interactive audio, balanced children's attention between their own bodies and sensory stimuli, and promoted socialisation. In their work, Ringland *et al.* discuss the importance of natural user interfaces (NUI) where combinations of multimodal interactions with physical objects augment sensory integration. As noted by Kientz *et al.* (2013), NUIs should mimic instructional scaffolding techniques to allow adoption and teaching of any new technology to users with minimum disruption to their established routines.

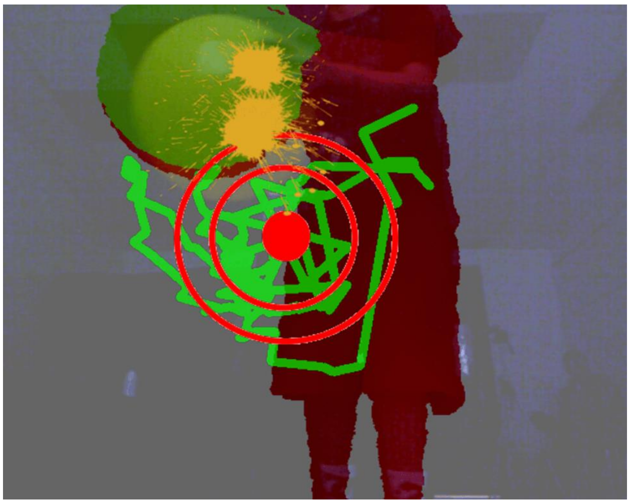


Figure 2-8: *SensoryPaint* screen example (Social and Technological Action Research Group, 2017)

RHYME (2016) was a five year research project (2011-2016) financed by Research Council of Norway (2016) through the VERDIKT programme. Its goal was to improve health and life quality for persons with severe disabilities, through a participatory design process known as “co-creative tangibles”. These were ICT based, mobile, networked and multimodal objects, which communicate following musical, narrative and communicative principles. RHYME focused on the designed qualities of the environment, and specifically on multi-sensorial and musical interaction design. Fowler (2008) described multi-sensory environments (MSE) as offering controlled sensory experiences, for people with profound and multiple disabilities, to provide positive changes in moods and emotional states over long periods of time. RHYME project’s *Polly World* (Cappelen and Andersson, 2016), was a fourth generation MSE that consisted of tactile surfaces embedded with technology. This included five soft and light-responsive touch-sensors, four soft bend-sensors, one textile embedded web-camera, a microphone, a back-projection screen, and several speakers (see Figure 2-9).

Figure 2-9: Family playing in the multi-sensorial environment Polly World (Cappelen and Andersson, 2016)

A number of objects tagged with RFID-tags could trigger 50 different interactive music scenes that also affected dynamic projected visuals and light colour. Other toys and artefacts acted as musical objects that could be played with (see Figure 2-10). The aim for end-users was to learn over time that combinations of interactions with the objects could create alternative multi-sensory feedback. This provided users with a variety of options where there were no wrongs, in a user functionality sense, only potentially unsatisfactory choices, in a musical or aesthetic sense.

Figure 2-10: Artefacts with RFID-tag to play music with based on users' desires and liking (Cappelen and Andersson, 2016)

Cappelen and Andersson (2016) have identified that the layered design and diversity of sensorial experiences allowed users to explore and develop their motivation, playability and learning over a longer time period.

Another interactive system is the MEDIATE environment designed for children with severe autism (Parés *et al.*, 2005). The authors argued lack of a sense of agency within an autistic child could be counteracted via a cause-and-effect interactive environment that mirrored the movements of the body in a variety of ways (see Figure 2-11). The initial phase of tests was successful, however, Parés *et al.* commented that the technology was not portable, and thus not accessible on a regular basis for potential participants.

Figure 2-11: A user interacting with the MEDIATE environment (Parés *et al.*, 2005)

Similar technology has since become available in the form of portable apps designed for laptop or tablet computers. A list of the best mobile autism apps has been compiled by Autism Parenting Magazine (2018). Portable apps may provide an accessible means to engage in cause-and-effect interactions, while sacrificing scale and immersive experience for the sake of accessibility. Some apps for autism are discussed in section 2.2, on Software Applications.

Research within a controlled setting may report success on the efficacy of new applications. However, there is a lack of data concerning the longer term benefits, for example, in the way that software-based interventions have affected clients in their day-to-day home life (Putnam and Chong, 2008). There are concerns that visual stimuli could be a distraction for people on the autism spectrum within a therapeutic environment (Herskowitz, 2003; Plaisted *et al.*, 1999). However, there is also evidence to suggest that it depends upon the individual client. Hunt *et al.* (2004) noted that in some cases visuals may distract the client from the music, whereas in other situations the visuals may be a way in to a client who was previously struggling to become engaged with the music.

Tangible User Interfaces

Cibrian *et al.* (2017) developed an interactive bendable surface that produces sound when touched. They designed the *BendableSound* prototype (Figure 2-12) to encourage movement and motor development for children with ASC within a music therapy environment. This work enabled use of elastic interactive surfaces, with its ability to represent pitch through vertical movement, and volume through the amount of strength used to push the fabric. However, it was somewhat restricted in its use of pre-programmed nursery rhymes, pre-set synthesized sounds and limited projected backdrops. The system also lacked portability for its installation and ease of use.

Figure 2-12: A child with ASC interacting with the *BendableSound* surface (El Heraldo de Saltillo, 2017)

Hardware like the Skoog (Figure 2-13) provide programmable tangible interfaces that can be more accessible to someone with no musical experience or limited dexterity (SkoogMusic, 2018). Designed for people with restricted motor skills, it has been used by a number of therapists as a programmable interface to trigger sounds via its large buttons. Its tactile and colourful nature makes it ideal for non-musicians and autistic children. Earlier versions needed to be wired to a computer, however, recent versions now include Bluetooth connectivity to allow users complete freedom to roam within a therapeutic space within a range of approximately 10 metres.

AudioCubes (Percussa, 2018a) are wireless coloured cubes that create sound dependent on their configuration and proximity to one another (see Figure 2-13). Designed for professional musicians, these have the potential to be used in a therapeutic environment; however, the programming interface could be too complex for non-musicians or for therapists with little time for training.

Figure 2-13: The Skoog (SkoogMusic, 2018) and AudioCubes (Percussa, 2018b)

Many research projects concerning people on the autism spectrum and their use of technology produce favourable results but rarely make for cost effective and accessible solutions (Grynszpan *et al*., 2014). Tangible User Interfaces (TUI) have been shown to encourage space sharing, imitation games and turn taking for people on the autism spectrum. For example, the *Reactable* (Jordà *et al.*, 2007), shown below in Figure 2-14, allowed therapists to observe non-verbal children develop musical skills and become involved in social communication while using the TUI as an audio visual focal point (Villafuerte *et al.*, 2012).

Figure 2-14: An autistic child interacting with the *Reactable* (Villafuerte *et al.*, 2012)

A recent prototype development in interactive textiles by Zhiglova and Yulia (2018) is the *Interactive Carpet.* A smart textile based interface has been designed to encourage development of social skills for children with ASC. Zhiglova and Yulia proposed that the interactive properties of the interface should promote attention and enhance socialisation. Soft tactile objects are embedded within the carpet to encourage sensual interaction and promote collaboration. For example, a rainbow image flashes when touched by two players - by placing a physical element of the child's choice onto a raindrop image, the sound of rain will be played. Similarly, a fish symbol gently vibrates any object placed on top of it (see Figure 2-15). At the time of writing, the prototype has been designed to accommodate one child and one caregiver for play, and has yet to be empirically tested.

Figure 2-15: The *Interactive Carpet* prototype (Zhiglova and Yulia, 2018).

Do-It-Yourself Tangible User Interfaces

A lack of resources can have an adverse effect that may deny clients the opportunity to use state-of-the-art equipment within music therapy sessions. For example, through a lack of time, staffing, training and funding (Black and Penrose-Thompson, 2012; Kvam, 2015). This may be attributed to charitable organisations being dependent on public contributions (MTC, 2014; Robbins, 2016), or state-run projects that have limited budgets. For example, it was suggested that a lack of resources affected the level of interest shown by participants with ADHD within a music therapy session (Helle-Valle *et al.*, 2017). On the other hand, an enterprising attitude combined with an imaginative therapist can lead to beneficial and fun group sessions. The use of do-it-yourself technology, like *Makey Makey* (JoyLabz, 2018), allows creation of novel tangible user interfaces or musical instruments constructed out of almost any object. An electrical current is conducted from chosen objects through its supplied simple electronic circuit board, connectors and clips (Figure 2-16). Gehlhaar *et al.* (2014) used *Makey Makey* in the development of tools that facilitated the musical expression of a group of physically and mentally challenged people. The group composed and subsequently performed a musical piece entitled *Viagem* in the main concert hall of Casa da Música, Portugal, in April 2010. In the performance, 37 musicians were divided into eight groups, playing a variety of constructed instruments and were accompanied by two choirs of 25 singers each.

Figure 2-16: Makey Makey Banana Piano (JoyLabz, 2018)

Similarly, *Touchboard* offers the opportunity to create interfaces or switches that can trigger audio or video-based electronic devices, which can benefit clients with limited motor skills (Bare Conductive, 2018). *Touchboard* is limited in its lack of a pre-designed user interface and instant usability, as the purpose of the kit is to build your own. However, these attributes could be considered as strengths, if the session leader is a proponent of non-traditional forms of therapy.

<u>Software Applications</u>

Technology, and in particular computer-based software, has been shown to be an effective form of intervention for people on the autism spectrum. Software can offer a level of predictability; it does not get impatient through repetition of use; and it is delivered via a focused visual medium which appeals to many people on the autism spectrum (Putnam and Chong, 2008).

With the introduction of affordable tablet computers, developers have seen opportunities for the autistic, and as a 2012 article pointed out, the iTunes store had more than 580 autism related apps, while Android had around 250 (IDG Consumer and SMB, 2012). A more recent report by Cardon (2016) indicated that there were over one million apps available, and that the numbers were continuing to grow daily. However, these apps have not been researched for their effectiveness, thus calling for empirical studies (Hourcade *et al.*, 2013). The authors highlighted that the downside to these untested apps is that developers may see them merely as a profitable enterprise. The attention of the autist can be diverted towards visual aesthetic elements, rather than being designed with their long term interests at heart. Emphasis on a user-centred design approach in the development of any application, would be more beneficial in terms of usability and development resources (Neale *et al.*, 2002). This approach has been adopted by a number of proponents of participatory design (section 2.1.5) including Putnam and Chong (2008), Cibrian *et al.* (2017), Fletcher-Watson *et al.* (2016) and Porayska-Pomsta *et al*. (2012).

Mobile devices are also increasingly used to support people with ASC in their social interactions (Hourcade *et al*., 2013). Mobile computing allows the use of remote interfaces for larger systems, proving the freedom and capabilities that stand-alone PC-based systems do not provide. For example, Smule's *iPhone Ocarina* (Wang and Clarke, 2009) is a virtual musical instrument that can be networked with other instruments to create a sense of social connectivity. Other popular apps for children on the autism spectrum developed for iPad, iPhone, Android and Kindle, include the following:

Cause-and-effect *Light Box* (see Figure 2-17) is an application designed for teenagers with autism and complex needs, but is also used by younger children without any special needs for entertainment purposes (Cognable, 2016). *Light Box* has 24 abstract interactive scenes that can encourage exploration of basic cause-and-effect through a range of colours, contrasts and background options. The desktop version includes support for *LEAP Motion* (2018), a hands free controller that tracks both hands and all fingers, mice, multi-touch screens and several other controllers. An audio section allows tactile interaction that has implemented a pitch to height mapping of its pre-set sounds. Reviews on the website indicate that this app is entertaining, has a calming effect and is cost effective. The application was praised by the DART (Development, Autism, Research, Technology) project (The University of Edinburgh, 2018) in teaching touchscreen interaction skills and the notion of cause and effect to those with limited comprehension of these. However, Light Box does not include external sound input.

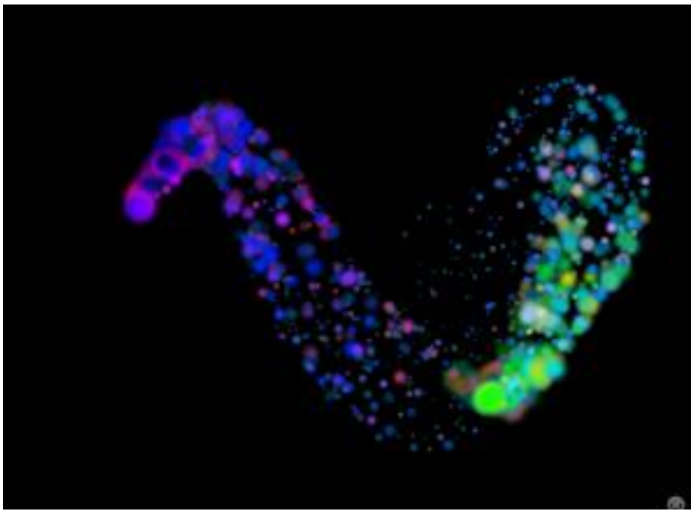


Figure 2-17: Cause-and-effect Light Box (Cognable, 2016)

The *Somantics* suite of applications (Figure 2-18) use touch, gesture and camera input to capture, reflect and exaggerate the movement and creative expressive interests of young people with ASC and other related communication difficulties (Cariad Interactive, 2018b). Designed to promote greater self-awareness, confidence and independence, the apps use simple camera effects, colour and shape to provide a playful reflection of movement on screen. This application is similar to the ideas proposed by natural user interfaces, like the MEDIATE environment (Figure 2-11), but are packaged in a more accessible way. However, the applications do not employ audio.

Figure 2-18: Somantics (Cariad Interactive, 2018b)

Similarly, *ReacTickles Magic* (Figure 2-19) is a suite of applications that use touch, gesture and audio input to encourage interactive communication (Cariad Interactive, 2018a). The goal of *ReacTickles Magic* is to allow users to explore the system without

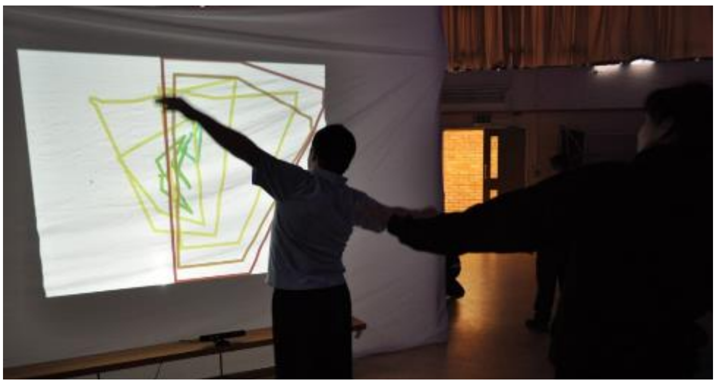


Figure 2-19: ReacTickles (Cariad Interactive, 2018a)

prior knowledge or skill with technology. A variety of input modes responds to gestural action with a dynamic array of animated shapes and patterns. *ReacTickles* has been developed to encourage interaction and collaboration. Its design has involved children and adults on the autism spectrum, who have themselves reported the benefits of being able to use the software for relaxation and to learn about cause-and-effect.

Virtual Reality

Virtual Reality Technology (VRT) has shown some level of success within educational and clinical groups in the way that it can provide a safe and less stressful environment for people on the autism spectrum (Parsons and Mitchell, 2002). By reducing potential stress within real-world social interaction, VRT can provide autistic people with opportunities to practice social situations. For example, recognising and responding to facial cues (Abirached *et al.*, 2011) or improving social cognition for high functioning young adults with autism on their transition into adulthood (Kandalaft *et al.*, 2013). A concern was that VRT will become a focal obsession and substitute for the real world (Howlin, 1998). However, by using VRT to augment practice with a therapist, parents or other group members, the situation itself becomes one of social interaction (Murray, 1997). The advantage of using VRT lies in its ability to support social interaction surrounding a computer, which can stimulate talk between users in small groups, as well as being a cost effective solution (Neale *et al.*, 2002). Parsons and Mitchell (2002) commented that care must be taken not to make VRT a replacement for current practice. However, Grynszpan *et al*. (2014) highlighted that there is still little evidence supporting the efficacy of VRT technology for supporting and promoting the learning of new social skills, and more studies investigating this area of research are called for.

However, people with ASC also have less efficient eye-hand coordination in visual detection tasks (Crippa *et al.*, 2013). Mei *et al.* (2014) suggested that enhanced spatial cognitive abilities could potentially improve ASC participants' task performance with 3D interfaces. The authors assessed both high functioning autistic and NT participants in a study, through a combination of 3D user interaction and written tests that included embedded figures and mental rotation tasks. Within VRT, users can interact with objects using 3D user interfaces (3DUI) that include tracker balls (see Figure 2-20), electronic gloves, electromiography (EMG) bands, rings, and other sensors as input devices (Ortiz-Vigon Uriarte *et al.*, 2015).

Figure 2-20: Hand-held finger ball input device (Infmetry, 2018)

The results of the study, by Mei *et al.* (2014), suggested that the deficits of poorer hand-eye coordination of the users with ASC negatively influenced their 3DUI performance more than their spatial ability did. Consequently, they have advised that designers of 3D user interfaces should consider providing additional cues for autistic users to aid them in hand-eye coordination.

In relation to ethical concerns surrounding the use of VRT on autistic children, a number of studies proposed that children with ASC could tolerate virtual reality environments. Strickland *et al.* (1996) showed that awkward, heavy headgear could be worn without problems. Max and Burke (1997) tested that children with ASC could interact with virtual environments, ignore distractors and acquire skills. Although durations varied, participants tolerated sessions up to 11 minutes successfully with improved attention and performance across sessions, thus providing preliminary support for further research into this area. In a study that explored willingness, acceptance, sense of presence and levels of immersion using VR headsets, Newbutt *et* *al*. (2016) commented that the majority of the participants reported an enjoyable experience, and were likely to use them again.

Augmented and Mixed Reality

Augmented reality (AR) is defined as an overlay of digital content on the real world, but that content is not anchored to, or part of it. The real-world content and the computer generated content are not able to respond to one other (Foundry, 2018). This allows users to see their real-world environment, allowing for them to more readily navigate an environmental hazard than VRT, or to socially engage with another person (Sahin *et al*., 2017). Mixed reality (MR) is an overlay of synthetic content on the real world that is anchored to and interacts with the real world, in real time. For the purposes of simplicity within this section, both are referred to as AR. Augmented reality may be represented through a range of technologies, including mobile devices like the iPad (Apple, 2019), and applications designed for individual and group use. A non-exhaustive list of head-worn hardware and autism related software, associated with AR and VRT, is summarised in Table 2-5.

An ethical study concerned with the wearability and safety of augmented reality (AR) hardware, used by autistic children and adults, was investigated by Sahin *et al*. (2017). The study indicated that VR headsets and some AR devices are large, heavy, and block the social world considerably. Figure 2-21 compares three head-worn displays in use for AR and VR technologies. Sahin *et al*. (2017) commented that most users (77%) had no negative effects or design concerns in wearing smart glasses over a period of between 1 to 1.5 hours.

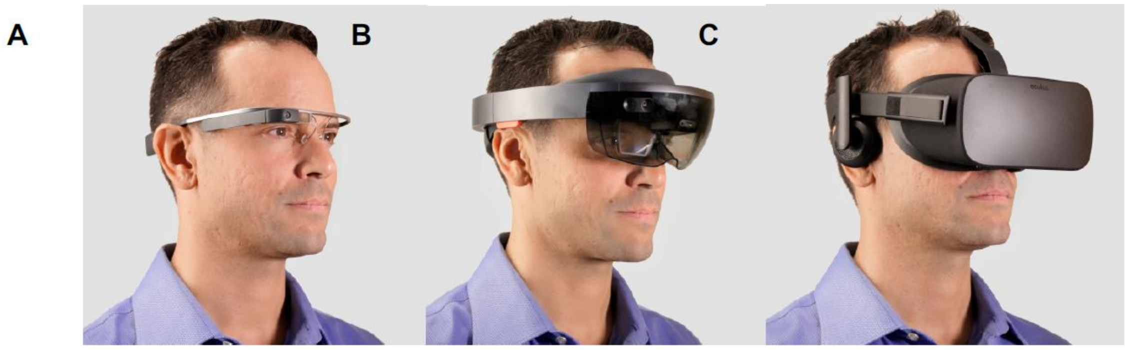


Figure 2-21: Head-worn Computers or Displays. (A) Glass Explorer Edition (Google Developers, 2018): AR smart glasses with fully stand-alone on-board computer. (B) Microsoft Hololens (Microsoft Corporation a, 2018): AR headset with fully stand-alone on-board computer and depth camera. (C) Oculus Rift (Oculus VR, 2018): VR headset display, which must be tethered continuously to a powerful computer to drive it (Sahin *et al*., 2017).

Applications designed for mobile and head-worn devices have advantages in portability over larger installations that require computers, sensors and screens projections like the MEDIATE environment (see Figure 2-11). However, larger displays have been shown to encourage greater social interaction and collaboration between autistic users (Ringland *et al*., 2014). Smart glasses have demonstrated their advantages in wearability compared to heavier head-mounted displays (Sahin *et al*., 2017). However, limitations in the use of smart glasses may include lower resolution graphics (Purch, 2018) and increased visual latency times, as the computational power of the devices are generally lower than VR headsets (Situation Publishing, 2018).

Name	Type	Input	Output	Description	User	Comments
Head-Worn Hardware						
Oculus Rift (Oculus VR, 2018)	VR	Computer-based, gestural, 2D/3D interfaces, microphone	2D/3D Visual display, headphones	Head-worn display	Solo	Tethered, high quality graphics, weight 470 grams
Microsoft Hololens (Microsoft Corporation a, 2018)	AR	Camera-based mapping, gestural, microphone	2D/3D Visual display, bone conduction transducer	Head-worn display	Solo	Stand-alone, weight 579 grams
Glass Explorer Edition (Google Developers, 2018)	AR	Camera, microphone,	Liquid crystal on silicon display, bone conduction transducer	Smart glasses	Solo	Stand-alone, weight 42 grams
Software and Installations						
LIFEisGAME (Abirached *et al.*, 2011)	VR	Camera, computer keyboard	Screen display, speakers	Computer application	Solo	Improve recognition of facial expression and emotion
Virtual Reality Social Skills Intervention (Kandalaft *et al.*, 2013)	VR	Camera, computer keyboard, microphone	Screen display, speakers	Computer application	Solo	Enhance Social Communication
SensoryPaint (Ringland *et al.*, 2014)	AR	Camera-based gestural	Projected display, speakers	Installation	Solo / Group	Enhance bodily awareness and creativity
MEDIATE (Parés *et al.*, 2005)	AR	Camera-based gestural	Projected display	Installation	Solo / Group	Enhance bodily awareness and creativity
MOSOCO (Escobedo et al., 2012)	AR	Touch screen	Screen display, simple sounds	Mobile app	Solo / Group	Develop social skills
Video-modelling storybook (Chen *et al.*, 2016)	AR	Camera	Screen display	Mobile app	Solo	Improve recognition of facial expression and emotion
Brain Power Autism System (Keshav *et al.*, 2017)	AR	Camera, microphone	Smart glasses display, bone conduction sound	Apps for smart glasses	Solo	Enhance Social Communication
Virtual Musical Instrument (Hobbs & Worthington-Eyre, 2008)	AR	Camera	Screen display, speakers	Installation	Solo / Group	Encourage musical creation through movement

Table 2-5: Overview of AR and VR technologies and applications

A number of AR applications have been developed to support engagement in social interactions. For example, a video-modelling storybook was developed to improve perceptions of facial expressions and emotions for participants with ASC (Chen *et al.*, 2016). Restricted elements of a text-based story were extended through AR, which focused the attention of participants and aided in their learning of recognition of social features (Figure 2-22).

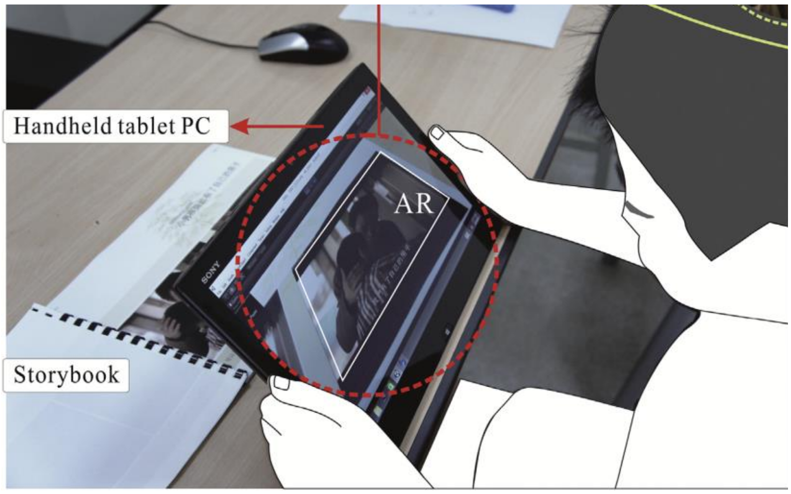


Figure 2-22: The Augmented Reality-Based Video-Modeling with Storybook (Chen *et al.*, 2016).

Gamified AR applications utilising artificial intelligence have been developed for smart glasses, including the *Brain Power Autism System* (Keshav *et al.*, 2017). These have been designed to provide children and adults with coaching for emotion recognition (see Figure 2-23), face directed gaze, eye contact, and behavioural self-regulation (Liu *et al.*, 2017).

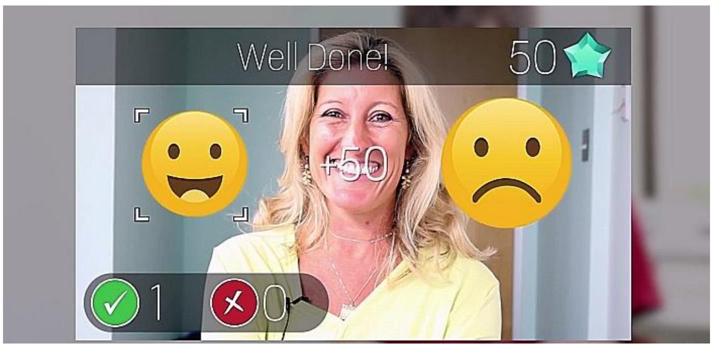


Figure 2-23: Example visual output for the *Brain Power Autism System* (Brain Power, 2018).

Augmented reality systems have also indicated their effectiveness in developing play amongst children with autism. Bai *et al.* (2015) developed a system to visually conceptualise the representation of pretence within an open-ended play environment. One example presented a reflection of the world in which a simple play object, a wooden block, was replaced by an imaginary alternative, seen as a car on screen (see Figure 2-24). The study demonstrated a significant improvement of pretend play in terms of frequency, duration and relevance using the AR system in comparison to a non-computer-assisted situation.

Figure 2-24: A child interacting with the AR system (Bai *et al*., 2015)

Attempts have been made to use AR within music therapy. Hobbs and Worthington-Eyre (2008) created the *Virtual Musical Instrument*, which used gestural interaction to create music. In a preliminary study, an individual or group of children could interact with projected coloured shapes, described as hot spots, by moving their body to select and play a musical sound or note (see Figure 2-25). The system was later developed to become a gestural-based virtual art program for children with severe motor impairments (Diment and Hobbs, 2014).

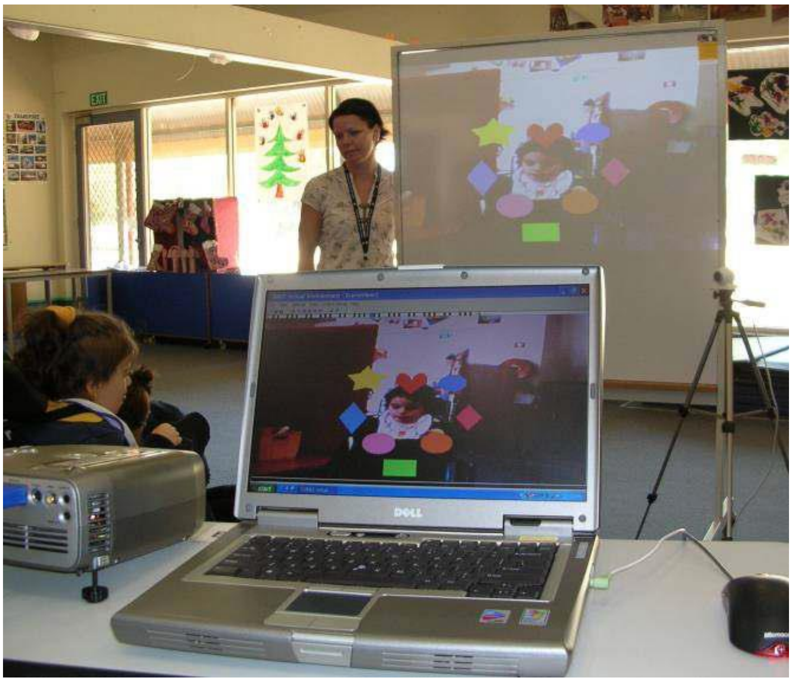


Figure 2-25: The VMI showing the webcam on a tripod (right hand side of the figure), the laptop (foreground), the projector screen (background), and the data projector (left hand side) arranged for optimal use (Hobbs and Worthington-Eyre, 2008).

2.3 Methods of Evaluating Interventions

This section examines the evaluative methods, designs and development criteria of existing autism-based research. It examines quantitative and qualitative approaches, used in the appraisal of a variety of interventions, and discusses strategies for initial studies for a prototype application. Table 2-6 presents an overview of the methods discussed.

Method	Classification	Description
Questionnaires and rating-scales	Quantitative	Pre and post questionnaires and/or rating-scales can provide both qualitative and quantitative data
CBT	Quantitative	Cognitive behavioural therapy
RCT	Quantitative	Randomised controlled trials
Semi-structured interviews	Qualitative	With the therapist and/or the study participant
Calendar/medical diaries	Qualitative	Participants' or parents/carers can keep regular calendar or medical diaries on observed behaviour
Questionnaires and rating-scales	Qualitative	Pre and post questionnaires and/or rating-scales can provide both qualitative and quantitative data
Longitudinal case studies	Qualitative and Quantitative	Methods that take place over long periods of time
Observation	Quantitative and Qualitative	Video analysis can also be used for statistical analysis of chosen variables within a study
Single case studies	Quantitative and Qualitative	Can use a variety of methods to gather data from clients (see 2.3.3)

Table 2-6: Quantitative and Qualitative Methods Overview

2.3.1 Quantitative

Quantitative research focuses on gathering numerical data and generalising it across groups of people, or to explain a particular phenomenon (Babbie, 2012). Observation can be used for statistical analysis of chosen variables within an autism-based study (Cibriani *et al.*, 2017). Case studies can employ a variety of observational methods to gather data from clients, for example, frequency of eye contact, turn-taking, verbalisation and so on (Hailpern *et al.*, 2008; Villafuerte *et al.*, 2012). Case studies are discussed in more depth in section 2.3.3. Table 2-7 provides an overview of quantitative methods.

Quantitative Method	Description
Observation	Video analysis can also be used for statistical analysis of chosen variables within a study
Single case studies	Can use a variety of methods to gather data from clients (see 2.3.3)
Questionnaires and rating-scales	Pre and post questionnaires and/or rating-scales can provide both qualitative and quantitative data
CBT	Cognitive behavioural therapy
RCT	Randomised controlled trials

Table 2-7: Quantitative Evaluative Methods for People with ASC

Questionnaires and ratings scales can be an efficient way to gather large amounts of information in a short space of time. Questionnaires can be classified as both, quantitative and qualitative methods, depending on the nature of the questions (Research Methodology, 2018). The advantages of questionnaires include increased speed of data collection, low or no cost requirements, and higher levels of objectivity compared to many alternative methods of primary data collection. However, disadvantages include selection of random answer choices by respondents who may not properly read the question. There is also usually no possibility for respondents to express their additional thoughts about matters due to the absence of a relevant question. A number of existing scales may be adapted for experimental studies: System Usability Scale (Brooke, 2011) is a 10 item Likert scale mainly used for quick industrial use (Figure 2-26).

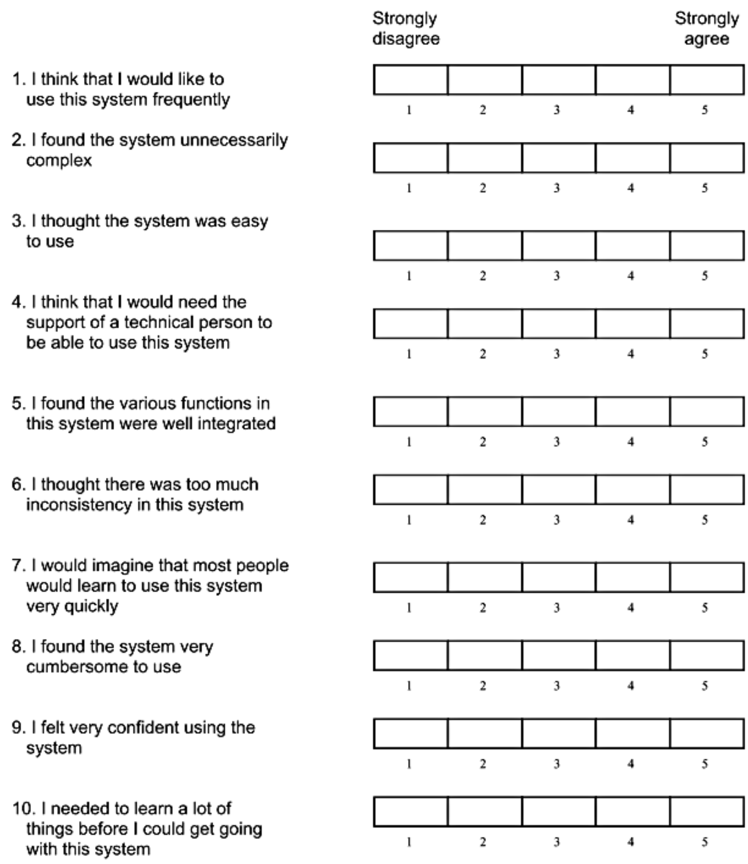


Figure 2-26: System Usability Scale (Brooke, 2011)

The System Usability Scale was designed to provide a global overview of the usability of a system. It could be used within a first phase of prototype testing as one of a series of tests, rather than the sole method, due to its restrictive nature. Similarly, the NASA Task Load Index (Hart and Staveland, 1988) is a multidimensional scale designed to obtain workload estimates from one or more operators while performing a task or immediately afterwards. Modified by users of a variety of systems, the scale uses six subscales including: Mental, Physical, and Temporal Demands, Frustration, Effort, and Performance – with an overall workload calculated from an average of these factors. An advantage of the system includes: users' common modification of eliminating the weighting process; analysing the individual subscales; or doing both, as 20% of the studies show in a 2006 survey (Hart, 2006). This type of scale could be suitable for use by a music therapist or by a high functioning autistic client to analyse the usability of the system itself.

The Griffiths Scales of Mental Development (1970) measure development trends which are significant for intelligence, or indicative of functional mental growth in babies and young children (ARICD, 2013). They provide a general development quotient in addition to measures of six domains of functioning, each of which is assessed on a separate subscale. These subscales are: A (Locomotor); B (Personal–Social); C (Hearing and Speech); D (Eye and Hand Coordination); E (Performance); and F (Practical Reasoning). The Griffiths Scales assess children from two to eight years of age. The items on the scales are diverse, tapping the main aspects of a child's development and are placed in order of gradually increasing difficulty. Many of the items are based on natural activities such as walking, talking and playing (Griffiths, 1970). The scales are supplied only to paediatricians and health professionals who have successfully completed a training course accredited by the Association for Research in Infant and Child Development. This method, generally quantitative in nature, would require resources over a longer time period, which is outwith the scope of the current research.

The Early Social Communication Scales (ESCS) is a structured measure for non-verbal communication skills in children (Mundy *et al.*, 2003). This was used as a measure within the testing of a tangible user interface for non-verbal autistic children and could be a suitable measure for evaluation of an application (Villafuerte *et al.*, 2012). Figure 2-27 shows a section of the coding sheet, which includes initiating, and responding to different behaviours.

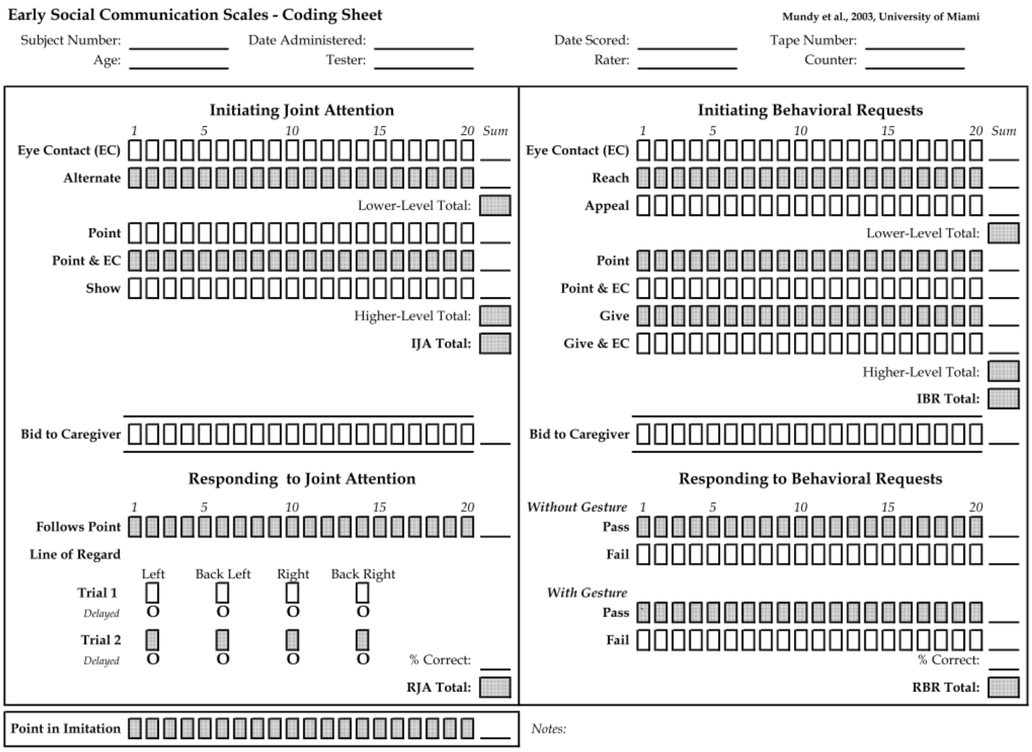


Figure 2-27: A section of the coding sheet for The Early Social Communication Scales (Mundy *et al.*, 2003)

One method for indicating improvement in self-esteem was utilised in the case study of a fifteen year old boy (Stanley and Miller, 1993). The School Form of the Coopersmith Self-Esteem Inventory (CSEI), a self-report measure of self-esteem for use with school-age students, was employed (Coopersmith, 1959). The form uses a number of statements like “I’m a lot of fun to be with”, to which the client responds by marking ‘like me’ or ‘not like me’ (see Figure 2-28). Eight of the items provide a Lie subscale that can be used as a measure of respondent defensiveness. This has been used by a number of other researchers and could be employed within the current research, dependent on the communicative abilities of the participant (Drummond *et al.*, 1977; Rosenberg and Gaier, 1977; Chiu, 1988; Butt and Phillips, 2008; Sharma, 2012). There is no evidence, however, of previous use of CSEI within an autism-related study.

Cognitive behavioural therapy (CBT) is used for psychiatric disorders but has been suggested as a basis for quantitative research in music therapy by Silverman (2008), due to the lack of quantitative data in music therapy. Silverman's research looked at best practice in psychotherapy to see if practices could be borrowed for future music therapy studies, and to provide details on how to set them up appropriately. However, according to Maratos *et al.* (2008), the few studies that use this approach have been focussed on mental illness or substance abuse, and confidence is low in its effectiveness. A lack of evidence of more recent research suggests that this is still the case.

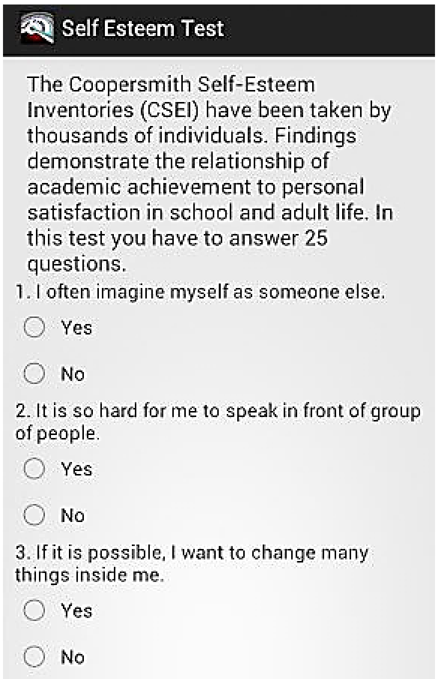


Figure 2-28: Sample questions from a Coopersmith Self-Esteem Inventory (Mobogenie, 2017)

Randomised controlled trials (RCTs) are the most common intervention studies within medicine. Typically they take a group of study participants and divide them into two separate groups – the intervention is implemented in one group but not the other and a comparison of intervention efficacy is measured between the two (Thiese, 2014). Geist and Hitchcock (2014) argued that If practitioners wish to seek out the very best internal validity for music therapy, then randomized controlled trials (RCTs) should be pursued. However, in dealing with autistic participants within music therapy sessions, there is no typical group where all participants can be treated in the same way. This has been and will continue to be a problem for RCTs relating to autistic participants.

2.3.2 Qualitative

Qualitative methods are exploratory in nature and are mainly concerned with gaining insights and understanding on human feelings and emotions that underlie reasons and motivations (Tracy, 2013). Table 2-8 provides an overview of qualitative methods considered.

Qualitative Method	**Description**
Observation	Video or still image and audio recording
Semi-structured interviews	With the therapist and/or the study participant
Calendar/medical diaries	Participants' or parents/carers can keep regular calendar or medical diaries on observed behaviour
Questionnaires and rating-scales	Pre and post questionnaires and/or rating-scales can provide both qualitative and quantitative data
Single case studies	Experimental design where the subject serves as their own control (see 2.3.3)
Longitudinal case studies	Methodologies that take place over long periods of time

Table 2-8: Qualitative Evaluative Methods for People with ASC

Observation through video recordings, or still images combined with audio recordings, are a common means of detailing and analysing experiments (Jones and Schwartz, 2009; White *et al.*, 2015; Ringland *et al.*, 2014). For participants, they can be a discreet and less distracting way to gather data than having an unknown observer monitor a session. They can also be an effective way, for example, to detail a case study within a home setting that takes place over a period of several months (Wimpory *et al.*, 1995).

Semi-structured interviews with study participants can provide a more detailed insight into feelings and emotions that questionnaires would not provide. Allen *et al.* (2009) employed a semi-structured approach to explore how high functioning adults with ASC experience music. However, as all potential study participants' within the present research may not be high functioning, interviews with practitioners may be a more suitable way to proceed within the given time period. Ringland *et al.* (2014) used semi-structured interviews to gather feedback from parents and psychologists, on non-verbal children, in their intervention-based study.

Participants, parents or carers can keep regular calendar or medical diaries on observed behaviour over a period of time, including pre and post-study. Commonly used within clinical practice, these can aid in a greater understanding of the effect of an intervention, where retrospective interviews may not be able to provide sufficient data before or after its introduction (Wale, 1977; Aldridge, 1994; Helle-Valle *et al.*, 2017). This approach can be seen as similar to a hypothesis-confirming approach.

Longitudinal case studies are methodologies that take place over extended periods of time. According to Accordino *et al.* (2007), longitudinal studies make it difficult to tell if therapy or natural maturation is the cause for change. One example of a longitudinal study involving autistic clients, employed a research tool named *Layered Analysis* (Ellis and Leeuwen, 2000; Education and Press, 2016). This sound therapy study used *SoundBeam* (see section 2.2.2), where video recorded data made over 24 months, had been disassembled and reassembled in order to reveal a picture of developmental progression. As useful as this would be for a longer-term research project, it may be unsuitable for the present research. This would be dependent on the availability and long-term focus of autistic participants, as well as access to sufficient resources for the development, testing and evaluation of a prototype application over a two to three-year period.

2.3.3 Single Case Studies

Aldridge (1994) noted that single case studies, as well as being the primary source of music therapy research (Accordino *et al.*, 2007), were ideal for creative arts therapists. Single case study designs have been used within a number of music therapy and related intervention studies with autism (Kern *et al.*, 2007; Simpson and Keen, 2011; Reichow *et al.*, 2011; Geist and Hitchcock, 2014; Villafuerte *et al.*, 2012). The following provides an overview of the approach.

According to Alridge (1994), single case study designs allow clients to express themselves over a period of time. They allow changes in the relationship with a therapist and with other family members to be noted using a variety of methods. Changes in emerging phenomena, such as new intervention, can be detailed and new models can be created. Therapists discuss cases within their working environment, and case studies attempt to formalise that process (Geist and Hitchcock, 2014). However, Aldridge goes on to suggest that validity of success can be open to question due to the subjective bias of the therapist and client expectations. He states that these difficulties have been addressed through randomising control treatment periods and blind assessment (Guyatt *et al*., 1986). Randomisation here means that treatment and control periods do not always occur in the same, or chosen, order. Blind assessment refers to the fact that the person assessing change does not know whether the client was or was not receiving treatment. Aldridge (1994) describes treatment sessions occurring on a weekly basis, once the target behaviour has been identified. However, the number of sessions described in previous single case studies has varied. A study by Pasiali (2004) took place on a daily basis over a four week period, with baseline and treatment alternating each week, while Lett (1993) utilised single case design in an arts-based project in weekly sessions over a 10-week period.

Single case research designs fall under a variety of formality and experimentation. For example, three approaches are: randomised single-case study designs (Guyatt et al., 1986); single-case experimental designs (Smith, 2012); and case study research (Yin, 2009), which may include diary or calendar methods and traditionally includes qualitative data. This may be the preferred approach for studies within the present research, as it looks at changes in a number of variables over time.

Described as a good approach for the beginning researcher, a common feature of single case research is that it stays close to the practice of the therapist, thus facilitating its design around them. Additionally, autistic clients can be researchers too - Putnam and Chong (2008) suggest this is ideal to counteract the lack of input of users with ASC as recognised in literature. Treatments are discussed between the therapist and client for maximum effectiveness and can be further developed during sessions.

The weakness of single case design is that it is difficult to argue for general validity of the treatment. Marwick (1996) noted that it was easier to generalise the results of a study with more than one participant, compared to a case study report, regardless of the detail that could be gathered. However, Hilliard (1993) argued that replication on a case by case basis counteracted this issue. A formal level of research design could be applied to turn a case study into a case history. According to Accordino *et al.* (2007), music therapists have argued that only case studies are appropriate since the treatment schedules are individualised for each client. Thus, the same regimen cannot be followed during therapy for several participants in a study. Moreover, Accordino *et al.* stated all but two of the reports in the meta-analysis were case studies. More recently, a number of case studies are highlighted in a Nordoff Robbins Scotland article, which illustrated how music therapy can help autistic children (McLachlan, 2016).

Overview of the approach:

Step 1: Identify the target behaviour – this is the baseline measure in the initial period of observation ('A' phase). This phase enables a stable pattern of behaviour to emerge. Three observation points are recommended before the intervention phase begins (Barlow & Hersen, 1973).

Step 2: Introduce the intervention (‘B’ phase).

Aldridge stated that case study research is recognised as a qualitative approach, although quantitative data can be created. There are possibilities for statistical analysis where daily measures can be plotted and traced over time. This can be done by therapists and by family members. There can be variations in the design – for example, if treatment variables cannot be randomised, single case experimental designs are used, which have been used in arts therapies (Stanley and Miller, 1993). Aldridge (1994) commented this was an improvement in case history design in that it offered comparative data in two clear phases. The design can also be extended with another A phase if need be, although there may be difficulties faced if ending on a ‘no intervention’ phase. Alternatively, there could therefore be an ‘ABAB’ design where the idea is to keep the phase lengths identical. Common design methods employed within music therapy and autism studies include withdrawal (ABA), and reversal (BAB) designs (Villafuerte *et al.*, 2012; Carnahan *et al.*, 2009).

A 10-week case study could be seen as a reasonable time period to test a hypothesis. Edgerton's study (1994a) involved 11 autistic clients who participated in half-hour sessions each week for 10 weeks. For the study, a communicative responses and acts score sheet (CRASS) was created to test the responses of autistic individuals. The score sheet was divided into two sections: musical and non-musical, which was further broken down into communicative responses and communicative acts. Communicative responses were defined as verbal, vocal, gestural or instrumental behaviours (tempo, rhythm, structure/form, pitch, and speech production) influenced by the therapist. Communicative acts were initiated by the client. A basic ABA withdrawal design was employed. Objective methods of control, observation and data reporting were used, including qualitative and quantitative analyses during and following the study by parents, teachers and speech therapists. This study provided clear and consistent results in favour of the use of improvisational music therapy, and backed up the case for single case design methods due to its successful use of a variety of methods.

2.4 Summary

Challenges associated with autism include problems in communication, social interaction and self-esteem. Current interventions for autism are numerous and have been listed throughout section 2.2. Behavioural interventions aim to provide a basis for flexible learning within an autistic child's development, while music therapy allows creative expression on a non-verbal level, but aids in developing communication and social interaction. Community music therapy seeks to adopt similar ideals but outwith a clinical setting, thereby encouraging greater interaction but within more challenging settings.

In section 2.2.2, it has been shown that technological interventions can provide an accessible means to illustrate concepts like cause-and-effect while being entertaining or acting as a relaxation tool, dependent on the needs on the individual. Tangible User Interfaces have demonstrated their ability to encourage space sharing, imitation games and turn taking (Villafuerte *et al.*, 2012). Virtual and augmented reality technologies have also shown promise for autistic people. There are concerns that clients could become more isolated, for example, becoming fixated with virtual characters (Abirached *et al.*, 2011), thus reducing social interaction with their peers. However, shared AR displays have been shown to encourage greater social interaction and collaboration between autistic end-users (Ringland *et al*., 2014).

A review of appropriate methods has indicated that gathering data from people on the autism spectrum, in a therapeutic environment with a variety of support needs, may require a mixed method approach. Semi-structured interviews were conducted with specialists to aid in the understanding of the context and design of the *BendableSound* intervention for potential participants (Cibrian *et al*., 2017). Evaluation of the prototype included interview and observation. Similarly, *Polly World,* developed and evaluated by Cappelen and Andersson (2016), used a variety of qualitative methods to assess the efficacy of their autism-based interactive multimodal environment. These included video observation, questionnaire and interviews.

Case studies have been identified as a potential way to analyse an intervention within a music therapy environment, due to their suitability in the collection of quantitative and qualitative data in previous research (Edgerton, 1994a). They provide immediate observable insight into studies where resources are limited. They are reliant upon the determination of a baseline stage and are suitable in the observation of a number of changing variables of a client over time, in the natural environment of the practitioner. The advantages of case studies lie in the flexibility of the approach, which can be co-designed by the researcher, therapist and client, if they are able to do so. Aldridge (1994) commented that case studies are also appropriate for therapists wishing to bring research into their practice, and for developing hypotheses that may be submitted for clinical validation at a later date.

The following section describes how music has been represented in the recent technological age, and how that may inform the basis of a design for a new audio-visual application.

3 Visual Representation of Sound

In this chapter, the ways in which music has been represented from a visual perspective are discussed. Music is defined as vocal or instrumental sounds (or both) combined in such a way as to produce beauty of form, harmony, and expression of emotion (Oxford University Press, 2017a). Beauty of form and expression of emotion are often considered subjective concepts which require exploration in relation to how music can be represented visually (Hill, 2013). Fourney and Fels (2009) state that music is rarely appreciated through sound alone. Performances are typically accompanied with lights, visual effects, facial expressions or the body language of performers, which they suggest can enhance the emotional content of the music. Harmony refers to the extensively developed system of chords, and the rules that allow or forbid relations between chords, that characterises Western music (Rich, 2018). However, Castellano *et al.* (1984) point out the primary source of musical expression in India is through melody, as opposed to western music's use of harmony as a musical priority, thus implying cultural bias toward musical appreciation. Sound can be measured using decibels (dB) and Hertz (Hz). For the purposes of clarity in this chapter, sound (Figure 3-1) describes vibrations that travel through the air or another medium, and can be heard when they reach a person's or animal's ear (Oxford University Press, 2017c). Audio signals refer to electrical or digital representations of sound or music (Hodgson, 2010).

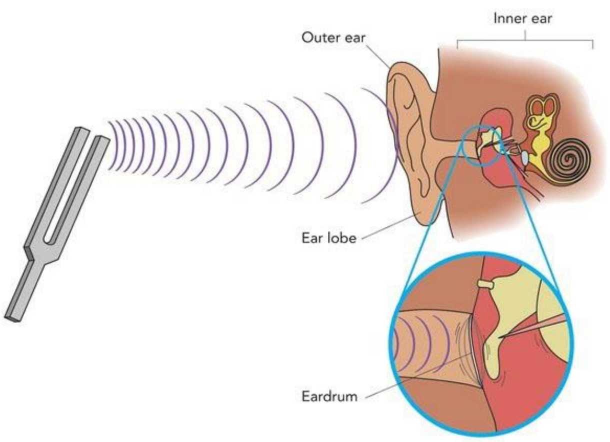


Figure 3-1: A vibrating tuning fork vibrates air molecules, reaching the ear as sound (Adobe Spark, 2018)

Mapping audio effectively to a visual counterpart requires an understanding of literature related to cross-modal correspondences (Evans and Treisman, 2011). An overview of theoretical and technological developments of musical sound are discussed in order to understand the reasons for sharing musical knowledge and the means in which to do so. The visual representation of sound is then described by two category areas – temporal graphical representation of musical structure, and temporal representation of audio signals. Visualising musical structure has commonly been used as a means of enhancing learning and teaching of musical composition (Krumhansl, 2005), while the visualisation of audio signals has typically been used for analytical purposes (Bergstrom *et al.*, 2007). Neither area is restricted to these groups exclusively, however, as technology has also allowed the development of artistic expression through audio-visual performance (Ox and Keefer, 2015). Interaction looks at how digital technology has allowed the mapping of audio parameters to a variety of visual metaphors within software applications. Cymatics explores visual geometry as a physical artefact of sound (Jenny, 1968), and how that could be further explored.

3.1 Cross-Modal Correspondences

Cross-modal correspondences have been defined as a tendency for a sensory feature in one modality, either physically present or merely imagined, to be matched (or associated) with a sensory feature in another sensory modality (Evans and Treisman, 2011). Multisensory associations are a common experience and research has shown that what we see, and how we feel about it, are more commonly influenced by the sense of smell (Luisa Demattè *et al.*, 2007). Similarly, touch can be influenced by smell, while crispness can be perceived through what we hear as well as what we feel in our mouths (Spence and Shankar, 2010). Psychophysical research has shown that auditory stimuli is often associated with visual stimuli (Marks, 1974; Spence, 2012). Kim *et al*. (2008) suggest that within an improvisational music therapy environment, frequency (pitch), amplitude (loudness), timbre (tone), and rhythm, are the key aspects of sound used as a non-verbal means of communication for people with autism. Despite the subjective nature of musical concepts, research has indicated shared cross-modal correspondences between paired attributes such as: amplitude and size, pitch and physical position, and pitch and visual brightness, for musically trained and untrained neurotypical participants (Tan and Kelly, 2004b; Küssner, 2014; Walker *et al*., 2010). Table 3-1 presents an overview of audio-visual cross-modal correspondences that could be used as a basis for the design of a potential audio-visual application for autistic users, within a real-time playing paradigm.

Audio Attribute	**Visual Attribute**	**Example Figures**	**References**
Frequency (Pitch)	Vertical height	Figure 3-4	(Küssner, 2014)
	Light intensity	n/a	(Hubbard, 1996)
	Size	n/a	(Marks *et al.*, 1987; Mondloch and Maurer, 2004)
Amplitude (Loudness)	Size	Figure 3-5	(Küssner, 2014)
	Light intensity	n/a	(Marks, 1974)
Timbre (Tone)	Rounded shapes (soft tones), sharper shapes (harder sounds)	Figure 3-8	(Adeli *et al.*, 2014)
	Colour	Figure 3-10	(Smith and Williams, 1997; Pietrowicz and Karahalios, 2013)
Time and Rhythm	Spatialized Metaphor	Figure 3-2, Figure 3-10	(Athanasopoulos *et al.*, 2016; Pietrowicz and Karahalios, 2013)
	Horizontal axis	See 3.5.1	(Küssner, 2014)

Table 3-1: Overview of audio-visual cross-modal correspondences

According to Honing (2001), rhythm is an important musical attribute which can be defined as the identification of patterns that function as a reference, relative to which deviations from strict mechanical timing can be appreciated by the listener (Clarke, 1999). It is often associated through spatialized visual metaphors, much like standard musical notation, which employs a left-to-right temporal-based directionality. Concerned with the relative timing of musical events, Honing suggests that tempo, meter and timing should also be considered (refer to sections 3.3 and 3.5 for examples). A study by Athanasopoulos *et al.* (2016) shows that literacy and literacy styles influence the directionality of representation of temporal events in music, which is further complicated by a listener's or a musician's cultural background (Figure 3-2).

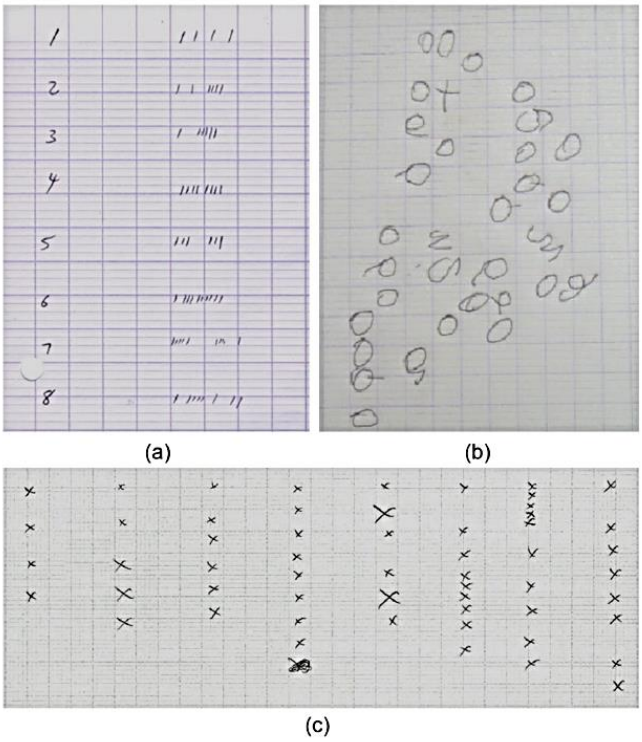


Figure 3-2: Examples of representations corresponding to auditory stimuli shown in (a) horizontally left-to-right by British participant; (b) no clear directionality, by BenaBena participant; (c) vertically top-to-bottom, by Japanese participant. (Athanasopoulos *et al.*, 2016)

For example, British participants detailed auditory stimuli in a left-to-right direction, whilst Japanese participants noted their responses in vertical rows top-to-bottom, which corresponds with traditional Japanese writing. Spectromorphology (Smalley, 1997), refers to research on the representation of electro-acoustic music by considering theoretical sound-shape associations, described through textual means. Smalley comments on the way music is no longer restricted to traditional acoustic or vocal instruments, as electro-acoustic music allows creation of an infinite array of sonic possibilities. Originally concerned with aural perception, analysis, visual representation and notational functions, spectromorphology is a descriptive tool intended to aid the listener in discerning tonal differences (Patton, 2007a). Smalley describes spectromorphology as a means to influence compositional methods, by raising awareness of words and concepts that would normally confuse composers in the understanding of structural relationships. The two parts of the term refer to the interaction between sound spectra and the ways they change and are shaped through time (morphology). It is concerned with the processes of growth and the either real or imagined motions of sound in free space. For example, Smalley discusses spectral density as a conceptual curtain or fog, where the spread of highest and lowest possible sounds can either: block the listener's ability to hear anything else, or be sufficiently transparent enough to allow other sounds to be heard (Figure 3-3).

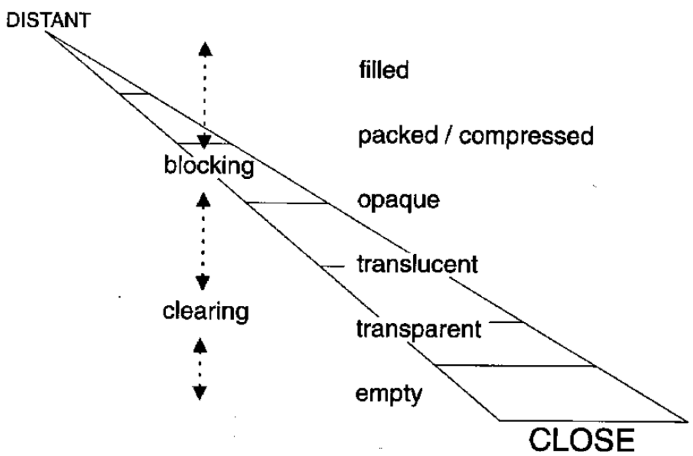


Figure 3-3: Spectral Density (Smalley, 1997)

Blackburn (2009) proposed alternative uses of spectromorphology in a reversal of conventional practice, to use vocabulary to precede the composition and subsequently direct the path of the composer. However, being primarily concerned with descriptive language, spectromorphology may not be an appropriate representational format for people on the autism spectrum, due to a preponderance in difficulty with language (Boucher *et al.*, 2000).

In a study by Küssner and Leech-Wilkinson (2014) investigating the notion of shape in music, in a real-time drawing paradigm, most participants mapped pitch onto the vertical axis and time onto the horizontal axis, analogous to music notation. Details of the sound stimuli for pitch and loudness representations in Figure 3-4 and Figure 3-5, are presented in Table 3-2 and Table 3-3 respectively.

No.	Length (Secs)	Pitch (Note name)	Amplitude	Tempo
1	14.3	up-down (B2-D4-B2)	Decreasing/increasing	Accelerando - accelerando
2	4.9	up-down (B2-D4-B2)	Increasing/decreasing	Equal, longer notes top and bottom
3	13.6	up-down (B2-D4-B2)	Increasing/decreasing	Decelerando – decelerando

Table 3-2: Overview of all experimental sound stimuli for pitch representations in Figure 3-4.

Participants included 30 musically trained and 41 musically untrained males and females, who used drawing tablets where the active area was 325 mm in length and by 203 mm in height. The research compared the audio-visual cognition of musicians and non-musicians, which has shown that both groups had a tendency to represent pitch with height (Figure 3-4), and loudness with size (thickness of lines) (Figure 3-5).

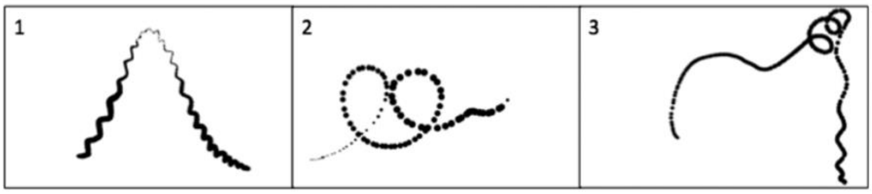


Figure 3-4: Examples of alternative pitch representations (Küssner and Leech-Wilkinson, 2014)

Previous studies in audio-visual and audio-spatial correspondences have shown similar results. For example, higher pitches have been related to higher elevation in space (Walker *et al.*, 2010), to greater brightness (Marks, 1974, 1982; Hubbard, 1996), and with more pointed shapes (Walker *et al.*, 2010).

No.	Length (Secs)	Pitch (Note name)	Amplitude	Tempo
1	13.6	up-down (B2-D4-B2)	Increasing/decreasing	Decelerando – decelerando
2	4.9	up-down (B2-D4-B2)	Increasing/decreasing	Equal, longer notes top and bottom
3	13.6	up-down (B2-D4-B2)	Constant	Decelerando – decelerando
4	14.3	up-down (B2-D4-B2)	Decreasing/increasing	Accelerando - accelerando
5	14.3	up-down (B2-D4-B2)	Decreasing/increasing	Accelerando - accelerando
6	13.6	up-down (B2-D4-B2)	Increasing/decreasing	Decelerando – decelerando

Table 3-3: Overview of all experimental sound stimuli for loudness representations in Figure 3-5

In research related to amplitude, loudness was mostly represented with larger scale (Smith and Sera, 1992; Walker, 1987), by size in drawings, and by various mapping strategies in gestures such as height, size and muscular energy (Küssner, 2014). However, louder sounds were also associated with greater brightness (Bond and Stevens, 1969; Marks, 1974), and with higher contrast (Wicker, 1968).

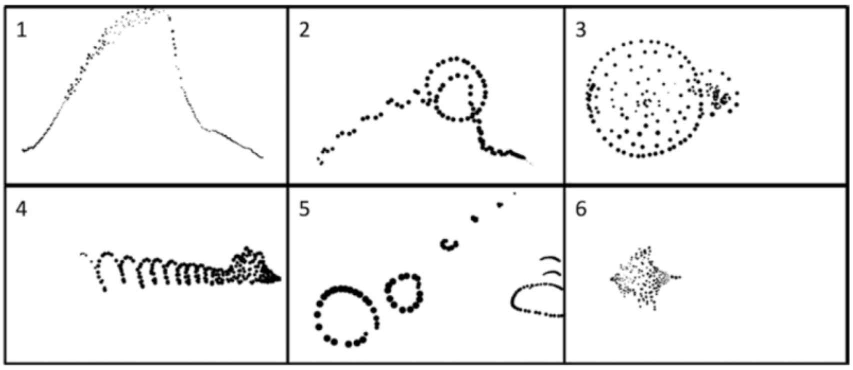


Figure 3-5: Examples of alternative loudness representations (Küssner and Leech-Wilkinson, 2014)

Within the real-time drawing paradigm, Küssner (2014) also highlighted that trained musicians' representations of both were more accurate. In a previously related study, Tan and Kelly (2004) have shown that musically trained individuals tended to visualise elements of intra-musical properties. For example, trained participants focused on musical themes, repetition, changes in pitch, types of instruments, interplay of different instruments, and sections of the composition. In comparison, musically untrained participants visualised external sensory and emotive factors as metaphor, through fleeting images or the creation of stories to accompany the music. Table 3-4 describes some related examples from both groups.

Musically Trained	**Musically Untrained**
Musical themes/motifs	‘The main idea', 'recurring pattern', ‘made me feel sad’, ‘it gave me chills, goose-bumps’
Phrases/sections	‘I saw butterflies in a field of sunshine, suddenly a ship in the middle of a storm. A toy doll dancing on tiptoes’
Repetition	‘Returns', 'reappears'
Changes in pitch	‘Tracking rising and falling', ‘jagged/rough melodic contour,’
Instrumental interplay	‘Different parts each doing their own thing,’ ‘separate streams or blocks of sound moving in different directions'
Volume	‘Loudness’ or ‘force’
Compositional section/segment	‘Piece was in three sections,’ ‘a fast segment between two slow ones,’
Tempo	‘Speed,’ ‘pace,’ ‘quickness,’ ‘fastness’
Texture/timbre and polyphony	‘Change in thickness', 'quality of collective sounds'
Major/minor mode	‘The music was sad,’ ‘the piece felt joyous,’ ‘it was cold, eerie’

Table 3-4: Comparison of descriptions of music by musically trained and untrained participants (Tan and Kelly, 2004a)

Representing music from a graphical perspective in the same study, participants tended to fall into two categories: either pictorial (30% of participants), or abstract representations (70% of participants). Musically trained participants provided greater abstract representations (Figure 3-6) than pictorial representations (Figure 3-7). Untrained participants did not favour one mode of representation or another, but the majority (over 72%) of the pictorial representations were created by untrained participants.

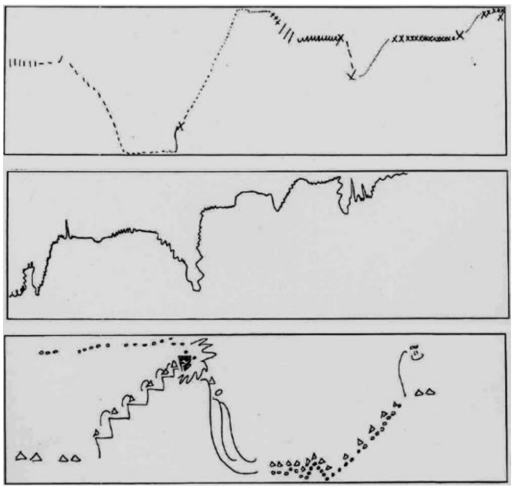


Figure 3-6: Three abstract examples from Copland's Jubilee Variations (Tan and Kelly, 2004a)

Other studies that have examined how children, and some musically untrained adults, have represented simple melodies. Davidson *et al.* (1988) describe how five-year-olds representations were comprised of pictures and abstract symbols (such as lines and dots), six-year-olds' representations consisted mainly of abstract symbols and words, often organized to show groupings of pitches or rhythm. By age seven years, most representations were made up of words and abstract symbols, conveying information about multiple elements of the music. The authors suggest that the more cognitively developed the participant is from a musical perspective; the less likely they are to represent music pictorially.

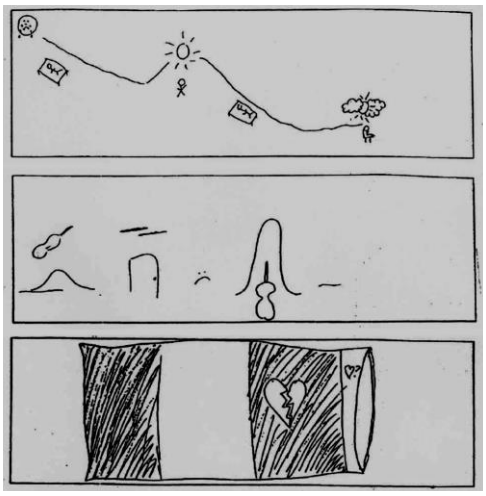


Figure 3-7: Three pictorial examples from Elgar's Theme from the Enigma Variations (Tan and Kelly, 2004a)

Previous published music therapy studies have either made no mention of the musical background of participants (LaGasse, 2014; Caltabiano, 2010), or have indicated that participants had no musical training (Dezfoolian *et al.*, 2013; Cibrian, Peña, *et al.*, 2017).

The perception of timbre is closely related to (but also distinct from) the physical notion of the spectrum of a sound (Delapaix, 2013). Timbre is identified as the perceived quality of relative intensities of harmonics within a tone (Fales, 2002). Butler (1973) describes timbre as not only carrying the most information about a source and its location, but of all parameters of music, it also carries the most information about the environment through which the sound has travelled. Gray (2013) describes timbre as the most fundamental of all musical parameters, one from which all others are derived. Gray goes on to suggest that music, as a sonic art form, derives its meaning from sounds over time. The audible waveform of a sound carries the complexity of the harmonic content that describes it timbre. From a visual perspective, waveforms of audio signals are frequently used within analysis (see section 3.4). However, from a metaphorical or creatively artistic basis, waveforms and timbre have been associated with pattern (Walker, 1987), and with colour (Fahlenbrach, 2008).

Participants within a study on timbre by Adeli *et al.* (2014) were asked to play a series of pre-set sounds from a variety of musical instruments, and to select a shape from three choices for each (Figure 3-8). The authors have shown that, in general, soft sounds have been associated with rounded shapes (S3) and harder sounds associated with sharper shapes (S1). The study also indicated that timbres perceived as having elements of softness and harshness together, were identified with a mixture of the two previous shapes (S2).

Figure 3-8: Shapes used as visual stimuli on correspondence between timbre and shape (Adeli *et al.*, 2014)

Smith and Williams (1997) mapped volume, pitch and timbre to spheres, designating colour to classes of instrument and scaling the spheres depending on volume. The classes of instrument chosen here could be considered analogous to the choice of timbre. The sphere's vertical position was determined by the relative pitch. The authors' goal was to present an alternative method of visualising music using colour and three-dimensional space.

In related research, Pouris and Fels (2012) created a visualisation system for hearing-impaired users that used 3D shapes as a basis for the representation of pitch, volume, tempo and rhythm of MIDI information (Figure 3-9). The authors *MusicViz* system represented differing styles of music using primitive shapes that identified each instrument present. Pop music, for example, had a greater number of visible elements compared to a simpler country music set-up. Pitch was represented via vertical movement of an object with volume represented by size and through colour lightness. Tempo was presented through object movement in the z-axis (depth in a 3D space), and rhythm through the movement of toroid objects that represented the rhythm section. The combination of these mappings were an attempt to create an informative and emotional experience for the users. Participants reported that differing styles could be identified through levels of dynamic movement; however, there were no significant differences in participants' ratings of discrete emotions for each style. In a review of music sensory substitute systems for deaf people, Petry *et al.* (2016) commented that *MusicViz* only partially facilitated musical exploration and did not support any customisation for users.

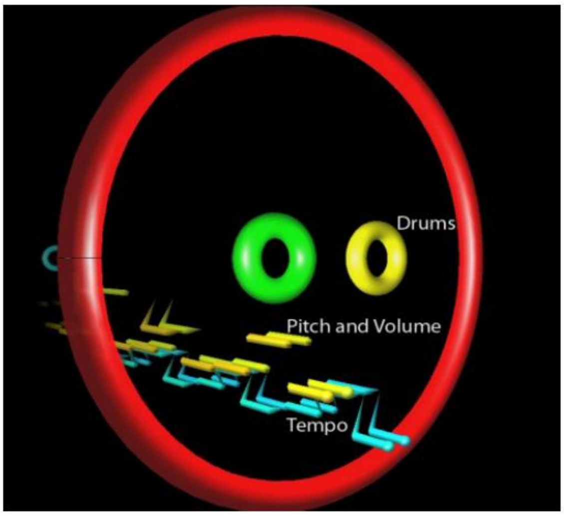


Figure 3-9: *MusicViz* visualisation (Pouris and Fels, 2012)

Theories on cognition and emotion point out that sensorial, cognitive and emotional processes of the stimuli are strongly related to one other (Fahlenbrach, 2008). The use of colour can affect the intensity of the audio-visual experience. Fahlenbrach (2008) argues that images and sound have to share emotional and physical characteristics that can be merged conceptually and metaphorically to improve the emotional and physical affects of a fictional character or object.

Hemphill (1996) and Davey (1998) recognise that colour can have an impact on the emotional perceptions of human beings. Hemphill comments that the colour red, for example, is known as being both dynamic and dominant. In positive respects it can be seen as active, strong and passionate, while in a negative way it can also been seen as angry, agressive and intense. Davey and Saito (1996) indicate that green is generally seen as a colour related to nature and implies feeling of relaxation, but can also have negative implications, such as guilt and tiredeness. A study by Kaya and Epps (2004) on colour-emotion associations, revealed that principle hues comprised the highest number of postive emotional responses, followed by intermediate hues and then by achromatic colours like grey and black. Table 3-5 highlights the colour-emotion associations.

	Emotional Association		
Color	Positive	Negative	No emotion
Principle Hues			
Red	63 (64.3)	32 (32.7)	3 (3.1)
Yellow	92 (93.9)	6 (6.1)	0
Green	94 (95.9)	0	4 (4.1)
Blue	78 (79.6)	17 (17.3)	3 (3.1)
Purple	63 (64.3)	32 (32.7)	3 (3.1)
Total	390 (79.6)	87 (17.8)	13 (2.6)
Intermediate Hues			
Yellow-red	73 (74.5)	18 (18.4)	7 (7.1)
Green-yellow	24 (24.5)	70 (71.4)	4 (4.1)
Blue-green	80 (81.6)	15 (15.3)	3 (3.1)
Purple-blue	64 (65.3)	30 (30.6)	4 (4.1)
Red-purple	75 (76.5)	15 (15.3)	8 (8.2)
Total	316 (64.5)	148 (30.2)	26 (5.3)
Achromatic Colors			
White	60 (61.2)	36 (36.7)	2 (2.0)
Gray	7 (7.1)	88 (89.8)	3 (3.1)
Black	19 (19.4)	77 (78.6)	2 (2.0)
Total	86 (29.2)	201 (68.4)	7 (2.4)
Overall	792 (62.2)	436 (34.2)	46 (3.6)

Table 3-5: Colour and Emotion Associations. The cell numbers indicate frequencies; the percentages are listed in brackets (Kaya and Epps, 2004)

Evidence also exists to support the idea that culture can affect colour preference (Choungourian, 1968; Saito, 1996). However, in a study by Gao *et al.* (2007), it was concluded that chroma (the purity of the colour) and lightness were the most important factors on colour-emotion association, whereas the influences of hue and cultural background were very limited. Twelve human colour-emotion word-pairs were chosen, from more than 100 colour description words, based on their frequency of sematic use (Table 3-6).

Emotion Word Pairs
Light-Dark
Soft-Hard
Warm-Cool
Turbid-Transparent
Deep-Pale
Vague-Distinct
Heavy-Light
Vivid-Sombre
Strong-Weak
Passive-Dynamic
Gaudy-Plain
Striking-Subdued

Table 3-6: Emotion word pairs

Participants were all university students aged between 17 and 24 from a variety of cultural backgrounds (Table 3-7). Colour samples were presented to participants who were asked to select the most appropriate word from the word pairs listed in Table 3-6. Values were then assigned to each response to quantify the findings.

Region	Number of subjects
Hong Kong	70
Japan	80
Thailand	60
Taiwan	56
Italy	56
Spain	56
Sweden	62

Table 3-7: Participants' regional background and total numbers

Gao *et al.* (2007) reported that 89% of total variance of the 'region-emotion' variables could be explained by three factors. Amongst these, 82% of total variance could be represented by the first two factors, namely chroma and lightness respectively. The third factor, hue, accounted for 7% of total variance.

From a neurological perspective, incoming sensory signals become centrally available to the human brain at different points in time. For example, when sprinters line up for the beginning of a race, a gunshot rather than a visual event is used to signal the start of competition. Despite the speed of light being faster than the speed of sound, auditory information is processed more rapidly in the brain by about 40ms compared to visual stimuli (King and Palmer, 1985; Pöppel *et al*, 1990). Sprinters can thus react much faster to a bang than a flash (Parsons *et al.*, 2013). The brain perceptually synchronizes signals that arrive less than 80 milliseconds apart less than a distance of 30 metres, however, past 30 meters the difference between the speeds of light and sound exceed this window (Eagleman, 2018). Thus, because sound is perceived temporally and faster than images are, sound can manipulate the visual structure. Parsons *et al.* (2013) hypothesise that perceptual timing derives from and is calibrated by our motor interactions with the world, highlighting how one modality can alter the perception of another.

Synesthesia is neurodevelopmental condition which occurs when the stimulation of one sensory modality automatically evokes a perception in another unstimulated modality (Baron-Cohen *et al.*, 1987). The most prevalent form of synesthesia is known as *audition coloree*, the phenomenon of seeing colours when hearing music or vowels (Van Campen, 2012). Most responses are visual, although any pairing of senses can be affected. Research has shown that people with autism have a higher than average chance of also having synesthesia. In a 2013 study, researchers identified that synesthesia was diagnosed in almost three times as many participants with autism as NT participants (Simon Baron-Cohen *et al*., 2013). Yet unidentified genetic factors may be responsible for these conditions, and the authors suggest that autism and synesthesia share common underlying mechanisms.

There is general agreement among synesthetes that high-frequency sounds produce smaller, brighter associations than do low-frequency sounds, thus relating higher pitches to smaller objects (Marks *et al.*, 1987; Mondloch and Maurer, 2004). Békésy (1957) points out higher frequency sounds are easier to spatially locate which makes them associated with smaller objects, whereas lower frequency sounds are more difficult to spatially locate allowing listeners to infer that they are larger in size. These data support the hypothesis that some cross-modal correspondences may be remnants of the neural mechanisms underlying neonatal perception. Although there may a higher than average number of autistic participants with synesthesia, the proposed design should aim to identify the most effective mapping for all participants.

Related work in autism studies has developed methods to visualise speech, in order to improve conversational communicative abilities in the autistic. Speech quality was visualised in research by Pietrowicz and Karahalios (Figure 3-10), who developed a method that represented phonetic sound quality, pitch contour, breathiness, noisiness, and sound amplitude (2013). Colour and saturation levels were used to differentiate between consonants and vowels. Time progressed on the horizontal axis with pitch being represented by the vertical axis. Amplitude was indicated by changes in size. The images were two-dimensional and designed with analytical purposes in mind that focused on the relational and expressive verbal gestures in speech, rather than as a meaningful expression of creative intent.

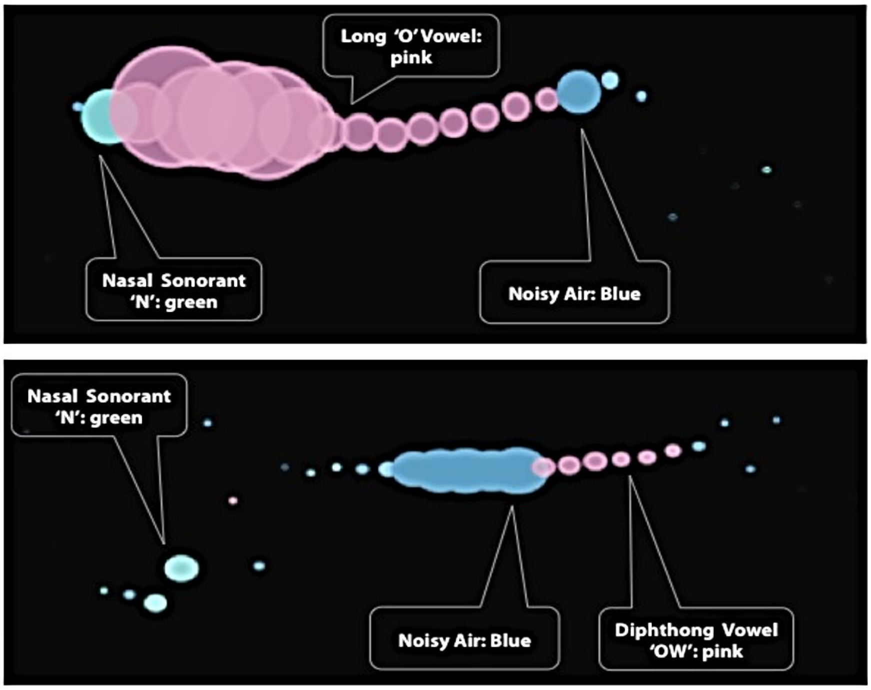


Figure 3-10: Visualised vocal expressions show a child saying similar words “no” and “now” (Pietrowicz and Karahalios, 2013)

Prior to 2015, the use of augmented reality (AR) within music education was limited. Chow *et al.* (2013) explored the use of AR to create an immersive experience to improve the efficiency of learning the piano, of neurotypical beginner students. The authors gamified the experience of learning through visual feedback of a head-mounted display worn by participants (Figure 3-11). Virtual notes would scroll down the screen allowing participants to see in advance which key to press before the visualised noted aligned with the real piano key. An informal user study indicated that the system initially put pressure on users, but that participants found it helpful and that it improved learning.

Figure 3-11: Augmented reality view of virtual notes aligned with physical keys (Chow *et al.*, 2013)

Since 2015, there has been an increase in research utilising augmented reality techniques that has seen applications developed specifically for the use of autistic children. A study by Chen *et al.* (2015) used animated expressions to facilitate practicing emotional judgements for adolescents with autism. A therapist recounted a short story and presented participants with six facial expression masks, depicting the emotional expression that corresponded to the situation. The chosen emotions represented fear, disgust, fear, happiness, sadness and surprise. Upon selection and wearing of the mask, a camera would detect and superimpose an animated model of the chosen expression, presented on a screen to allow the participant to observe their own emotional state within an AR environment (Figure 3-12). The results indicated an improvement in recognition and response to the facial emotional expressions used in the task.

Figure 3-12: A participant imitates the visual feedback provided by the 3-D facial model to make facial expressions that correspond to actions (the boy is simulating the facial action of opening his mouth) (Chen, Lee, & Lin, 2015b)

The *Brain Power Autism System* (Keshav *et al.*, 2017) also uses applications focusing on improving communication and managing social interactions for people on the autism spectrum. Coloured images and shapes can be overlaid onto the real world using augmented reality glasses (Glass, 2017), allowing greater portability than screen-based technology (Figure 3-13). However, the research team have not yet included applications that employ the use of sound.

Figure 3-13: *Empower Me* augmented reality glasses for autism (Brain Power, 2018)

Boyd *et al.* (2016) developed a system using a head-mounted display to detect and give feedback on autistic wearers' prosody. Atypical prosody is one of the characteristics of autism (Kanner, 1943), making those with the condition sound inadvertently monotone, and generally misunderstood from an emotional perspective. The project known as *SayWat* detects changes in pitch and volume, providing visual feedback via Google Glass by alerting the wearer of prolonged periods of monotone speech or periods of loudness (Figure 3-14). Results from the study indicated that wearable assistive technologies can automatically detect atypical prosody and deliver feedback in real time without disrupting the wearer, or the conversation partner.

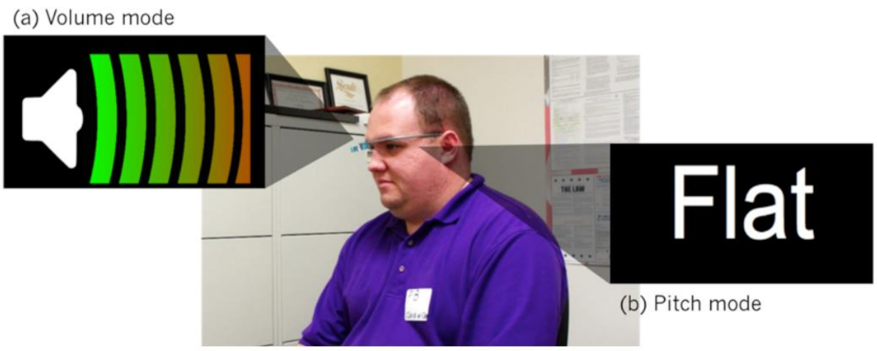


Figure 3-14: An individual with autism (shown with his permission) during the field study receiving on his Google Glass (left) a volume alert when speaking "too high" and (right) a pitch alert when talking "flat." (Boyd et al., 2016)

3.2 Theoretical and Technological Developments of Musical Sound

Historically, every musical culture possesses its own version of what constitutes a theoretical map of its musical terrain. A map provides a means of defining and creating a structure for musical theory to be used as a mechanism for the sharing of musical knowledge. The earliest substantive body of musical theory which partitioned music into three domains – pitch, rhythm and melody – was attributed to Aristoxenus of Tarentum, a Greek philosopher and pupil of Aristotle circa 375/360 BCE (Christensen, 2008). The origins of western notation are generally known to have been derived from accentuation signs from classical literature, approximately 2000 years ago. Subsequent developments by Quintilianus in the fourth century and Marchetto in the fourteenth century for example, have seen alternative schematization of music into differing categories. These were based on theoretical, practical, sacred or secular discourses, depending on their own cultural backdrop (Christensen, 2008).

Musical theory attempts to describe the structure of music by attributing characteristics to: intervals - the space between individual musical pitches; chords - groups of pitches played simultaneously; and rhythm - the systematic arrangement of musical sounds, principally according to duration and periodical stress (Oxford University Press, 2017b). The building of further concepts including musical keys, structure and harmony, are developed as a mechanism for musical comprehension and composition (Bergstrom et al., 2007). Structurally, music is probably best known through its notational form. Musical notation can be divided into two classes: Phonetic notation, in which sounds are represented by numbers or letters (Figure 3-15); or secondly, Diastematic notation (Figure 3-16), in which sounds are represented graphically (Rastall, 1982).

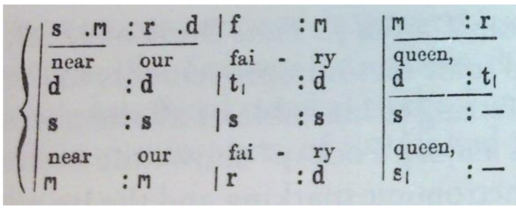


Figure 3-15: An example of Phonetic notation (Rastall, 1982)

Both classes have been used in the development of western musical notation, also known as staff notation, in its representation of pitch and duration in combination with instructions concerning dynamics and phrasing. Originally designed as a means to preserve music and record compositional ideas, it was optimised and used later as a prompt for performance (Rastall, 1982).

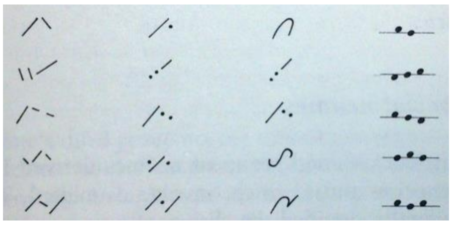


Figure 3-16: An example of Diastematic notation (Rastall, 1982)

However, most musicians agree that music notation is open to interpretation and thus not an accurate representation of all the potential attributes that music can convey (Patton, 2007b). This form, understood only by trained musicians, bears little relation to the abstract multi-sensory practice known as visual music (Ox and Keefer, 2008), where time-based visual imagery is displayed in synchronised form alongside its musical counterpart (see Table 3-8 for examples).

Technological developments of the digital era have contributed to rapid developments of musical representation techniques for a range of applications. Visually, shape has been used to represent music in a number of ways. For example, enhancing the understanding of the structure of music through geometric arches (Bewitched.com, 2005) or highlighting relationships between musical keys through the use of circular charts (Pelletier, 2018). Shape has also been used to identify tonality through static grids (Lerdahl, 2005)(refer to section 3.3). Colour has also been added as a means to add an extra dimension to a 2D image on paper, or electronically via a projector or screen. Representation of the dynamic nature of music, where psychological aspects of colour grounded in cognitive and cultural influences, can have a marked influence on the emotional mind-set of an individual (Hemphill, 1996; Davey, 1998).

Visual music has been represented through animation of form over time, interpreted by artists through audio-visual mapping techniques. Properties of audio have been measured through visible waveform to aid understanding of its attributes, as well as being used as a means of artistic expression (section 3.4). These representative techniques will be reviewed in this chapter.

3.3 Temporal Graphical Representation of Musical Structure

The temporal nature of musical structure has been represented graphically in a number of ways as a means to analyse, learn, and teach musical theory. A variety of technologies has allowed performers to visualise music in artistic ways, while the development of digital recording technologies have allowed visually aided composition methods. Table 3-8 provides an overview of alternative types of visualisation of temporal graphical representation of musical structure. It identifies their sub-class, and highlights their presentation medium, general purpose, intended group, and status of development.

Sub-Class	Type	Medium	Hue	Purpose	Group	Status	Examples
Analysis, Learning and Teaching	Circular Charts	2D screen based	Colour	Understand Musical Structure	Musician / Composer	Models still relevant	Circle of fifths - Figure 3-17
	Static Grid		B& W	Understand Musical Structure			Tonnetz template - Figure 3-18
			B& W				Harmony Space Figure 3-20
	Dynamic Grid		Colour	Understand Musical Structure during real time playback		Discontinued	Isochords - Figure 3-19
	Linear Display		B&W	Understand dynamic changes in music over time			Spectrogram Analogues - Figure 3-21
	Circular Display		Colour	Identify song structure via visualisation of arches	Composer / Artistic	One-off	The Shape of Song - Figure 3-22
	Static Grid			Identification of harmonic relationships	Musician / Composer	Research ongoing	Mardirossian and Chew's Visualization - Figure 3-23
	Colour Chart					Discontinued	Visual Hierarchical Key Analysis - Figure 3-24
	Piano Roll	3D screen based			Musician / Composer / Artistic	Models still relevant	Ciuha *et al.* - Figure 3-25
							Music Animation Machine - Figure 3-28
	Spatial Line Visualisation		B&W	Analysis of emotional content of music through visualisation	Artistic / Psychology	Research ongoing	Grekow Visualisations - Figure Figure 3-29
Performance	Visual Music	2D projected	Colour	Create artistic multi-sensory experience	Artistic	Led to further techniques	The Clavilux - Figure 3-30
		3D screen based				Ongoing artistic development	Audio visualisers - Figure 3-33
		3D projected					Cyclotone II - Figure 3-34
Composition	Digital Audio Workstation	2D screen based		For computer-based composition of music	Composer	Continued development	Apple GarageBand - Figure 3-35

Table 3-8: Temporal graphical representation of musical structure overview

3.3.1 Analysis, Learning and Teaching

To aid in the understanding of theory through visual means, Krumhansl (2005) proposed that the underlying structure of music can be represented geometrically. According to Hyer, tonality is one of the main conceptual categories in Western musical thought (Oxford University Press, 2017d). The term most often refers to the orientation of melodies and harmonies towards a referential, or tonic, pitch class, therefore representing an important theoretical construct. Tonality can be seen as a framework within which musical elements engender patterns of tension and expectation of musical resolution over time, linking the cognition of music to emotional responses (Krumhansl, 2005).

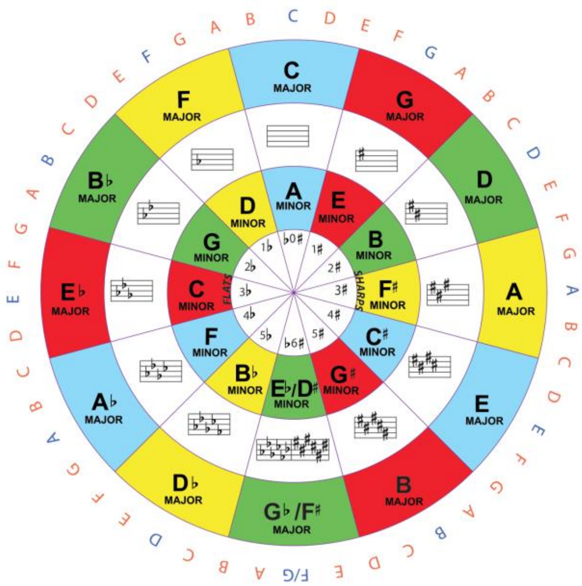


Figure 3-17: Circle of Fifths using C as the base tone class demonstrates the location of consonant (outer) and dissonant (inner) intervals (Seattle String Studio, 2017)

Notable models associating musical and geometric tonality are still relevant today. These include firstly, Kellner's (1737) regional circles, more commonly known as the circle of fifths (Figure 3-17), in which the model shows the relationships between the 12 chromatic tones of a musical scale, their corresponding key signatures and associated relative major and minor keys (Pelletier, 2018). Secondly, the harmonic network proposed by Leonard Euler in 1739 (Gatzsche *et al.*, 2007), a two-dimensional triangular isometric coordinate grid called Tonnetz (Kelley, 2003). The Tonnetz grid (Figure 3-18) is popular in modern musical analysis (Lerdahl, 2005).

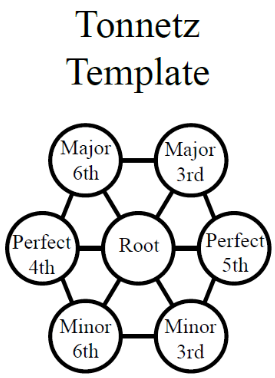


Figure 3-18: The Tonnetz grid surrounds each tone with its six consonant intervals (Bergstrom *et al.*, 2007)

This approach is used as a basis for Isochords (Figure 3-19), a means of representing the consonant intervals between notes and common chords. Isochords convey information about interval quality, chord quality, and chord progression synchronously during playback of digital music (Bergstrom *et al.*, 2007). One of the proposed advantages of using this approach includes increased interactivity within compositional

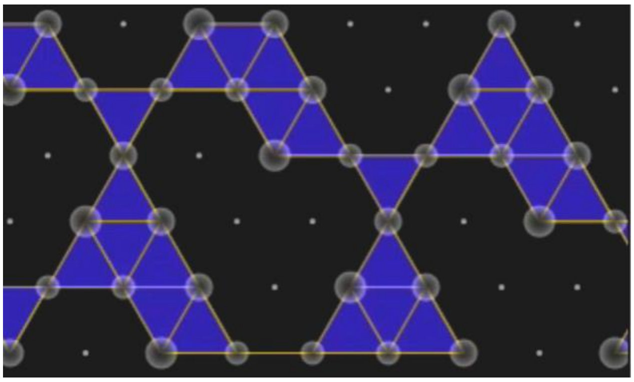


Figure 3-19: Isochords (Computer Graphics Illinois, 2011)

domains. For example, visualisation during composition creates an aid to understanding harmonic relationships or for improvisational purposes for a soloist, by notating the path that a section of music follows. However, as it was designed as a means of visualising pre-recorded music, the interface is not accessible for immediate and intuitive feedback of live music. Developments have attempted to address this through the Hexachord software, which caters for instantaneous compositional analysis (IRCAM, 2015). However, identification of similar chord shapes and creation of unique chord shapes make this system a less than ideal compositional tool. More crucially, this approach does not lend itself to temporal or rhythmic representation of a piece of music.

A similar approach was Harmony Space (Holland, 1994), where notes are arranged in a rectangular grid such that perfect fifths define one axis and major thirds the other (Figure 3-20). Isochords highlighted chords, triads and consonances more explicitly, while Harmony Space leaves it to the viewer to discover the relationships by examining only the notes (Bergstrom *et al.*, 2007).

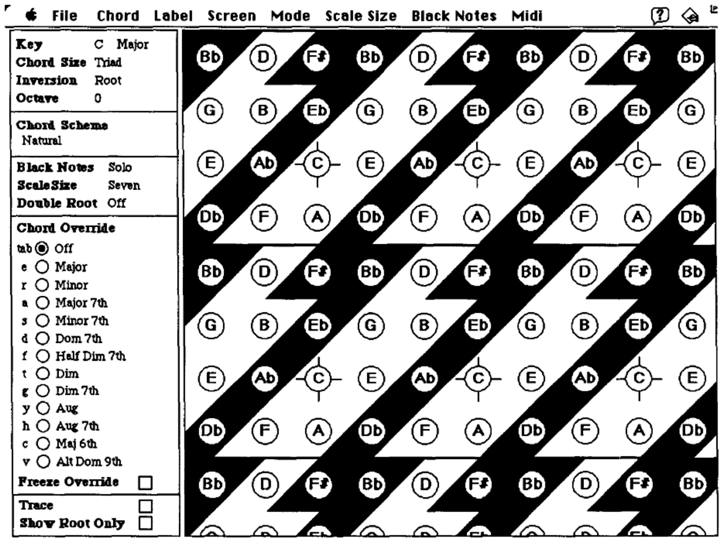


Figure 3-20: A harmony space display with the system in the key of C major (Holland, 1994)

Krumhansl (2005) noted, relating to the circle-of-fifths approach, that a low-dimensional space may not be sufficient to represent all of the desirable musical relations. This led to the development of other advanced geometric tonality models, including helix and spiral array models by Shepard (1982) and Chew (1999) respectively, designed to describe important aspects of the psychological aspects of tonality. Other developments include the concept of using colour to add dimensionality – Chew and Francois use colour to distinguish between tones, chords and keys (Krumhansl, 2005), while Sapp (2005) uses similar colours to represent related keys (see Figure 3-24).

Brinkman and Mesiti (1991) created Spectrogram Analogues, which include simplified 2D mappings of dynamics over time as well as graphic renditions of scores (Figure 3-21). Its advantages include the flattening of the contents of the various staves into a single coordinate system, as well as the elimination of the clutter of musical staves and traditional musical notation. However, this approach misses information on specific pitch and rhythmic meter, although its main focus succeeds in its ability to visualise melodic shape and changes in dynamic over time (Isaacson, 2005).

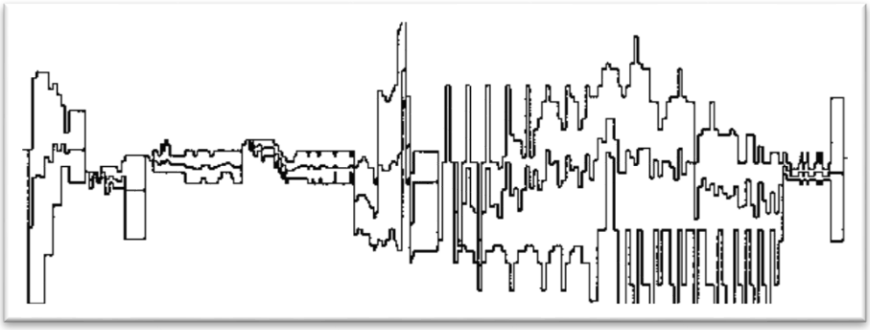


Figure 3-21: Spectrum Analogue example showing Bartok String Quartet No. 4, bars 1-26. Horizontal axis: time. Vertical axis: local mean, maximum and minimum pitches (Nettheim, 2015)

As an artist, Wattenberg employs 2D displays of musical form as a sequence of translucent arches (Figure 3-22), where each arch connects two repeated identical passages of a composition (Bewitched.com, 2005). Known as The Shape of Song, this approach to structural visualisation has aesthetic value in the way it demonstrates the use of repetition of musical events. However, it can lead to confusion over the relative importance of musical sections due to the height of the arches which are merely representative of the distance that the repeating events take place (Isaacson, 2005). Additionally, if the music had no repeating sections, there would be no visualisation at all, thus limiting the approach.

Figure 3-22: Wattenberg's Visualisation of Madonna's "Like a Prayer" (Bewitched.com, 2005)

Mardirossian and Chew (2007) created a 2D system that divides up music into slices and determines which key it is associated with, using colour to identify that slice (Figure 3-23). Thus, the whole visualisation shows not only the individual key slices but also the cumulative distribution of tonalities in the piece. They state that this is advantageous for the comparison of differing musical genres. Again, the circle of fifths is chosen as a model for distribution of colour for each key, based on Lerdahl's 2D representation of major and minor keys in his Tonal Pitch Space (Lerdahl, 2005). The system does demonstrate the relationship of musical tone through colour; again, however, the assignation of the initial colour to a specific key is made arbitrarily.

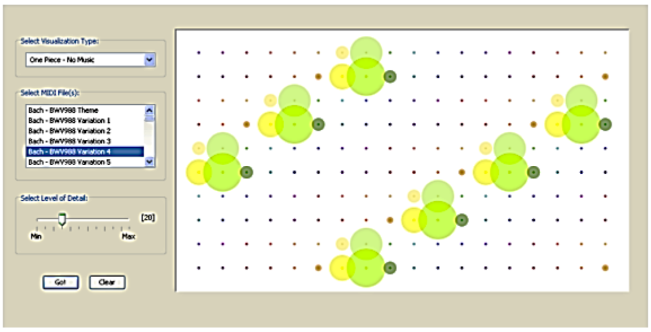


Figure 3-23: Mardirossian and Chew's visualization interface (2007)

Sapp's Visual Hierarchical Key Analysis is another system that assigns colour in a two dimensional way, using segments running from top to bottom of the display where the estimated overall key of that musical segment determines its colour (Sapp, 2005). Figure 3-24 shows how the changes in key relate to the visualisation. Isaacson (2005) points out that it is unlikely that we, as listeners, perceive as many tonal levels and shifts in a piece of music as the colour shifts imply, and that the use of colour does not imply a sense of key distance, as was intended. Isaacson implies that this approach may be more beneficial in the analysis of older styles of music, typical of pre-20th century styles.

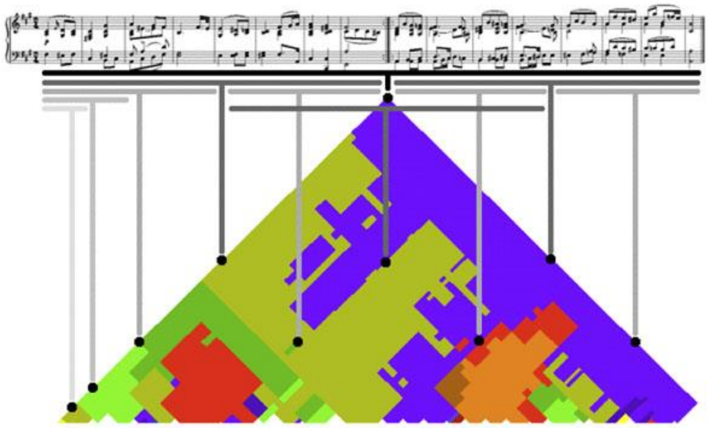


Figure 3-24: Visual Hierarchical Key Analysis (Lookingatsound, 2011)

Colour may be used as a teaching aid when creating music through a play-by-colour idea. The method proposed by Ciuha *et al.* (2010) involves assigning similar colour hues to the grouping of tones, chords and keys, where they are not perceived as separate but as a whole (Figure 3-25). In addition, dissonance and consonance are represented via low and high colour saturation respectively.

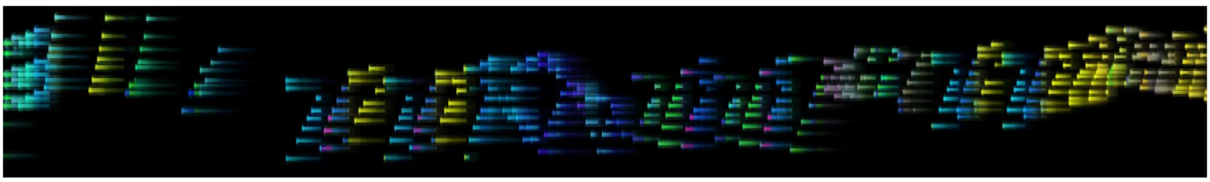


Figure 3-25: Representation of Debussy's Clair de Lune demonstrated on a prototype music visualization system using extended 3D piano roll notation (Ciuha *et al.*, 2010a)

This system was based upon Gatzsche's (2007) key spanning circle of thirds proposal (Figure 3-26), a variation of the circle of fifths in which major and minor thirds are inserted in between the fifths. These additional tones are represented as vectors of appropriate direction and length, super-imposed over the colour wheel. The colours of groups are calculated by adding the vectors for the resultant shade and are thus not limited to discrete set of colours.

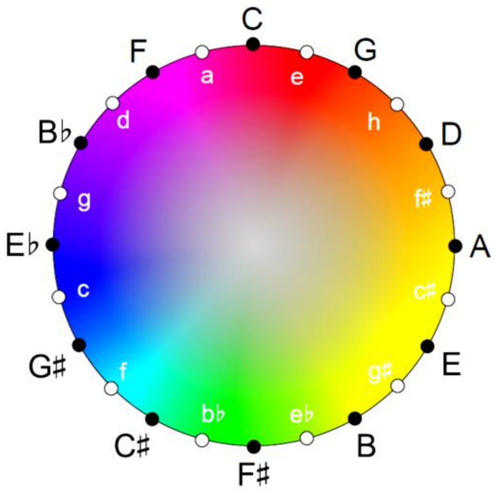


Figure 3-26: Key spanning circle of thirds assigned to the colour wheel. A particular tone is represented by a radius vector pointing in the direction of circle of fifths denoted by majuscule letters. (Ciuha et al., 2010b)

The visualisation by Ciuha *et al.* (2010b)*,* was based on a piano roll, a hybrid of spectrogram (see Figure 3-38) and music notation. Piano roll is a notation system derived from player pianos, where a roll of paper with punched holes would trigger a note to be played (Figure 3-27), known generically as piano roll notation (The Pianola Institute Ltd, 2016).

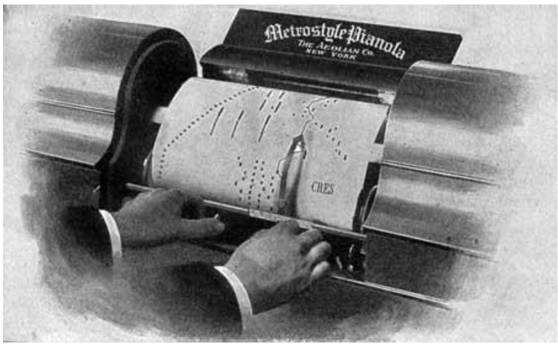


Figure 3-27: The Metrostyle Pianola (The Pianola Institute Ltd, 2016)

Malinowski's Music Animation machine (Figure 3-28) proposed a similar concept (Musanim.com, 2011). Colours were based on pitch classes - for example, one adjacent colour on the colour wheel would be an interval of a fifth apart from the first tone. This concept was in itself taken from Scriabin's proposal of mapping pitch classes to hues (Wells, 1980). Malinowski's visualisations were based on a 2D piano-roll style and may have been considered useful for understanding the relationships in musical harmony through colour (Ciuha *et al.,* 2010b).

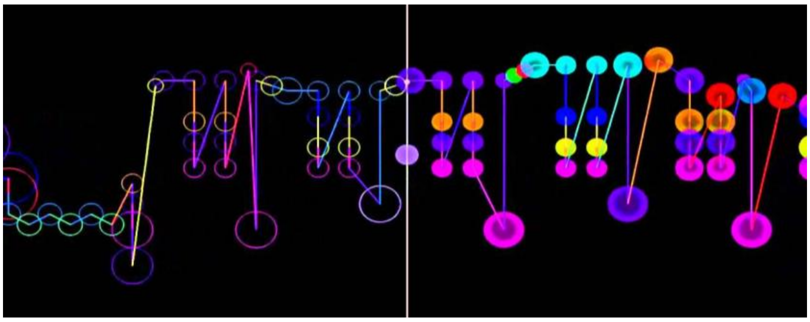


Figure 3-28: Malinowski's Music Animation Machine playing Rhapsody in Blue (YouTube, 2016)
(Access the video using this URL: https://www.youtube.com/watch?v=js-vlAIdCp0)

An alternative way of analysing music was shown through automatic detection of emotion. Grekow (2011) proposed a music visualisation system that was linked with an external system that automatically detected emotions from classical music. The emotional labels produced were then used to modify certain parameters of the visualisation. It was shown that mapping emotional labels with the creation of 3D musical figures enhanced their strength and attractiveness. Questionnaires were used to create user profiles and tailor it to individual preferences. For example, users were asked to define the parameters of a line that, according to them, should be used to draw figures visualising music with a particular emotion. For each emotion (e1, e2, e3, e4), a user chose one-line type: continuous, dashed, dotted, and one thickness: thin, medium and thick, etc. The approach focused on the extraction of emotional information from an existing piece of music as a means of analysis by providing 3D spatial line visualisations, some with relative geometric complexity and some similar to Lissajou figures (Weisstein, 2017). The figures are limited to line visualisation and analysis of MIDI information, rather than live audio, although future development aims toward expanding the visualisation parameters (Figure 3-29).

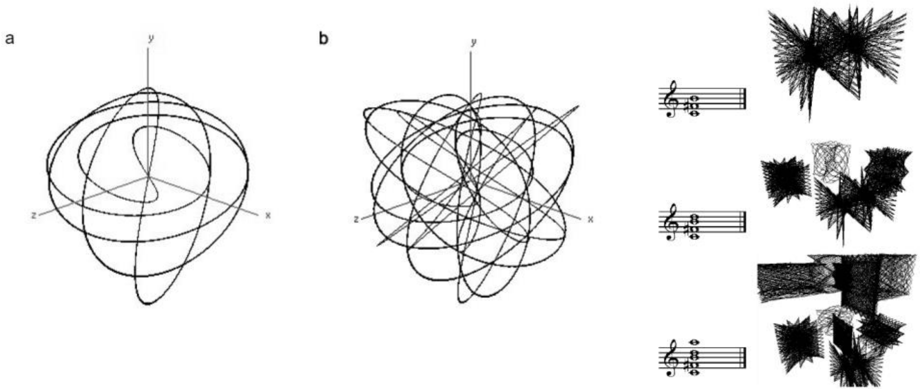


Figure 3-29: Grekow's 3D Visualisations based on MIDI files: left - major chord (a) and minor chord (b); right – number of tones forming a harmony and type of visualisation (Grekow, 2011)

3.3.2 Performance

Visual Music is a term that describes an area of practice concerned with the multimodal interplay of sound and image in real time. Described by the Center for Visual Music as a translation of a specific musical composition (or sound) into a visual language, the original syntax is emulated in a new visual rendition which can be done with or without a computer (Ox and Keefer, 2015). A number of alternative definitions exist - in general, however, visual music has purported to create an emotional multi-sensory experience since its inception.

The use of colour and shape within visual music, can be traced back to 1735, when Castel built an instrument that projected coloured light known as the Ocular Harpsichord (Popper, 1968). Castel adopted Newton's corresponding principles concerning the colour spectrum and the musical scale. He was followed in the 1890s by Rimington's instrument, termed the colour organ, which used 150 amperes of current to light colour filters and lamps, creating abstract shapes that flowed together onto a screen (Levin, 2000). In 1911, Scriabin created a work called Prometheus, where he devised an accompaniment of changing coloured lights, calling for instrumentation like that described by Rimington. A number of other light artists created similar systems, including The Clavilux by Wilfred in 1920 (Figure 3-30), however, all of these creations used an arbitrary pitch-to-colour correspondence (Conrad, 1999).

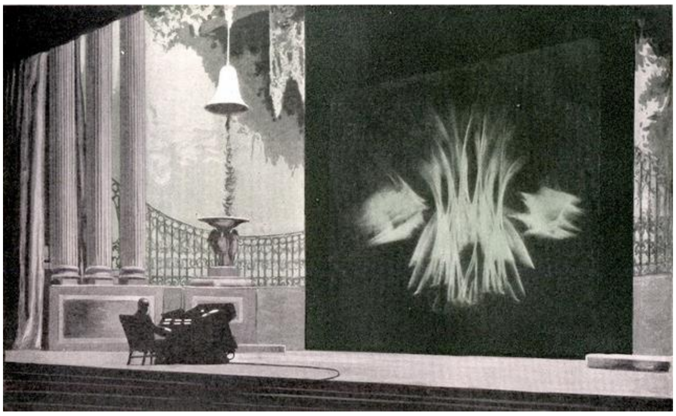


Figure 3-30: Wilfred performing with the Clavilux (The Creators Project, 2017)

With the development of cinema in the early 20th century, Fischinger created animations by combining music with graphic art and abstract design (Figure 3-31), thus influencing other American pioneers such as John and James Whitney (Möritz, 2004; Evans, 2005).

Figure 3-31: A still from Fischinger's animation Allegretto (Ox and Keefer, 2015)

John Whitney would go on to explore consonance and dissonance in music and visual art, indicating potential correspondences between: sensory elements such as pitch and colour; tension and resolution; and anticipation and stability in visual music (Whitney, 1980; Alves, 2012). Strick (2005) argues that John and James Whitney's creative work with sound and vision aspire toward synesthesia, a condition in which one sense leads to the involuntary stimulation of another sense (see section 3.1). Many discussions in art have centred on the realisation of a synesthetic analogy, such as the contemporary transcoded audio visuals created by Fox and Gadow (Figure 3-32), based on Fischinger animations (Whitelaw, 2008).

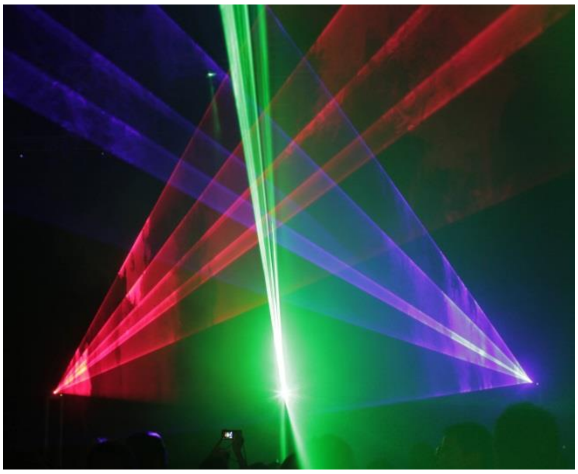


Figure 3-32: RGB Laser Show (Fox, 2018)

According to Ciuha *et al.* (2010a), the goal in visualising music in a meaningful way through colour mapping is to enable people, trained or untrained, to understand the harmonic relationships in musical tone through the use of colour.

The availability of relatively inexpensive and powerful computers in the present day has produced a number of creative audio-visual mappings (Figure 3-33). However, as Moritz (1986) argues, the creation of new visual technologies consistently end up as nothing more than an eccentric curiosity. This contradicts the initial self-held belief of breakthrough, and as many commercially available music visualisers do, synchronise waveforms with arbitrary colour for tone and mood but essentially do not provide meaningful feedback (Sykes, 2011). Alves (2012) argues that simple mapping techniques are naive in visualisation, for example mapping pitch to colour, and that more complex techniques are required to create a greater emotional experience for the viewer.

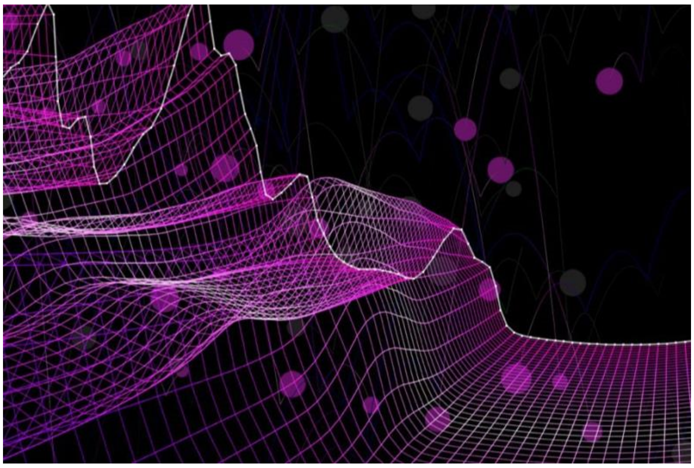


Figure 3-33: WhiteCap music visualisation (SoundSpectrum Inc., 2017)

Prudence (2017) has taken programming and real-time visualisation to an aesthetic level where he describes the music as more of an art-based meditational accompaniment (Figure 3-34). Prudence has also created visual references of cellular phenomena based on Cymatic principles (see section 3.6) in his work *BioAcousticPhenomena* (Visual Music Archive, 2009).

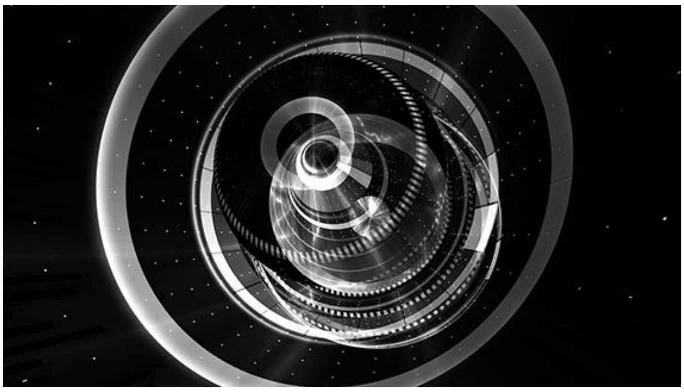


Figure 3-34: Cyclotone ll visualisation (Prudence, 2017)

3.3.3 Composition

Traditional music notation uses a left-to-right timeline of musical events which are performed in a linear fashion, much like a series of scheduled events within a Gantt chart (Gantt, 1910). Linear editing of film involved physically cutting up the physical media and reordering it into a new sequence, referred to as destructive editing (motionelements, 2013). Software-based non-linear editing systems perform non-destructive editing on audio and video source material, via the ability to easily access, copy digital information from one location, and reorder it within another location. Accessibility and availability of computer hardware has spawned a variety of software whose role is to facilitate music composition through structural understanding, both in two and three-dimensional interactive ways.

Figure 3-35: Apple GarageBand Interface (Future Publishing Limited, 2017)

The introduction of the Digital Audio Workstation (DAW) has provided a screen-based interface for the recording and sequencing of music in a non-linear fashion, similar to video production packages like Premiere (Adobe, 2018). A number of commercially available packages include: Avid Pro Tools (2017); Steinberg Cubase (2017); Apple Logic Pro (2017b); and Ableton Live (2017). Each has their own design ethos and priorities, dependent on their target audience. For example, in 2017 Apple GarageBand (Figure 3-35) was regarded as the most user-friendly DAW for the beginner or non-musician (Future Publishing Limited, 2017). GarageBand allows easy looping of a readily available library of pre-recorded sounds, and allows control via mobile devices like the iPad. GarageBand provides limited functionality compared to Avid Pro Tools, however, it has shown to be an ideal tool for music therapists and community musicians within therapeutic environments (Hillier *et al.*, 2012). Cevasco and Hong (2011) suggest that if DAWs are automatically provided within the installed software of a new computer, it increases the opportunity for users to experiment with current technology. Regardless of the functionality of the variety of DAWs on offer, they all rely on a similar linear set-up. Layers of instrumental tracks display audio-wave or Musical Instrument Digital Interface (MIDI) data over time, their focus being on composition through visual organisation.

Typically, many DAWs use systems based on piano roll notation. In addition, DAWs include other forms of visualisation methods, for example spectrograms, which are designed to analyse audio signals. This and other methods will be discussed in the next section.

3.4 Temporal Representation of Audio Signals

Visualisation of audio signals are typically used for the purposes of analysis, in both recording and live situations, but can also be used as an artistic means of expression through performance. Table 3-9 provides an overview of examples of temporal representation of audio signals. Divided into two sub-classes, it highlights their presentation medium, general purpose, intended group, and status of development.

Sub-Class	Type	Medium	Hue	Purpose	Group	Status	Examples
Analysis	VU Meter	2D screen based	Colour	Display of levels of amplitude	Analysis, artistic	Continued use	VU meter Figure 3-36
	Spectro-gram	2D screen based	Colour	Analysis and audio editing of waveforms	Analysis, editor, designer	Continued development	Spectrogram Analysis of a waveform Figure 3-38
	Cartesian Graphs (Spectro-gram)	2D screen based	Colour	Analysis of audio waveforms	Analysis, artistic	Research ongoing	Oscilloscope Figure 3-39
	Cartesian Graphs (Spectro-gram)	2D screen based	Colour	Comparison of Peak and RMS audio power levels	Analysis	Continued use	Peak and RMS Power History Figure 3-40
Performance	Pellegrino Figure	3D screen based	Colour	3D Visualisation of audio tones	Analysis, artistic	Led to further research	Oscilloscope Figure 3-42
	Computer animation	2D screen based	BandW	Show harmonic relationships through geometry	Analysis, artistic	Led to further research	Differential dynamics Figure 3-43

Table 3-9: Overview of temporal representation of audio signals

3.4.1 Analysis

A standard volume indicator (SVI), or volume meter (VU), is a graphical representation of the level of amplitude within a given audio signal (Chinn *et al.*, 1940). Generally used as a means of visualising audio input levels, VU meters can also be used as aesthetic displays for playback of audio (Figure 3-36).

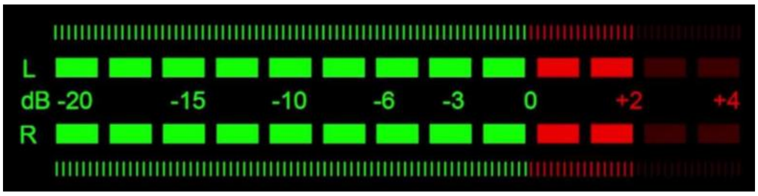


Figure 3-36: A VU meter displaying amplitude levels in left and right channels (Griffin, 2013)

Digital peak programme meters (PPM) are more responsive than VU meters to the dynamic range of audio input (Figure 3-37). Peak metering is designed to display the maximum decibel amplitude level of a signal's waveform more quickly, and in exact proportion to the voltage of the audio signal (Dubspot, 2016).

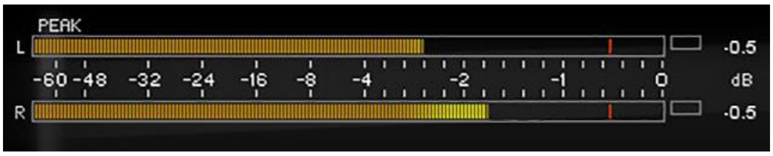


Figure 3-37: Peak programme meter (Dubspot, 2016)

The temporal representation of sound is commonly drawn using computer hardware and software as a trace of sound pressure variations over time, known as a waveform. The waveform is seen as a graph of amplitude, in the vertical axis, over time in the horizontal axis (Figure 3-39). Additional properties of audio can be visualised by using spectrograms, which show a range of audio frequencies spread over time (Smith, 2007). Typically, these are used in a variety of software packages as a means of evaluating waveforms using spectral analysis (Figure 3-38). They do not, however, provide an easily understood means of conveying information concerning musical structure or quality of timbre (Bergstrom *et al.*, 2007).

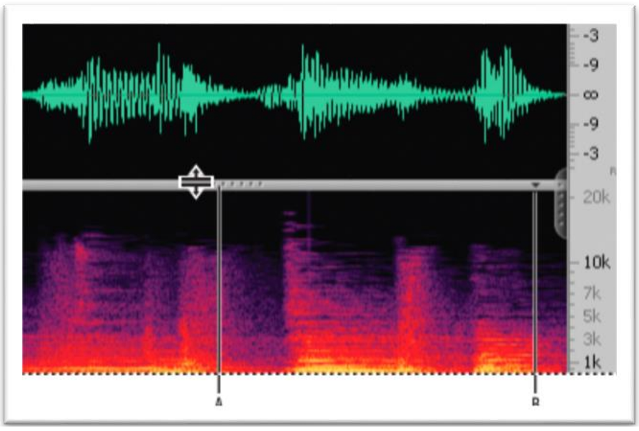


Figure 3-38: Spectrogram Analysis of a Waveform (Adobe, 2010)

The oscilloscope is an electronic test instrument that can convert sound into voltages for analysis. Consisting of a cathode ray tube and fluorescent screen, the vertical axis represents the amplitude of the signal, and the horizontal axis the frequency (Whatis.com, 2018). It has been used as an analytical tool and an artistic one. Regarding sound as a wave, its amplitude, frequency and form are visualised for the currently sounded tone as seen in Figure 3-39.

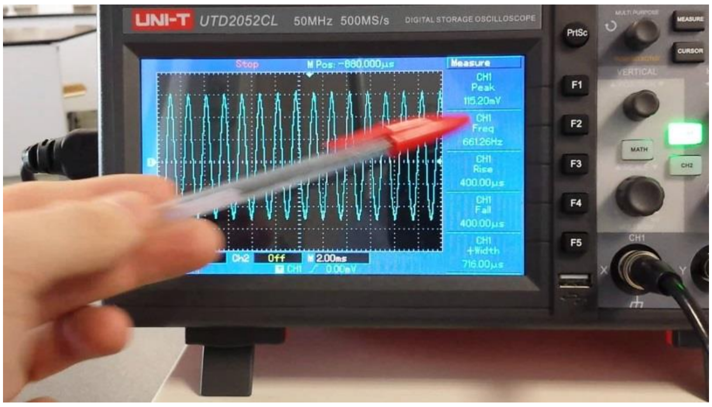


Figure 3-39: Oscilloscope showing the waveform (frequency and amplitude) of an audio signal (Animated Science, 2015)

Spectrafoo (Metric Halo, 2018) is a suite of audio analysis tools that allow a number of techniques to be employed, dependent on the needs of a recording or live audio engineer. Specialist tools include spectrograms, waveforms, and meters that compare the peak and root mean square (RMS) audio power levels over time (Figure 3-40).

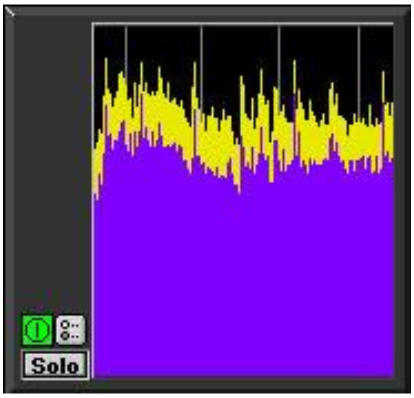


Figure 3-40: Peak and RMS Power History (Metric Halo, 2018)

The light grey "tick" marks indicate the passage of one second of time, and the height of the each colour for each time "slice" indicates the Peak (yellow) and RMS (purple) power levels of the program.

Polarity refers to the audio signal's voltage level above or below the median line and can cause unwanted frequency responses or cancellation of sound if not appropriately positioned (Total Pro Audio, 2018). Another feature within *Spectrafoo* is the Lissajous Phase Scope, which shows the amplitude of the first input signal versus the amplitude of a second input signal (Figure 3-41). This can help in identifying polarity problems within an audio mix and the width of the stereo field of the sound being monitored, from a visual perspective.

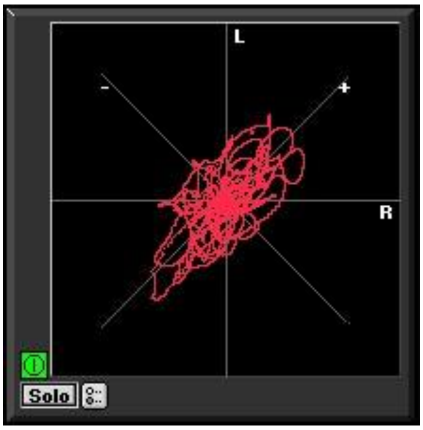


Figure 3-41: The Lissajous Phase Scope showing the audio signal as a 2D line visualisation (Metric Halo, 2018)

3.4.2 Performance

Artists such as Pellegrino (1983), used the oscilloscope to visualise sound in spatial, complex three dimensional ways. Pellegrino visualised the result of combining two simple tones (Figure 3-42), created via a different tuning system based on whole number frequency relationships known as Just Intonation, resulting in symmetrical Lissajou figures. The typical western way of tuning instruments, known as Equal Temperament, divides the notes of an octave into 12 equal intervals. Just Intonation is the name given to a tuning system based on whole number ratios as defined by the Pythagorean Laws of Harmony (Sykes, 2015).

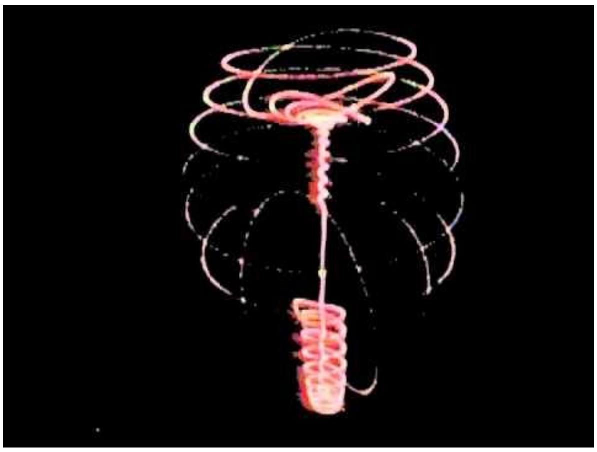


Figure 3-42: Pellegrino figure (Video Circuits, 2005)

Whitney (1980) hypothesised that Pythagorean harmony could be matched in visual art. He also realised that computers could be a useful tool to animate, in a visual manner, the same kind of form found in Grecian music (Alves, 2005). Whitney's motivation was the creation of computer animations that focused not on colour, space or musical intervals, but on motion. By applying the principles of Just Intonation to the motion of elements within a given space, the resulting animations demonstrated symmetry corresponding to the same ratios that define musical consonances. For example, a set of points going around a circle start at the 12 o'clock position, the second point travels twice the speed of the first; the third point travels three times the speed of the first and so on. By experimenting and extending these principles with parametric curves and other shapes, Whitney was able to show the same points of resonance, and of symmetry, occurring at the same points of harmonic proportions (Figure 3-43). Alves (2005) took Whitney's animations a step further when he extended the polar coordinate curves into three-dimensional graphics, using only tones from Just Intonation tuning.

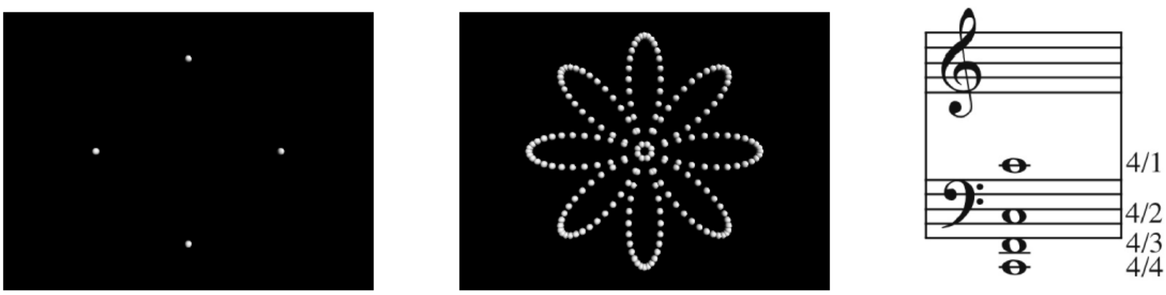


Figure 3-43: Differential dynamics example showing spheres moving in a circle compared to spheres moving in a rose curve pattern with the corresponding musical pitches (Alves, 2005)

3.5 Interaction

Musical interaction implies a human-to-human, or a human-to-computer dialog. Table 3-10 provides an overview of examples of visual representation of musical interaction. Divided into three sub-classes, it identifies their interaction type, highlights their presentation medium, general purpose, intended group, and status of development.

Sub-Class	Type	Medium	Hue	Purpose	Group	Status	Examples
Composition	Piano Roll	2D screen based	Colour	Social musical game shared across a network	Gamers, musicians	Led to further research	World stage Figure 3-46
	3D Piano Roll	3D screen based		Understanding the nature of musical structure	Composer s, musicians	One-off but similar tools developed	comp-i system Figure 3-47
	2D Dynamic Grid	2D screen based		Web-based digital audio workstation	Composer s, musicians	One-off but similar tools developed	Tonematrix - Figure 3-50
Analysis	3D Spectro-gram	3D screen based		Real-time analysis of audio waveforms	Analysis	Continued develop-ment	SNDTOOLS Figure 3-45
Performance	Interactive Multi-media Display	2D iPad based		Virtual instrument	Musicians, non-musicians	Led to further research	Magic Fiddle Figure 3-55
Composition	Interactive Display	2D iPad based		Real time visual editing and processing of audio	Composer s, musicians	Continued develop-ment	Borderlands Figure 3-57

Table 3-10: Overview of Interaction

Causation in interaction design, or cause-and-effect, refers to user actions that have an immediately perceptible effect in the virtual world (Thompson *et al.*, 2009). Thompson *et al.* highlight the importance of causation in creating a sense of connectivity between the user and the perceived environment. Cause-and-effect has been demonstrated as a commonly used and effective method of interactivity for autistic people within simple applications (Cariad Interactive, 2018a). Technological developments have allowed attributes of sound to be mapped to any visual metaphor. For example, custom visual programing in Max or PD (Pure Data) allow complex functions or visualisations to be created (Figure 3-44) through the connection of elementary modules, including mapping pitch and amplitude to shape and colour (Cycling ’74, 2018b; IEM, 2017).

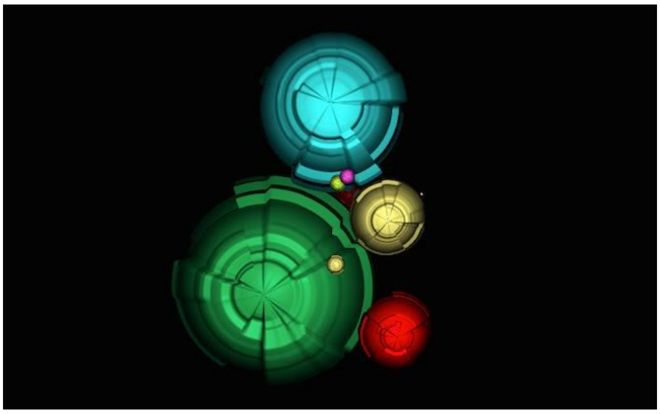


Figure 3-44: *Synesthetic Audio-Visual Platform* – an example project created in Max (Cycling '74, 2018c)

Technology used to develop applications has significantly accelerated since the late 1990s, and subsequent interactive applications embody augmentations of the piano roll concept; art-based installation; web-based interactive interfaces; interactive virtual characters; virtual musical instruments; video sampling; and granular audio synthesis. This non-exhaustive list has led to some general design recommendations for the visual design for computer-based music. These applications will be discussed in the forthcoming section.

3.5.1 Applications

Graphics tools such as the Open Graphics Library (2018), a multi-platform application programming interface for rendering 2D and 3D vector graphics, can be used to enable real-time 3D visualisation of Digital Signal Processing (DSP) algorithms. Optimised to take up few resources, OpenGL offers standard library routines and customisability, which is ideal for the development of cross-platform real-time audio-visualisation. Misra *et al.* (2005) have taken advantage of OpenGL in the development of a number of audio-visual tools. SNDTOOLS was a set of tools designed to analyse and display audio in real time, and focused mainly on the spectral analysis of audio waveforms for instructive purposes (Figure 3-45). For example, how the use of pitch manipulation affected the shape of the resultant waveform from a visual perspective.

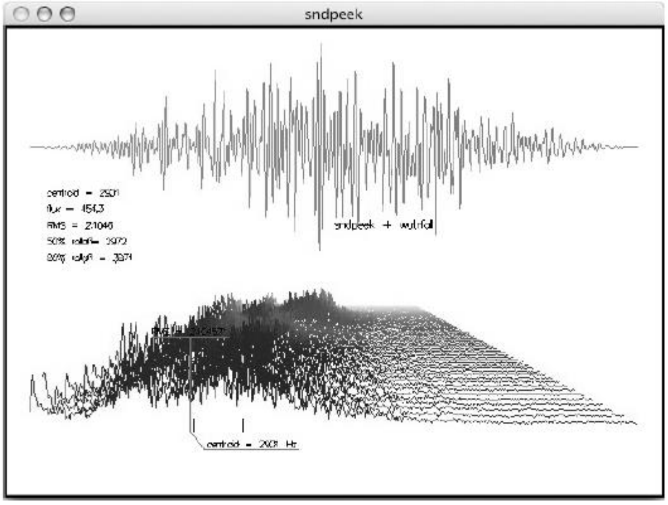


Figure 3-45: SNDTOOLS performs real-time linear analysis of audio input and displays a visual synthesis of the results (Misra *et al*., 2005)

World Stage (Figure 3-46) was a social-musical game involving compositional tools based on piano roll notation, expressive musical performance and collaborative musical feedback (Wang *et al.*, 2011). The authors described World Stage as a musical experiment that combined a commercial iPad application, cloud computing and human computation. It offered a place for a community to score arrangements for each other, perform music to one another, and even anonymously judge performances (Kruge and Wang, 2011). Interactions were anonymous, allowing people to submit their ideas for judgement by other users using emoticons.

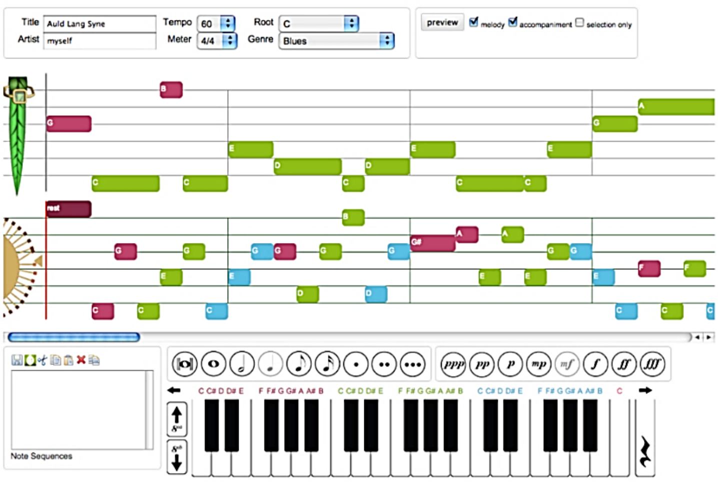


Figure 3-46: World Stage composing interface for Leaf Trombone and the accompanying music box (Wang *et al.*, 2011)

The comp-i system (Comprehensible MIDI Player – Interactive) explored the 3D piano roll visualisation of MIDI data sets with the aim of better understanding the nature of musical structure embedded in a multi-channel sequence of note events (Miyazaki, 2003). Pitch, volume and tempo were represented by height, diameter and colour saturation of cylinder shapes respectively (Figure 3-47).

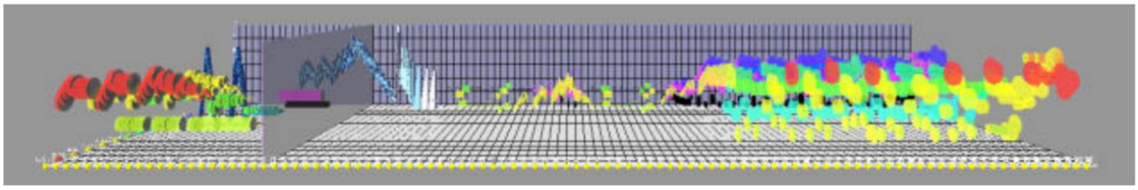


Figure 3-47: Overview of comp-i virtual space visualizing the introduction of “Valse des fleurs ” (16 channels, 101 subsections) (Miyazaki, 2003)

It allowed users to observe the information through a perspective view or zoom in to see specific information. Some customisability was afforded to changing the visible properties of the objects including light shadows, while the current position in time was marked by a moving orthogonal plane from left to right. Alternative visualisation options included circular and Cone Tree multi-resolution techniques. Cone Tree was a description of a process used to visualise hierarchical structures of information (Figure 3-48) reflecting the hierarchical nature of musical structure, whilst enabling a longer piece of music to fit into a compact 3D space (Robertson *et al.*, 1991). Cone Trees have continued to be used by software designers and programmers as a means to display hierarchical information in 3D (Berghammer and Fronk, 2004; Teyseyre and Campo, 2009).

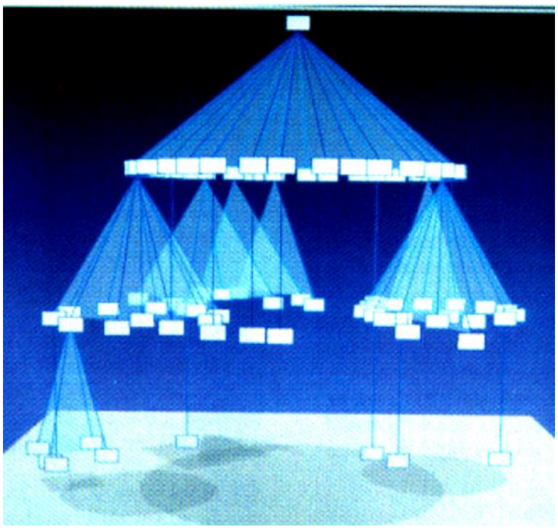


Figure 3-48: An example of a Cone Tree 3D visualisation (G. G. Robertson et al., 1991)

A number of web-based applications employ limited levels of interactivity, the reliability of which depend on robust internet connections and using the appropriate browser. *Adive in Music* was a particle-based web music visualiser, with a number of pre-set alternative visualisation forms to choose from (Damien, 2018). The site used arbitrary colour choice and dynamic movement spiralling out from a central point, however, interactivity was limited to controlling screen movement with the mouse (Figure 3-49).

Figure 3-49: *Adive In Music* screenshot (Damien, 2018)

Tonematrix was a pentatonic 2D grid that lights up when squares on the grid were selected in a similar fashion to a linear sequencer (Audiotool, 2015). The horizontal axis determined the timing from left to right, while the vertical axis played notes from a pentatonic scale depending on the squares selected. However, there appeared to be no control over instrument choice or tempo. A button named 'add drums' allowed access to a full virtual studio set up, which could be edited, however, the accessibility of the software was limited to a quick tour of the tools via a small set of pop-up text messages (Figure 3-50).

Figure 3-50: Tonematrix Interface (Audiotool, 2015)

Tonecraft was another web-based interactive 3D interface with a grid and blocks that represented where user selected notes were being placed (Figure 3-52). Navigation of the space was limited to a pre-determined rotation of the scene, while the electronic sounds and tempo were also pre-set (Dinahmoelabs.com, 2015).

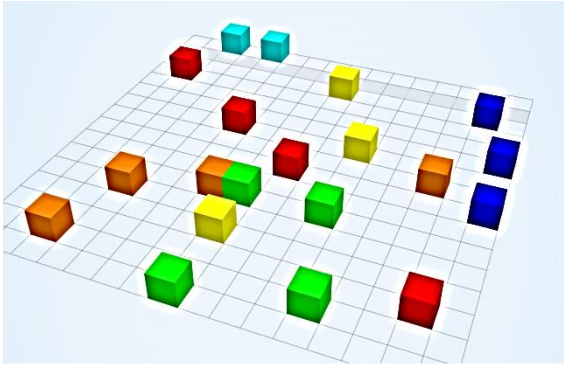


Figure 3-52: *Tonecraft* grid interface (Dinahmoelabs.com, 2015)

Turner's *Loop Waveform Visualizer* (Figure 3-51) was an experiment that output ever-widening concentric circles based on a 3D visualisation of the currently selected audio file (Chrome Experiments, 2015). Designed to visualise pre-set or user defines audio files, it was responsive to changes in amplitude and frequency in a similar manner to a spectrogram.

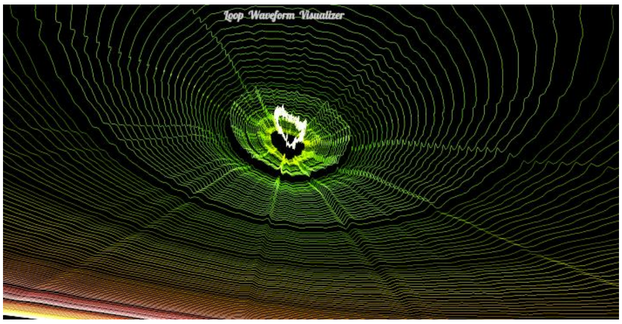


Figure 3-51: *Loop Waveform Visualizer* (Chrome Experiments, 2015)

Taylor *et al.* (2005) developed a real-time interactive system that allowed interaction between a live musician and a virtual 3D character. The authors *Animus* system simulated human-like emotion in response to musical input (Figure 3-53). A lizard-like virtual character responded to vocal and keyboard input, analysing major and minor chords, as well as amplitude and pitch of vocal sounds, to create movement. Analysis of the musical input was mapped to previously created movements associated with perceived emotional states. This could be described as an extension of Grekow's approach where he used emoticons to represent emotion, however, the addition of the ability to analyse real-time audio was an improvement on the MIDI-only system. Additionally, Taylor *et al.* (2005) used the Max programming environment to allow mapping of audio to video. They analysed changes in vocal timbre and assign changes in colour to super-imposed images. The system was primarily a performative one and the authors have continued to develop interactive systems for use in museums and theatre (Taylor *et al*., 2015).

Figure 3-53: A musician interacting with a virtual character (Taylor *et al.*, 2005)

Another approach that employed virtual environments to visualise music was Ox's (2001) *Color Organ.* It explored the harmonic relationships of musical input through interactive 3D landscapes and colour, combining interactivity with musical structure. 3D landscapes were created from sketches of original photographs of real landscapes. Transparent layers of colour were then overlaid onto the 3D images by analysing MIDI information played in by the user (Figure 3-54). The colours selected were assigned by the timbre of the electronic instrument chosen by the user and was based upon the Circle of Fifths colour maps (see section 3.3.1).

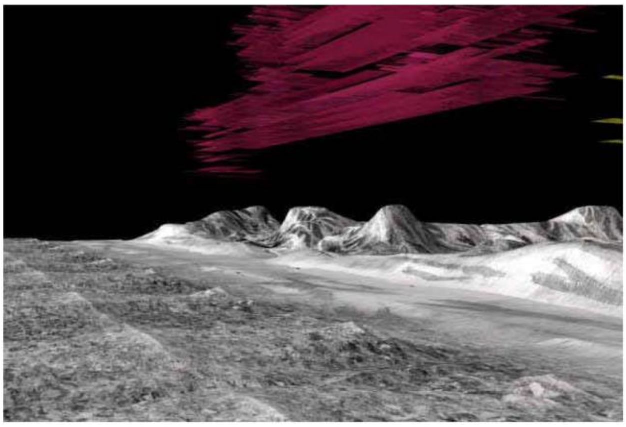


Figure 3-54: Still from the Color Organ (Ox, 2001)

Further developments in mobile touch-screen technology have allowed the development of a number of audio-visual applications that combine performance, composition and interactivity. Since the display was also the interactive surface, coupling visual design with physical interaction design became a new challenge (Wang, 2014b). Smule, a company dedicated toward the creation of mobile networked music apps that began in 2008, developed a successful line, some of which are discussed here (Smule Inc., 2017).

Magic Fiddle was a virtual instrument designed for the iPad to represent a virtual violin where a real-time interface was implemented using OpenGl (Wang, 2011). Efforts to make the instrument more accessible included voice, image and textual feedback, to allow customisation of the interface as a tool to teach or provide feedback on playing (Figure 3-55). This type of virtual instrument provided an accessible interactive experience that allows users with limited musical knowledge an opportunity to create music and gain an understanding of musical theory in the process.

Figure 3-55: Magic Fiddle (Wang, 2011)

In a similar manner, the *Virtual Ocarina* was an exercise to create an expressive virtual instrument specifically tailored to the iPhone, which included blowing into the microphone as well as using finger articulation on the screen where the holes were represented (Wang, 2014a).

An alternative approach to mobile interactivity used video sampling - Madpad was a networked audio-visual sample station for mobile devices (Kruge and Wang, 2011). Twelve short video clips were loaded onto the screen in a grid and playback was triggered by tapping anywhere on the clip (Figure 3-56). This was similar to tapping the pads of an audio sample station, but extended that interaction to add visual sampling. Clips could be created instantly by the user with access to a camera-enabled mobile device; alternatively, clips could be downloaded and posted to and from an online forum. Its advantages included its portability, thereby not restricting it to a clinical environment; the nature of sharing clips, which encouraged social interaction; cause-and-effect was obvious – touch a picture and it would play. Its limitations were characterised by its nature as a video based application, its focus not on the visualisation of music as such.

Figure 3-56: MadPad being used on the Apple iPad (Kruge and Wang, 2011)

The idea of decomposing and reassembling of digital media can be traced back to the idea of audio sampling that began with the use of tape loops in the mid -20th century (Holmes, 2012). Theorized by Gabor (1947) in the 1940s, any sound could be decomposed into discrete acoustic quanta or grains with independent time, amplitude and frequencies. Following this, the first so-called granular synthesis programs were created in the 1970s by Roads (1988), allowing musicians access to these quantum acoustical spectra for innovative compositional creation. The same deconstruction methodology has been applied to visual material whereby the smallest deconstructed visual grain can be mapped to the audio for re-composition into larger macro compositional works (Batty and Horn, 2013). This allowed the creation of new audio-visual instruments, such as Carlson and Wang's (2012) *Borderlands* (Figure 3-57),

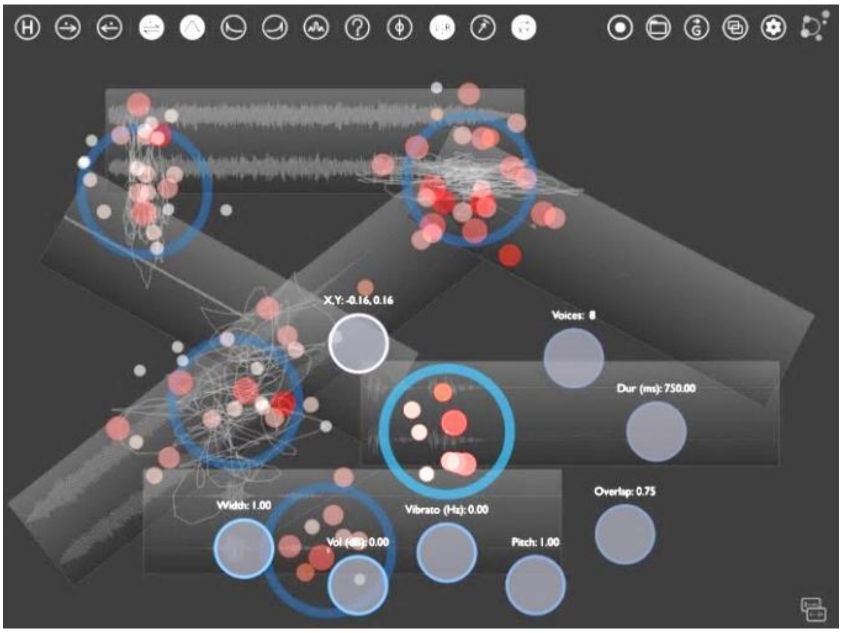


Figure 3-57: *Borderlands* interface (iOS MARS, 2017)

where traditional musical structures were replaced by real-time manipulation of digital sound. Direct touch control over areas of rectangular bounded waveforms, and so-called grain clouds, allowed users to place any number of sound loops into the system. It was therefore possible to have several overlapping sounds that could be manipulated further. This was an interesting way to use digital audio and manipulate it in real time in an integrated audio-visual way. It did not focus on the real-time visualisation of acoustic signals as a priority, although it was able to, but rather it was concerned with the creation of unexplored sound and visuals through digital experimentation. The strength of this approach lay in its ability to create new unexplored audio combinations with visual feedback of the associated waveforms and clustering of such. However, the same reason could also be a limitation in a therapeutic scenario where an autistic user would lack clear cause-and-effect, with visual complexity and cluttering of screen space adding to the confusion of the client (Putnam and Chong, 2008).

Wang has been involved in the visual design for computer music, and has taken from his predecessors and from his own experience a set of design principles (Wang, 2014b) to be used as general guidelines (Table 3-11). Although not generated with autistic users in mind, many of the principles here are echoed by Fabri and Andrews (2016) desire for simplistic interface design for young autistic students.

Some user-oriented principles	1) Real-time: make it so whenever possible 2) Design sound and graphics in tandem 3) Invite the eye – of experts and newcomers alike 4) Induce viewer to experience substance, not technology; hide the technology 5) Do not be afraid to introduce arbitrary constraints 6) Graphics can reinforce physical interaction (especially on touch screens)
Some aesthetic principles	7) Simplify: identify core elements, trim the rest 8) Animate, create smoothness, imply motion: it is not just about how things look, but how they move 9) Be whimsical, organic: glow, flow, pulsate, breathe: imbue visual elements with personality 10) Aesthetic: have one; never be satisfied with "functional"
Additional observations	11) Iterate (there is no substitute for relentlessness) 12) Visualizing an algorithm can help to understand it more deeply (and can suggest new directions) 13) Video games, movies (and just about anything) can offer inspiration for visual design

Table 3-11: Principles of Visual Design for Computer Music (Wang, 2014b)

Lumisonic was an audio-visual real-time application designed for hearing-impaired and autistic individuals (Grierson, 2011). Inspired by experimental film tradition including Fischinger (Keefer and Guldemond, 2013), it aimed to help those with hearing difficulties have a better understanding of sound. Deaf and autistic users selected sounds using the Nintendo Wii and can adjust pitch, pan position and volume via the remote control. The system could also accept live sound input, allowing interaction through alternative means and other musicians. The software analysed the harmonic content of the audio signal through spectral analysis techniques, and translated the harmonic content into a one-dimensional array of banded colour. This band was transformed into circles that radiated on a display (Figure 3-58). This created a real-time representation of sound that was designed to elicit responses quickly in the human brain. The system was built on the Max programming environment (Cycling '74, 2018b).

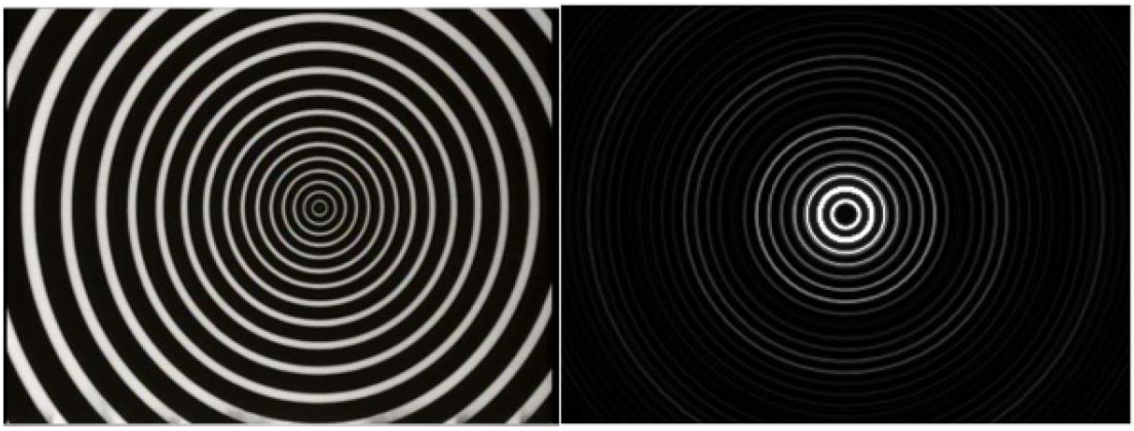


Figure 3-58: Still image from *Spiralen* (1924) by Fischinger (left), and a screengrab from the *Lumisonic* software (right) (Grierson, 2011)

Most visualisation techniques, in the examples presented thus far, have relied upon a choice of audio-visual mapping, including conceptual augmentations of: geometric grids; piano roll notation; waveform manipulation; and any form of artistic expression using colour and shape in arbitrary ways. The spatialisation techniques discussed in section 3.4.2 focused on the temporal 2D and 3D geometry created by audio signals in real-time. Analogously, geometry created by electroacoustic signals in real-time will be discussed in the following section.

3.6 Cymatics

Cymatics, named after the Greek *ta kymatika* meaning "matters pertaining to waves", refer to physical impressions of sound created in media (Jenny, 1968), for example, in sand on a plate, or as wavelets on a bounded area of water (Figure 3-59). They involve the transcription of the periodicities in a given airborne sound or music, to periodicities in a physical medium, thereby revealing its inherent acoustic energy patterns.

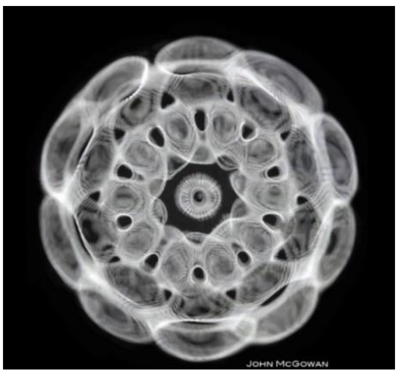


Figure 3-59: Cymascope image of Cymatic geometry in water (McGowan, 2014)

This section provides an outline of Cymatics and its potential for use in a therapeutic application. Table 3-12 presents an overview of examples.

Sub-Class	Type	Medium	Hue	Purpose	Group	Status	Examples
Analysis / Performance	Physical Impression	Bubbles	Trans-parent	Understand the physical nature of sound waves	Analysis, artistic	Research ongoing	Harmonic bubble - Figure 3-65
		Sand on brass	None		Analysis, artistic	Led to further research	Chladni plate - Figure 3-61
		Sand on latex surface	None		Analysis, artistic	Led to further research	Tonoscope - Figure 3-62
		Water	Trans-parent	Understand the physical nature of sound waves, visual art form	Analysis, artistic	Research ongoing	Cymascope - Figure 3-59
		2D projected	Colour		Artistic, perform-ance	Continued development	KIMA visualisation - Figure 3-63

Table 3-12: Overview of Cymatics

Devereux (2011) argued that what is now regarded as Cymatics has been known about for longer than recorded history. He suggested that cave drawings, depicting circular forms, were analogues of visible sound that at certain times of the year, could be seen when the appropriate conditions were manifest (Figure 3-60).

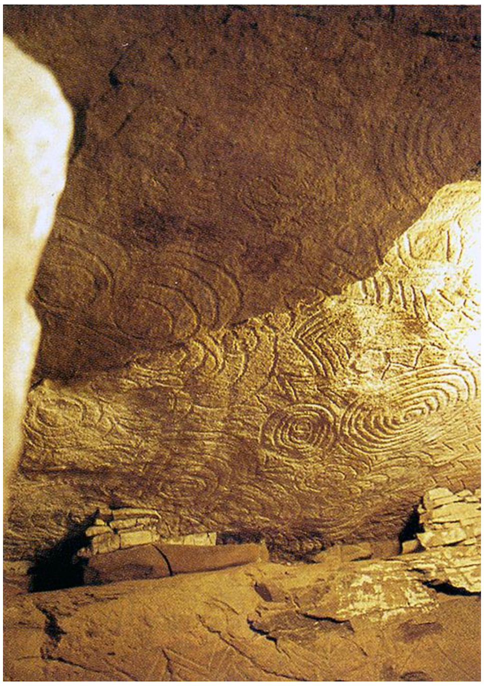


Figure 3-60: A range of rock-art inside the chamber at Newgrange – concentric rings, lozenge patterns, zigzags (Devereux, 2001)

The earliest attested record of Cymatic phenomena was that of da Vinci who, in the late 1400s, noticed how dust behaved on a vibrating table (Reid, 2018b). Galileo noted a similar phenomenon in 1638 when he was filing a brass plate; the act of filing produced a high-pitched sound that caused brass filings to be arranged in a series of parallel striations on the plate’s surface and made a strong impression on him (Reid, 2018b).

In 1680 Hooke experimented with a glass dish strewn with flour and noted what he theorized to be an anti-gravity effect: when the dish was made to ring the flour rose up the sides of the dish (Monist, 2014). Chladni, in 1787, created the apparatus known today as the ‘Chladni Plate’ (Figure 3-61). A violin bow would be run down the side of a brass plate, the resonance of the metal creating a sound that caused sand that he had strewn over its surface to be organized into patterns (Articles *et al.*, 2010).

Figure 3-61: A Chladni Plate being stimulated by a violin bow (University of Cambridge, 2016)

Cymatics are also referred to as Faraday wave-patterns (Sheldrake and Sheldrake, 2017), due to Faraday’s vibration experimentations in the 1800s (Miles and Henderson, 1990). Jenny (1968) likewise experimented with a variety of vibrating mediums, such as liquids, semi-solid pastes and iron filings. He also invented the Tonoscope, a simple drum-based device into which sound could be made via an input tube.

The drum was covered by a tensioned latex membrane and he observed patterns in the sand sprinkled on its surface when vocal sounds were made into the tube (Figure 3-62).

Figure 3-62: Tonoscope surface image (Jenny, 1968)

The mathematics needed to model the Tonoscope principle was laid down by Chladni and has been used to predict the geometry associated with specific frequencies and the size and thickness of the plates onto which they are visualised (Stöckmann, 2007). Software versions of these principles exist and were employed by artists including the KIMA collective (Gingrich *et al.*, 2013) in performance and installations (Figure 3-63), and Wakefield's 2D and 3D patches for a software Tonoscope (Sykes, 2011). Chladni plates are a mechanism for visualising a cross section of a sonic bubble created by the resonant tone of a particular plate, not the shape of sound. Physics tells us that sound does not travel in longitudinal waves within rectangular blocks but rather propagates spherically in air (Smith, 2010). Due to diffraction, the reactive result of molecular collisions would create three dimensional patterns from the sound source (Cymascope.com, 2018c). The 3D images produced by KIMA are artistic representations of Chladni's 18th century principles, and not a physically accurate visual representation of the propagation of sound.

Figure 3-63: KIMA Cymatic visualisation (Analema Group, 2017)

Gingrich *et al.* (2013) mapped these images onto spherical shapes in an attempt to synthesise the three-dimensional nature of sound (Figure 3-64), although they failed to create the structure evident within water-based Cymatic images (Figure 3-59).

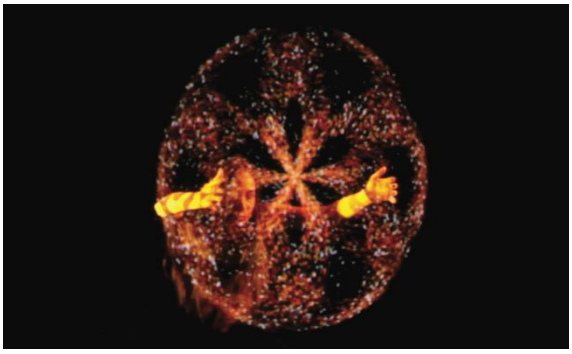


Figure 3-64: KIMA Cymatic images mapped onto spheres (Gingrich et al., 2013)

Within the early 21st Century, the creation of a water-based instrument, the Cymascope, rendered sound visible in water, producing highly detailed images (Reid, 2018b). The basic principle of the instrument was that airborne periodicities in a given sound sample were transcribed to periodic wavelets on the surface and sub-surface of water. The resulting imagery was therefore quasi-3D in form (Figure 3-59).

It has been noted by Sykes (2015) that western-based tuning (Equal Temperament) has shown harmonic inconsistencies and that the Pythagorean-based Just Intonation (JI) has shown greater and more consistent visual symmetry (see 3.4.2). This has also shown to be true through experimentation with audio visualisation in water. JI has a rich history from the Pythagorean tuned music of ancient Greece through Catholic plainchant song (Sykes, 2015) and more contemporary work by the likes of Telfer (2010). Telfer created his own instruments based on JI tuning, as well as having conducted bubble (Figure 3-65) and water experiments. His bubble experiments tested the connection between musical harmony and the corresponding visual structures, specifically whether spheres would vibrate to a series of sine wave harmonics. His results demonstrated how harmony could affect the geometry of a three-dimensional structure. Telfer also questioned whether Cymatic patterns could be interpreted musically by comparing particular sonic frequencies with their corresponding vibrational forms.

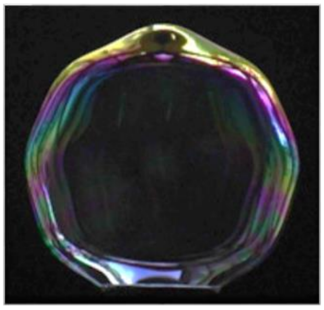


Figure 3-65: 7th Harmonic Bubble Experiment (Telfer, 2010)

While Telfer's (2010) research focused on the relationships between musical frequency and visual structure relating to Cymatics, Whitney's (1980) animations focused on the artistic realisation of harmonic principles. This could be considered analogous to Telfer's work in terms of the geometric structure that sound can create, its symmetry, and the clarity of the geometry based on the use of Just Intonation.

Sykes (2011) asked whether the augmentation of sensory modalities would provide a clearer relationship between the audio and the visual in the art world, however, he did not seek a direct beneficial application for it. Sykes questioned whether it was possible to develop an analogous language between Cymatics and music.

Cymatics could be considered analogues of the natural geometry created by vibration, the underlying principle being that of periodicity, and was so ubiquitous in nature, that it could be found in all manner of phenomena (Jenny, 1968). Table 3-13 provides a few examples of geometrical similarities between objects found in nature and Cymatic images.

In related research, an unfinished project known as *AudioVision*, looked into using Cymatics as a basis for hearing impaired users to detect and visualise customised sounds adapted to their environment and needs (Hipke *et al.*, 2010). The aim of the project was as a practical aid for deaf and hearing-impaired users to identify sound events in the home. The authors wished to utilise the *Lumisonic* (Grierson, 2011) application (see 3.5.1) to aid in the Cymatic visualisation but were unable to complete the work.

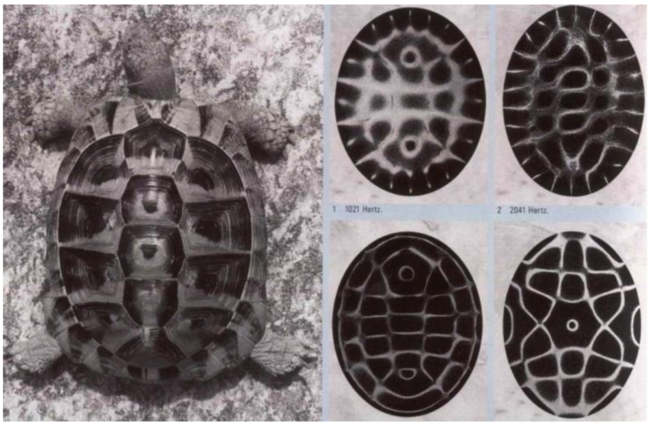
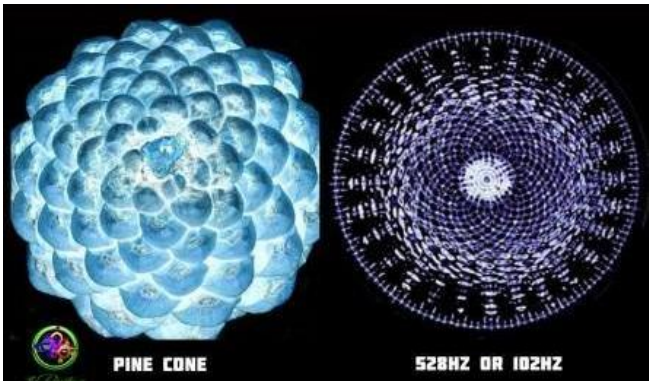
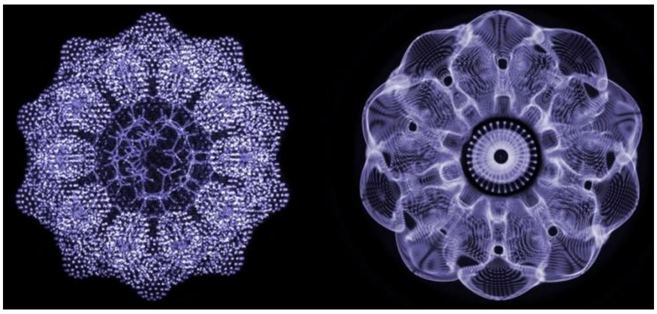
Description	Medium	Image
Comparison of tortoise shell with Cymatic images	Salt on a brass plate	 (i.pininmg.com, 2018)
Comparison of an ariel view of a pine cone (left) with Cymatic image (right)	Water	 (in5d.com, 2018)
Comparison of D.N.A. cross-section (left) with Cymatic image (right)	Water	 (Reid, 2018a)

Table 3-13: Comparison of natural phenomenon with Cymatic shapes

3.7 Conclusions

This chapter has reviewed historical and contemporary audio-visual work. Research in cross-modal correspondence has identified a variety of ways to visualise sound. Common themes between volume and scale have been suggested, while pitch is commonly represented through changes in vertical height. Timbre has been shown to be best represented through changes in shape, whilst the use of principle colour hues and chroma have been identified as being the most appropriate way to represent timbre and emotion. Research has highlighted how cross-modal correspondences can be affected by levels of musical training, cognitive development and cultural background. It has also identified that musically untrained participants focused more on the emotive aspects of music representation.

It has been suggested that effective visualisation of music is dependent on its contextual use. Temporal graphical representation of musical structure has defined a number of solutions for analytical, compositional and teaching purposes. Styles of representation include piano-roll notation, graphs, grids, linear diagrams and the use of colour to identify tonal relationships. Representation of audio signals are typically used within an analytical framework by composers or designers, through use of spectrograms and oscilloscopes, although artists have also used audio signals to show harmonic and temporal relationships in music.

Many audio-visual techniques are based on arbitrary mapping of audio parameters, that may create artistic performance pieces but do not necessarily provide meaningful feedback to every observer or user. Interaction has demonstrated many interesting developments in virtual instruments and sharing of virtual musical space. A number of networked and standalone applications offer an array of functions for users including analysis, composition and performance, including some specifically designed for autistic users. The key features in interactive design for people on the autism spectrum include the use of cause-and-effect and customisation, to allow meaningful use for each user and their own range of abilities.

Cymatics is a relatively unexplored means of visualising music within interactive applications, although its aesthetic appeal and direct relationship with sound make it worthy of further exploration. It is interesting to note that Cymatics is not included in numerous books detailing the history of Visual Music, as though it would not fit comfortably within a scientific or an artistic framework (Collopy, 2007).

4 Requirements Gathering

The previous chapter discussed the differing ways that sound can be visually represented, dependent on its intended audience and context for use. An investigation into cross-modal correspondences identified some common audio-visual mappings. However, it would be beneficial within the current research to conduct interviews concerning the current working practices of therapeutic music practitioners, and with regard to the preferences of their autistic clients. This chapter describes a preliminary study with music practitioners. Four interviews were conducted to address how a multimodal application could improve communicative behaviours of autistic users within music therapy sessions, and how it may improve the working practices of practitioners themselves. The study aimed to identify which attributes should be included within an application, and how that could be facilitated within a therapeutic music session.

4.1 Rationale

A series of interviews with therapeutic music practitioners provided a basis for the development of a multimodal tool. The goals of the interviews were to outline current practice; highlight the ways in which technology is currently used; indicate where potential lies for augmented working practices using new tools; and produce a requirements analysis for a prototype. The purpose of this study was the first pass in generating an initial list of requirements. These would feed into the design of a prototype interactive audio-visual tool to be used within a future study.

4.2 Method

Therapeutic music practitioners, from both a clinical and arts-based background, were asked to take part in a semi-structured interview. The interviews were audio recorded and analysed using qualitative methods in order to identify common themes that could be transcribed and coded. The coded responses would aid in identification of the requirements of the prototype application.

4.2.1 Participants

Six therapeutic music practitioners were invited to participate in the interview. Four agreed to take part, providing a response rate of 66%. The four interviews included two with clinical music therapists; one with a community music therapist (see table 2-4); and one with the head music tutor of a charitable organisation. The clinical participants are qualified therapists validated by the Health and Care Professions Council (NHS Education for Scotland, 2014), whose aims are focused on the wellfare of vulnerable adults and children, including autistic clients, through music-centred approaches to therapy (see 2.2.1). The community music therapist (CoMT) is qualified in clinical therapy, but at the time of interview was working primarily with different groups of young adults with additional support needs, including autistic clients. The focus of each CoMT group session would differ, dependent on who the funders were, but their objectives typically included more culture-centred and context-sensitive activities. The music tutor is not a qualified therapist, however, had many years experience running improvisational therapeutic music sessions for a number of children and adults within a charitable organisation, Sense Scotland (2017a). Their aims included providing support for people with a variety of additional support needs, including autism, but also mirrored aspects of clinical music therapy approaches. This was achieved through planned programs focusing on client aims and development, and session review and documentation. All participants were contacted directly by the researcher several weeks prior to the interviews taking place to allow time for approval. After reading a participant information sheet, participants provided consent for their responses to be included in the study (Appendix B – Requirements Gathering Documents for Music Therapist).

4.2.2 Materials

The interviews took place within an environment requested by each interviewee: the first in the home of one practitioner; the second in a public café; and the remaining two within their music session rooms. A digital audio recorder was used to record the interviews for later transcription and coding. Interviewees were also provided with the interview questions on paper for referral purposes.

4.2.3 Design

A semi-structured face-to-face interview technique was chosen to allow participants the opportunity to elaborate, as additional questions may have emerged from the dialogue between interviewer and interviewee. This provided qualitative information regarding the diverse nature of working with people on the autism spectrum in music therapy. It was considered that other methods, including surveys or structured interviews, would be too restrictive in their scope, as they are primarily designed to obtain quantitative information (DiCicco-Bloom and Crabtree, 2006).

The interview questions were derived from previously published music therapy research for children with autism. Mackay *et al.* (2013) observe and discuss good practice within a number of music therapy projects for people with autism. Nordoff and Robbins (2014) use improvisational techniques which have been shown to be popular in many clinical and community-based therapy sessions. These studies highlight the variety of ways in which engagement can be facilitated for clients with a variety of needs, and were used as a basis to construct a set of general questions regarding current practice.

Allen *et al.* (2009) discuss the importance of understanding how people with autism spectrum condition (ASC) experience music. It was necessary to understand how therapeutic music practitioners facilitated this and if that could be channelled into a multimodal application. Brown (1997) questions whether there is a distinction between musical improvisation, as an art form, compared to clinical improvisation, as therapy. It was therefore relevant to discuss the importance of the personal relationships between therapeutic practitioner and client, including those within a group context. Specific questions relating to one-to-one and group sessions were created to address these issues.

Multimodal technology, involving audio-visual and tangible user interfaces, has been used in numerous music therapy research projects for people on the autistic spectrum

(Villafuerte *et al*., 2012; Cibrian, Peña, *et al*., 2017; Nath and Young, 2015). However, it was necessary to gather information concerning the current use of technology in practice, and the potential for a new tool.

The four participants were asked questions from a pool of 31 questions dependent on their relevance (for example, therapeutic practitioners who conducted one-to-one sessions were not asked about group work). Eleven questions referred to current general practice, their working environment, and the type of clients that they work with; two questions specifically related to one-to-one sessions; four questions related to group work; while the remaining 14 questions related to the ways technology currently plays a part within their practice (See Table 4-1). In addition, interviewees offered opinions on how improvements to their practice could be made, using a new audio-visual tool.

Current Practice General Music Therapy Questions	
1.	What kind of instruments do you like to use?
2.	Do you use client's favourite songs/tastes?
3.	How rigid are your practices with clients?
4.	How do you measure progression with a client?
5.	Do you get feedback from parents/carers or directly from clients?
6.	Do any of your clients need support during/before/after a session, either physically or to play?
7.	Do you ever use a reward system to motivate your clients?
8.	How long would you hope to engage with your clients, for the duration of your session, or would you work with your client and then take a break and go back?
9.	Do you try and measure communication – for example, through eye contact or through verbal feedback? Do you measure social interaction through turn taking?
10.	By what means do you engage with them?
11.	What level of voice do you use with the clients that you work with?
One-to-One Sessions	
12.	Do you run individual sessions and group projects?
13.	Do you aim for goals in your sessions or do you work mainly on a session-by-session basis?
CoMT Group Sessions	
14.	Can you tell me about the kinds of projects you run?
15.	Where do you hold them?
16.	How do you coordinate group sessions?
17.	What's your preferred visual output for your clients?
Using Technology to Augment Practice	
18.	To what extent do you use technology/contemporary music production equipment?
19.	Have you ever used accessible interfaces or instruments like the Skoog or SoundBeam? What are your impressions?
20.	Previous research has mentioned cause-and-effect. Is this important to you?
21.	Do you think that having a customisable user interface for each client would be worthwhile?
22.	Do you think clients would like to be able to modify what *you* play?
23.	Do you consider privacy an important issue? For example, do you think it would be beneficial for the client to be able to practice something in a private 'mode' before sharing it publicly?
24.	Do you think a visual looping of music would be beneficial to people with ASC?
25.	Would you be happy taking time to learn new technology, if you thought it was worthwhile?
26.	Are there any features of a potential application that would make your job easier?
27.	Is highlighting musical structure important, for the client to predict or know where they are at any point in time?
28.	How best would you use the tool as you see it at the moment?
29.	Do you think you would be drawn to use a 1-user or 2-user version or both?
30.	The facility to record and play back the audio, is that something you would use?
31.	Do you think that clients would ever bring in their own objects as the means of creating sound?

Table 4-1: Questions Posed to Practitioners

4.2.4 Procedure

The four participants were interviewed individually within their chosen environment. The interviews were expected to last up to an hour and varied in length between 30 and 60 minutes, dependent on how much information each participant contributed. Interviews were audio recorded, transcribed, and then coded using NVivo software (QSR International Pty Ltd., 2018). Interviews began with questions concerning the nature of current practice and went on to query how technology was currently used, and what the advantages and disadvantages were. Questions were then posed on preconceived ideas about new technology and what they would like to see within a new real-time interactive audio-visual tool.

Informed consent was provided by all participants as established by Edinburgh Napier University protocol (Appendix B –). Participants were informed that their responses would remain anonymous, they did not have to answer all of the questions and that they could stop at any time. Permission was obtained to make use of the results within a thesis or associated publications.

Coding was conducted using the transcriptions from the interviews based on a qualitative Grounded Theory approach (Wagner *et al.*, 1968). Codes were allocated to quotations using an open approach where interpretation of quotations suggested appropriate codes, as opposed to pre-defining codes and assigning quotations to them. Following the first pass, which determined a substantial set of codes a further three passes merged the codes into a condensed set of seven, which were checked against the transcripts again for assuredness. An inter-rater reliability check was not necessary due to the small sample size (Armstrong *et al.*, 1997). Table 4-2 provides an overview of the codes resulting from the transcriptions.

4.2.5 Results

Code	Respondents	Instances	%	Rank
Tailoring Sessions for Individuals or Groups	4	130	33%	1
Existing Accessible Technology	4	84	21%	2
Facilitating Experience with a New Tool	4	80	20%	3
Providing a Suitable Environment	4	35	9%	4
Expanding Communication Channels	4	33	8%	5
Reviewing Effectiveness	4	17	4%	6
Following Procedure	4	16	4%	7

Table 4-2: Codes resulting from transcribed terms

The number of instances of interpreted quotations for each interviewee was noted and the list was ranked according to frequency. Tailoring Sessions for Individuals or Groups was the predominant code, with respondents commenting on accommodating the individual needs of clients. Typical comments referred to empowering clients with choice, allowing them person agency, and to use the skills and abilities of clients to drive music sessions.

The code Existing Accessible Technology was ranked second, and gathered opinions on customisable technology currently in use by clients and practitioners. It included references to related hardware and software being increasingly used within therapeutic music sessions, and their levels of perceived success for autistic users. For example, iPad (Apple, 2019) applications, Soundbeam (2018), and Skoog (SkoogMusic, 2018).

The third ranked code, Facilitating Experience with a New Tool, expressed interviewees opinions concerning the potential use of new technology to facilitate innovative experiences for people with autism. This included phrases related to enabling novel experience, and how this could encourage exploration and increased levels of confidence.

Providing a Suitable Environment was ranked fourth, and was applied to feedback regarding the creation of safe and comfortable spaces for clients to express themselves freely. Interviewee comments typically referred to available time for client development and suitable physical spaces, where relationships could be built as a basis for positive therapeutic outcomes.

The fifth ranked code, Expanding Communication Channels, detailed measurable increases in client interaction through musical improvisation, vocalisation, eye-contact, turn-taking, or social interaction with peers. References were made to the ways in which music is used as a means of communication, and facilitating clients' expressions through that channel.

The sixth ranked code, Reviewing Effectiveness, referred to iterative processes of recording, evaluating, reviewing, and formulation of client and practitioner goals. Respondents commented on the importance of feedback, and of sharing opinion and experiences with all stakeholders.

The seventh code, Following Procedure, referred to procedures used to record and evaluate the progress of clients for effective treatment. Phrases were mentioned relating to the use of review meetings and reports for public or private funding bodies.

The seven derived codes were split into two main groups - Current Practice, and Using Technology to Augment Practice. The code descriptions are described below (Table 4-3) followed by detailed findings from the transcripts.

Group	Code	Description
Current Practice	Providing a Suitable Environment	Creating a safe and comfortable space where clients can freely express themselves
	Expanding Communication Channels	A measurable increase in the amount of time a client interacts through: musical improvisation; vocalisation; eye-contact; turn-taking; or social interaction with peers
	Tailoring Sessions for Individuals or Groups	Due to the varying needs of clients on the autistic spectrum, each session has to be customised to accommodate the individual or group
	Following Procedure	Strict procedures are used to record and evaluate the progress of clients for effective treatment
	Reviewing Effectiveness	An iterative process of recording, evaluating, reviewing and of formulating new goals, from both a practitioner's and a client's perspective
Using Technology to Augment Practice	Existing Accessible Technology	Opinions on current technology that can be customised for individual clients or groups
	Facilitating Experience with a New Tool	Opinions on how novel experience can be created for people on the autism spectrum through innovative technology

Table 4-3: Code Descriptions

(Key - E1, E2, E3, E4: Expert 1, 2, 3, 4 transcripts)

Current Practice

Providing a Suitable Environment **-** *Creating a safe and comfortable space where clients can freely express themselves.*

It is important within therapeutic music sessions to create a comfortable space for clients to be able to express themselves. From the practitioner's perspective, this allows an accurate evaluation of the client before being able to decide on what the aims of the sessions will be – 'Normally we have six to eight weeks' (E1). The length of time it takes depends on the individual and their needs – 'for other people it can take longer' (E1). Therapists indicated that support is provided to those who need it in terms of both physical support, by additional staff, and mental encouragement, provided by the therapist – 'for the people who are less able, just to give them the attention and support' (E1) – 'If we can build up a relationship in that kind of safe environment, people start to develop that openness to engage and explore.' (E4). Therapists implied familiarity and predictability within sessions helped to create a safe environment for autistic clients – 'Normally the sessions are structured' (E1). They identified certain objects which can be used to symbolise the different elements of that structured session – 'quite often I might use a singing bowl for the goodbye song' (E1).

Practitioners reported that group work within sessions is dependent on the suitability of available space – 'we lack the space' (E2). The environment, it is indicated, determined the type of interaction that was appropriate which also included the amount of support required. Practitioners noted as a general rule, there were always two leaders in a group scenario – 'I tend to try and work on a model of always having two leaders' (E3).

For community music therapy (CoMT) sessions, practitioners reported that there has to be support to aid in the organisation and leadership of a group, which can also be useful in the event of taking appropriate action in unplanned or dangerous circumstances – 'if somebody turns up and they are drunk or have been using substances, …what do you do?' (E3). However, the therapist implied there is generally support for individuals who need assistance within a group – 'the support was incredible' (E3).

<u>Expanding Communication Channels</u> - *A measurable increase in the amount of time a client interacts through: musical improvisation; vocalisation; eye-contact; turn-taking; or social interaction with peers.*

Interviewees reported that clinical one-to-one sessions are very confidential – 'privacy is hugely important to what we do' (E1) – and are based on an open channel of communication between the therapist and the client where a relationship of trust needs to be built. Therapists identified musical improvisation as a good way to open communication channels as it can create a non-verbal back-and-forth conversation – '[music] can be a very conversational way of clients interacting with each other and with me' (E1). Respondents implied that this communication was the basis for behavioural change, however, the therapy itself was a non-behavioural approach where the client could express themselves, allowing them the freedom to evolve and learn – 'Whatever's happening in the music is how the person is' (E2).

Clinical therapists reported they generally have one-to-one sessions with clients but occasionally have small sized groups which focus on social interaction as a group aim – 'I think generally to give people the support and attention that they need. That's one of the reasons we limit numbers a little bit' (E1). They mentioned that clinical therapy allocates time to make the client feel comfortable before deciding on what the aims should be – '[it] gives me time to get to know the client and them time to get to know me' (E1). Therapists reported that by lengthening musical participation over a period of time, they could concentrate on developing other communication-based aims - 'So [by] increasing interaction we can focus on the length of time that people participate in an activity or are really engaged in music' (E1). The therapist pointed out that this included 'using music to motivate movement, trying to increase whatever vocalisations the client has, working on social interaction, eye contact, and turn-taking' (E1).

Interviewees mentioned that successful therapy does not focus on musical dexterity but rather on using music as a medium – 'music therapy isn't so much about developing musical skills, but using music as a form of communication' (E1) – 'I think the best instruments really are the body and the voice' (E4). Some therapists were thus reluctant to bring in technology for fear of distraction and breaking communication channels – 'taking it away and communicating with a computer is a bit different from what I would be aiming to do' (E1). Respondents commented that most of the sessions involve musical improvisation rather than using other people's songs, as it is the expression of the client that is the key to communication within the session – 'Generally, music comes from the clients … If nothing's going on, then I might bring in a song just as a suggestion and then see what happens' (E1). Being flexible was essential from the therapist's point of view to open up potential communication channels – 'just to offer something different, we may take a very familiar song and start to change it within the music … we can be flexible, we can learn that playfulness' (E2).

The immediacy of the musical channel of communication allowed therapists to gauge what the clients tastes were, as well as talking to family – 'really it's about that immediate interaction between therapist and client, and very often we'll get to know a client's taste, either what they spontaneously bring in the session or through contacting their families' (E2). However, therapists noted it could be necessary to gently change any repetitive behaviour for developmental purposes – 'they may want to sing the same song over and over again, and so we may look to interrupt that sensitively' (E2). Therapists identified setting up a communication channel between family and therapist helps create a bigger picture of what is going on within the sessions and how that affects life at home – 'to find out how that's impacting the client on the outside of the session' (E1).

Away from the sessions themselves, one respondent noted that the sustainability of the sessions is checked with home life – 'And what's the effect after the sessions, what happens the hour after the session? We may be looking into that as well' (E2). They indicated that the clients also fed back if they are able to help improve experience – 'Yes we do, if the clients are able to … people who can't necessarily verbalise experience but they can indicate in other ways they're experiencing and what they think about the therapy' (E2).

In CoMT, the therapist noted one challenge in communication was being flexible and accommodating enough to include all participants in a fun and stimulating way – 'I find the challenges of how do you enable a group of clients, whatever their background is, how can you make them appreciate playing music together? ... I find that music is really, really fun … really amazing thing, particularly in a therapeutic context' (E3). As a CoMT leader, they signified it was vital to give the group themselves control over the direction of the session, which was sometimes necessary with a little help – 'I'm very keen to make the group lead, to give that sense of ownership' – 'they don't have an idea because they perhaps don't know how to have an idea … "well I tell you what, we'll try a few things, and you can say what you like", and then we'll take it from there' (E3). They suggested empowering the clients instilled a desire to do and learn more – 'hopefully you'll leave people with a skill and an interest and a desire to go forward' (E3).

<u>Tailoring Sessions for Individual or Group Needs</u> - *Due to the varying needs of clients on the autistic spectrum, each session has to be customised to accommodate the individual or group.*

Music therapists reported that they work with a wide variety of disabilities and with clients who may have complex needs – 'the youngest client I work with is three and the oldest is ninety-six' (E1). Consequently, goals of a session varied, whether clinical or community-based – 'Some of the goals will take a lot longer to achieve than others' (E1).

Two practitioners indicated that part of their role included being sensitive and responding to their clients' emotional being in order to facilitate the best experience for them, and empower the client to facilitate growth – 'it would depend on what they do at the beginning of the session, if it feels like they need maybe a little bit of encouragement or support, I might start to play something and see how they respond to that' (E1) – 'So ideally I like to start with taster sessions for that individual…on a one-to-one basis and then really allow that person agency in the situation' (E4).

The interviewees indicated that any type of change within the therapeutic environment has to be incremental and flexible to allow the client the time to adapt to new experience and feel in control – ‘let’s try to find a very gentle way in’ (E2) – ‘just building a bit more and more and more’ (E2). The therapist suggested for some autistic people, if they understand changes they can make in a music therapy session, they could apply it to other aspects of their life - ‘they’re looking to control their world’ (E2) – ‘well, I can change in this scenario maybe I can try changing in that’ (E2) - ‘I want that person to actually feel some sort of control in the setting’ (E4).

A clinical therapist referred to the majority of sessions typically using traditional acoustic instruments, like guitar, voice, and ‘lots of different types of drums’ (E1), implying these instruments are easily accessible. However, participants also reported they found there is growth in the use of technology with electronic devices becoming more popular – ‘We’re using more electronic instruments, but generally acoustic’ (E2). Historically, some therapists have used assistive technology like *SoundBeam*, while more recently some clients have brought in tablet computers with a variety of applications that use sound effects or a variety of instrumental sounds – ‘We are using GarageBand through the iPads and all of us use that’ (E2).

Regardless of available resources, therapists identified that it was important to encourage and facilitate what skills and abilities the client had, and not to help them too much – ‘it’s empowering that person with the choice’ (E3). They implied technology is useful in that respect, for example, the iPad (Apple, 2019) can allow experiences that do not demand complete dexterity – ‘an iPad is really useful for clients who have limited physical mobility’ (E2). Practitioners within this study suggested that clients should be encouraged to create music themselves. In terms of what to play, improvisation of new music was preferable to learning another artist’s music as it belonged to the participants, and they could not make a mistake, thus increasing self-confidence – ‘the experience of being able to listen back to whatever it is, the instruments you’ve chosen, your own voice, your own words, your own melody, whatever it is, can be really exciting’ (E3) – ‘I think that might be a big part of the therapy in making choices and for the client to feel they have ownership over that’ (E2) – ‘But it’s about the dynamic of allowing that person agency so they’re able to lead and it becomes reciprocal so that they’re then able to listen and share the space and have that exchange of ideas’ (E4).

Respondents signified enabling client choice was very important, especially as it may be one of the few times that institutionalised people get to make choices – ‘I see clients who are very angry about the way they are institutionalised … to be able to enable them to say “oh yes, actually, I want to play this one not that one”, it really will open them up’ (E3). Indeed, clinical therapists suggested working within your own musical context was more stimulating and created a higher level of ownership – ‘[the] main thing we do with any of our work that clients are empowered to create their own sounds and control their own sounds and that the therapist is then responding to that’ (E2), whilst CoMT’s recognised the importance of giving an individual or group a sense of ownership to lead what that group activity will be - ‘I’m very keen to make the group lead’ (E3). Practitioners recognised that making decisions can be difficult when clients do not know what they want, if they have not had that opportunity throughout their lives for whatever reason – ‘if you work with marginalised young people, they might not necessarily know what the options are’ (E3). The therapist added that it may therefore be necessary to provide options for them, again gently leading them, but ultimately letting them decide – ‘discovering the things that they didn’t know that they liked’ (E3).

It was reported by E3 that technology could be a useful tool within group music therapy, provided the group understood clearly what it was that the technology did – ‘I remember going to a really riotous youth group, and the young people instantly understood how it worked’. Similarly, another therapist noted within a one-to-one session, technology should facilitate the experience for the client of creating sounds by themselves – ‘they’re still getting that experience of creating that sound’ (E2).

Practitioners described seeing a camera as another tool for use in CoMT sessions for people who were more visually driven – ‘”I’m not that interested in playing the guitar, but pointing a camera is fun”, it’s another tool to offer’ (E3). They added that video could also be useful for simple, but effective, animation that demonstrated cause-and-effect – ‘the simplicity of taking images and viewing them back in rapid succession, there was again that cause-and-effect’ (E3).

If sharing visual information within a group scenario, some practitioners suggested the use of a projector was a better way to do so if the resources were available – ‘even if your video projector is just showing what your laptop is doing it’s just, “here’s Ableton Live on a big screen”, people can see it a bit clearer. That’s better’ (E3).

Practitioners have suggested that using elements of nature as inspiration could elevate group projects in the visual realm – ‘it had that ‘wow’ factor… [I] photographed some roses … then we made cut-out butterflies, and then we did the butterflies flying onto the roses … I mean all of us actually, it didn’t matter if you had learning difficulties, we all thought it was magical’ (E3).

Overall, practitioners indicated a passion for the value of music in a therapeutic context, as they could see music as a fun activity that could change lives in a positive and therapeutic way and they constantly looked for ways to achieve that – ‘it can really, really change people’s lives’ (E3).

<u>Following Procedure</u> - *Strict procedures are used to record and evaluate the progress of clients for effective treatment.*

Therapists recognised strict procedures for recording and evaluating the progress of clients within clinical music therapy - ‘Every single session we have to write up notes, and then the council, they have annual review meetings for clients’ (E1). They referred to a constant cycle of recording, evaluating and reviewing as much information as possible to build an accurate picture of the client for effective treatment - ‘we establish aims and the bulk of the therapy works starts after that’ (E1) (see also Reviewing Effectiveness). In addition, clinical therapists mentioned thorough reviews and recording processes were needed to follow client progress and to feedback to the clients themselves, family and the appropriate funding authority – ‘the council, they have annual review meetings for clients, and so I normally submit a report for that’ (E1). Participants also pointed out there are confidentiality restrictions to be taken into account for the sake of the client, so reports could be restrictive – ‘there’s the element of confidentiality for the client so I can’t disclose things that would not feel right to disclose if things come up in sessions – reports can be a bit difficult sometimes’ (E1).

Community music therapists indicated their work was not as goal oriented as clinical music therapy due to the nature of funding, which came from a variety of sources – ‘we sourced funding through Creative Scotland’s youth music initiative strand to work with young people’ - ‘it was funding specific’ (E3). Consequently, groups that benefitted from funded projects varied, dependent on who the funding body was, what the aims of the project were and what resources were available – ‘based on what the project is, what the budget is’ (E3).

<u>Reviewing Effectiveness</u> - *An iterative process of recording, evaluating, reviewing and of formulating new goals, from both a therapist’s and a client’s perspective.*

Therapists commented that the clinical review process aimed to check on the impact of the sessions on the client in the outside world via feedback from family, carers and the clients themselves – ‘it’s really important to feed back and let people know what it is we’re achieving’ (E1). They inferred a dynamic, constantly evolving process of recording, evaluation, review and of formulating new goals – ‘we’re constantly evaluating what went on, what the relationship is like, what are our own experiences of that person’ (E2). They suggested a greater number of opinions created a better impression and thus a more informed guidance for relevant therapy – ‘getting feedback from anyone either involved in the sessions’ (E2).

Community music therapy leaders mentioned trying to consider the longer-term benefits of their current projects – ‘Something that we do try and think about is sustainability of things’ (E3) - but suggested that what could be achieved in a short space of time may not have always had a lasting effect – ‘Whilst they might get a lot out of playing music in a supportive environment, that doesn’t necessarily mean that their illness is going to disappear’ (E3). They implied maximising the effectiveness of the project became more important than administrative evaluation, as group sessions may not have the same sustainability that focussed individual sessions have – ‘you might not be able to identify what those really precise outcomes are until you’ve done it’ (E3). Consequently, there was not the same demand for paper based evaluation in CoMT – ‘what’s my funder looking for? My funder might just be saying, “can you get 20 people to turn up over the course of x number of sessions?’’’ (E3). However, CoMT’s noted the importance of analysis and report writing could be a valuable means of securing future funding, even if the current funder did not require it – 'look at this analysis of my project, by recording this kind of data we can really track how each participant and how the project as a whole has succeeded' (E3).

One therapist commented, that from the clients' point of view, recording and reviewing sessions within a group could be as rewarding a process as performing in front of an audience – 'that for me is as good an act of participation as is doing a performance' (E3) - and depending on the comfort level of the participants, could be less stressful – 'if you've got a group who, perhaps the goal is just to encourage them to turn up six times, and that in itself would be a success' (E3). Another therapist mentioned, alternatively, that the use of video could be a useful way of reviewing the progress of clients – 'we're always monitoring the work to see if any of those aims need to change' (E2) - '…often video can be a great evaluative tool because then you can see…that period of time when that person was engaged or that person lost engagement, that person vocalised, or there was a fleeting response. And then you're able to measure that against session two, and session three, and session four' (E4).

Using Technology to Augment Practice

Existing Accessible Technology - *Opinions on current technology that can be customised for individual clients or groups.*

Therapists reported that they found the use of technology was on the increase due to accessibility of applications on the iPad and mobile technology – 'We're using more technology, like *SoundBeam*, we use iPad apps' (E2). Some therapists used more in-depth music production tools too – 'GarageBand (Apple Inc., 2018), I really like it, that's been great for a lot of my clients own abilities' (E2). One of the most important factors mentioned by therapists in a useable tool was cause-and-effect – 'the client is able to make the connection that what they are doing has a visual effect somewhere else' (E2). Therapists commented that this led to an understanding for autistic people, creating empowerment and control – 'clients are empowered to create their own sounds and control their own sounds' (E2). They continued to infer that ownership encouraged confidence in clients – '[A] big part of the therapy is making choices and for the client to feel they have ownership over that' (E2). They suggested enabling choice was important for the user as it could build confidence and feelings of control, an attribute generally lacking in people with autism – 'enabling the client to make a choice I think is really important' (E3).

Moreover, some practitioners noted that the immediacy of an application could be of interest for autistic people – 'the participants understood the cause-and-effect within music technology as instantly as they did that you know you've got to hit a drum with a stick to make a noise … cause-and-effect is very important for me' (E3). They suggested some applications that attempted to do this failed, because poor design did not reflect a clear cause-and-effect principle, regardless of how fun the app was – 'you just feel like you're hitting random things and it changes' (E2). One therapist noted an example of a popular and well-designed application, *Loopseque for Kids* (Loopseque, 2012). They pointed out its ease of use, simple aesthetic and interactivity – 'this is really nice because this is super user friendly. There's not a lot of variation in what it does … it's a nice visual one' (E2). The therapist mentioned one autistic user who commented that they enjoyed matching up elements and creating their own patterns that synchronised with the music – '[They said] I like making the patterns myself, I like looking at the patterns' (E2). The client inferred there was logic between the music and visuals that appealed, as well as being fun to use.

Other practitioners also mentioned autistic clients who reacted very positively to simple cause-and-effect scenarios that triggered off different sound effects – 'she was just there pushing all of these buttons, and again, it was the cause-and-effect of it was amazing'(E3) – 'I have a man that I work with who is on the autistic spectrum and he loves the sound effects, he gets very drawn into the sound effects that range from like animal noises to water sounds to clapping to drum beats and things' (E1).

The interviewees indicated that simple music technology apps were popular and encouraged exploration of musical styles as long as the interface was easily accessible and understandable by the users – 'there's so much you can do with it' (E2). However, participants pointed out that too much functionality could also be intimidating –

'sometimes overwhelming for some folks' (E2). They suggested, it was best to keep the design simple.

Additionally, practitioners proposed that music technology could be exciting for small groups in creating more complex music – 'music technology can enable a small number of people to create really complex and exciting bits of recorded music' (E3). They mentioned that *Launchpad* (Novation, 2018) in particular was very useful, as it provided immediate feedback, clear cause-and-effect, and facilitated accessible opportunities to experiment with musical loops – 'it was one of the first times where the participants understood the cause-and-effect within music technology as instantly as they did' (E3).

There appeared to be an interest from therapists in using electronic music looping for some clients – 'I haven't used a loop station but I can imagine being really good fun and really useful for some clients' (E1) – while other therapists already used apps with audio-visual looping capabilities – referring to *Thumbjam* (Sonosaurus LLC, 2017) - 'that one is really cool … I'm using this one with some of my young clients' (E2)' - 'Yes, I've used one through a couple of iPad apps that have them, and they can be fun' (E2).

One therapist inferred that sampling video could also be effective for clients, especially if the technology offered the flexibility to try new things -, 'you do a little video, a vine video, and you can set sound to it' (E2), 'I think for some people they're just visual people and that might enhance their musical experience. Yeah, it would be fun to be able to play with a little bit more' (E2). The therapist here referred to audio-video sampling as a novel way to create loops, employed via an application called *Madpad* (Kruge and Wang, 2011).

Practitioners referred to tablet computers which allowed access for people with limited physical mobility. This in turn facilitated experiences with musical sounds they would not be able to create with the real instrument – 'we want it to be an accessible interface that someone can play the notes of a guitar if they only have this kind of motion with their hand but they couldn't normally do with a real guitar' (E2). They also indicated it was advantageous to play accessible instruments that encouraged sharing and communication within group sessions – 'We don't tend to use things that only one person can play, say like a flute, because then we can't share it' (E2). However, they mentioned tangible user interfaces can be more appealing – 'the *Tenori-On* (SOS, 2008) software on an iPad isn't half as good, because you can't feel it, it doesn't have that tactility' (E3). They inferred this was an important element in understanding a client's sense of agency – 'I like the idea of the Skoog because it's this tactile thing' (E3). This was evident in some therapist's opinions of *SoundBeam* (2018) technology. They suggested that the concept was a good idea, but it failed with respect to obvious cause-and-effect, in that the lack of tactility meant that separate demarcated spaces would have to be created for each beam to be effective – '[my own kids] were running up and down this line trying to break all the sound beams, but they didn't understand what sounds they were creating … I don't think it works in terms of cause-and-effect' (E3). They went on to say that even through training, it failed to be user friendly, however there remained potential for a great idea – 'The software's terrible! Really clunky!' (E3).

One participant specified that having a simple way to set up any technological tool was desirable for a therapist – 'My main concern, as a bit of a technophobe, is that it is super easy to do' (E2). They favoured apps that tended to be clear and simple in their functionality, whilst being visual and interactive – 'not a lot of variation in what it does' – '[it was a] nice little interactive one' (E2). Another attractive feature, from a therapist's point of view, is making the apps affordable as funding is scarce – 'I'm trying to get more for my money' (E2).

One therapist pointed out that the fundamentals of accessible technology should be the augmentation of human expression – 'the roots of what we're doing here, it's all about human expression' (E4).

<u>Facilitating Experience with a New Tool</u> - *Opinions on how novel experience can be created for people on the autism spectrum through innovative technology*.

Practitioners suggested that a client's musical communication was a reflection of the client themselves, so enabling exploration and change within music could affect other areas of their life – 'Whatever's happening in the music is how the person is. You know, they're maybe going to be the same in a music therapy session as they are in everyday life, and these experiences can help them find – "well, I can change in this scenario maybe I can try changing in that"' (E2). They continued to indicate a tool that enabled clients to experience something new within themselves could have a positive knock-on effect – 'trying to offer something different and enable clients to have a different experience of themselves, to be able to do something new, even in that instance, if I can do X that's a little bit different when I normally would, then that can be a positive experience' (E2). Another therapist indicated that a prototype tool could aid in this respect – 'the way that you're able to visualise, and somebody's able to get a kind of representation of their voice in a sense … they could use it on their own terms. [If] it's not too prescriptive and it's not too rigid' (E4).

Therapists recognised an important aspect of their work was empowering the client to make their own choices. However, it was the therapist who managed that choice-making decision and when it would be appropriate for the client to do so regarding use of a new tool – 'I think the control, to have it in the therapist's hands but then to have the option, if it's appropriate, and you know your client – say they can handle this, so then give them the control as well' (E2). Therapists pointed out praise and reward systems do not allow clients to help themselves, and implied that a privacy mode within a new tool would make the client more isolated rather than encourage communication – 'it's about their experience … I wouldn't use a reward system' – 'I haven't ever had a time when I've felt like the client needs to have time on their own to do things on their own' (E1).

Therapists expressed interest in a new tool through exploring the idea of providing a number of choices for the client to alter the audio or the visual content in real time. When asked about the possibility of customising shape, colour, brightness and scale for users, the therapist responded 'I think yes, all these things, if we can make it as personal as possible' (E2). Practitioners encouraged the idea of making augmentative tools personal, and commented that the ability to customise attributes like colour would be positive – 'If there could be an option for choices … say a colour … then that could be pretty useful' (E1) – '[I would like] that you really make it user friendly so that person has as much control as possible. Whether that's patterns they're triggering or the colour palette' (E4).

Practitioners proposed, that for choice, the same could be said for cultural or psychological reasons – 'I've met young people who … wouldn't play a drum kit, because the drum kit was green. And in the west of Scotland a green drum kit or a blue drum kit, for obvious reasons, can be a turnoff. So I think actually, that would be really important for me, yes, to be able to allow them to make choices for lots of different reasons' (E3).

One participant highlighted the importance of sensory integration for a potential new tool, for their clients to experience some sense of meaning from their own musical output – 'sensory integration is so essential for a lot of the people we work with because it's making sense of that sound … [If] you're able to visualise, and somebody's able to get a kind of representation of their voice in a sense … is amazing' (E4). One therapist suggested using clients' personal objects as a means to create sound, which could be an interesting way of expressing themselves – 'manipulating sounds or exploring music, expressing through their personal object, then could be really interesting and fruitful, and unexplored' (E4).

Interviewees indicated the importance of enabling their clients to represent sound as a shape of their choosing – '[I] want to have different shapes and different colours, because then I really understand it better' (E3) - or in whichever way was familiar to them – 'that would be really interesting if it had the capacity to implement whatever the person uses, you know if they use a pax notation system' (E2). Practitioners requested the capacity to be able to choose whether the whole sound was represented or the independent sounds that contributed to the music – 'I think it's good to break down those elements' (E3).

The interviewees have identified an interest in providing clients with the ability to change what the therapist (or leader) played, perhaps through the use of knobs or sliders – 'I like the idea of saying 'right, this is your filter here, and this is something else, well I can play and you can really change that' (E3). The practitioners again referred to how cause-and-effect would be emphasised, as would interaction – 'I think that would be really interesting, like something happens and the client is actively changing the colour, or actively changing [something else] … yeah, and that's another way they might be involved' (E3).

The interviewees queried whether visual representation of sound should allow the user to be able to choose which instruments are being represented – 'is [a new tool] responding to the entire frequency mix of the whole song or is it specific instruments? … I think that we need to break it down' (E3). They implied that this could include the ability to represent multiple layered sounds – 'I just want to see one pattern for the whole thing' (E3). The community music therapist pointed out in a group scenario, each individual should be able to identify their own contribution on screen – 'you should be able to differentiate' (E3).

From a teaching perspective, therapists indicated an interest in using a new tool as a means to teach and learn musical skills and theory – 'Whereas I'm not a music teacher so that's not the goal, but if we can communicate better by knowing what we're all talking about' (E2). Musical notation using colour and shape could also be a useful learning tool for non-musicians. Therapists noted it could improve communications between client and therapist for more productive sessions – 'Figure notes (FigurenotesGlobal Ltd., 2018) … that's a really cool system that makes musical notation instantly accessible' (E2). The therapist referred to an accessible audio-visual system that employs colour and shape to represent specific notes – 'it's basically a colour coded musical notation system' (E2). Therapists commented it was designed to make music easier to understand for non-musicians, and they implied that similar systems could be useful – 'I think for some people they're just visual people and that might enhance their musical experience. Yeah, it would be fun to be able to play with a little bit more' (E2).

Similar to visual scores, participants implied a new tool that visually indicated musical sections for improvisation, or as a cue, could enhance musical experience for some people – 'There's a lot of people who use visual scores, you could use that in improvisation' (E3) – 'so yeah, I think for some people they're just visual people and that might enhance their musical experience' (E2). Therapists noted, however, that any music technology should not distract from the experience of playing music – some clients could become fixated with distractors – 'But then the flipside of that is for some clients they may fixate on that' (E2).

Interviewees mentioned that as time and resources were precious, there were potential restrictions in the adoption of new tools - 'Potential restrictions could be cost' (E1). Therapists also expressed concern over learning new technology that was complicated and time consuming – 'we don't have a lot of time before and after … it has to be very user friendly' (E2) - although they were happy to do so if they thought it worthwhile for their clients – 'I would be willing to put time in if I thought it was going to be beneficial' (E1).

Other therapist suggestions have included segregation of files, for individual therapists and their associated clients for security whilst maintaining accessibility. They indicated the desire to be able to reach what they needed quickly, but without having to search through their colleagues' files in the process – 'so that CM can't see all the things that MD has done, but you can easily get to CM's things' (E2). Practitioners also suggested facilitating single and multiple user versions of the prototype – 'I can think of initially, a single user usage, and then it could be then the development of that is that person then becomes more open to sharing that with somebody else, it becomes more a shared activity than just a solitary activity' (E4). Additional proposals from practitioners included the ability to record and playback audio-visual session work – 'it's really meaningful to capture that experience or that memory and be able to record an event and play that back, and then that becomes really imbedded in that person that that's something they have created' (E4). Moreover, this functionality could lead to an improved sense of agency through the ability to recognise their own expressiveness – 'that can lead the whole series of really positive responses … reinforcing personal identity' (E4).

Overall, participants implied that a new audio-visual tool might make the job of a therapist more transparent to the client – 'I don't know if it would make it easier, but it would make it more understandable' (E3). Ideally, some participants saw a new tool as a response mechanism to what would be happening in real time, again in a cause-and-effect way – 'I mean I see this as being, it's a visual response to what's happening immediately in real time' (E3). One therapist mentioned that visual feedback on vocalisation could be a powerful tool for some clients – 'I mentioned before about the man who has locked-in syndrome, and having a visual representation of his voice and to be able to control that, for him could be incredibly powerful' (E1) – implying interactive changes in timbre and frequency might be a useful tool.

One therapist identified a stimulation factor involved in the synchronisation of audio and visual content, in the same way that concerts or clubs can be entertaining. They recognised that by combining original music with original visuals, it could be an exciting combination yet to be tested within therapy – 'there's the possibility of a 'wow' factor with the combination of audio-visual … if you think of going into that immersive environment, flashing lights synchronising with the music, it really adds to the excitement of it. So I think from that point of view it can have more of an impact.' (E3).

Participants had been shown a number of previous audio-visualisations prior to the interviews, including Cymatic images, regarding the literature within the current research. Some practitioners were interested in the organic nature of Cymatic shapes in terms of their visual appeal – 'it's not an area I know lots about. But I thought, ah would that be accessible for that specific person? There were some people I thought who would really engage with Cymatics set-up straight away' (E4) - 'The thing that I liked about the video that I saw was that there was this kind of sense of organic shape, but it was interesting to look at, but there was also the symmetry that was intriguing' (E2). The participant refers to the author's short film, Holographic Music (Figure 4-1).

Figure 4-1: Screenshot from Holographic Music, an animated simulation of Cymatics (McGowan, 2014)

4.3 Discussion

For each of the seven codes, a number of discussion points have been noted. Table 4-4 provides a summary overview of the results from the music therapist interviews for each of the coded sections. The overview presents a list of requirements for a prototype audio-visual application, in particular the findings for ‘existing accessible technology’ and ‘facilitating experience with a new tool’.

Code	Findings Overview
Providing suitable environment	Clients need comfortable spaces to express themselves
	Environment determines type of possible interaction – group work would require at least two support staff
Expanding communication channels	Musical improvisation considered good for developing communication – used as basis for behavioural change
	Music used to motivate movement, increase vocalisations, social interaction, eye-contact, turn-taking
	Good therapy does not focus on musical skill but developing each client's skills and tastes
Tailoring sessions for clients	Enabling client choice is key - important to give clients a sense of ownership for independence
	Takes time for individual development
	Sharing of resources useful for therapist and clients, or for groups
	Sessions should be fun
Following procedure and reviewing effectiveness	Maintain confidentiality and pace the sessions appropriately
	Important to feed back to clients, families, and to authorities on projects
	Check on progress of clients at home if possible
Existing accessible technology	Application needs to be accessible and easy to use
	Clients becoming increasingly familiar with technology
	Cause-and-effect applications useful for autism
	Useable applications have good use of visual stimuli – colour, patterns, and allow selection of audio stimuli – acoustic and electronic
	Ability to connect with existing technologies good for accessibility
	Tangible interfaces better than touchscreens for touch and sharing
Facilitating experience with a new tool	Should augment human expression (for example, visualising voice in real time), reflect clients' emotions, not be prescriptive, be flexible, be fun
	Should not disrupt current music therapist practice
	Provide choice through colour, brightness, scale, shape
	Could help teach simple musical theory through shape and colour
	Recording and playing back session work good for feedback
	Using elements of nature seems to inspire clients - symmetry and organic nature of Cymatics considered appealing

Table 4-4: Overview of the interview findings

The interviewees reported that clients needed to feel comfortable in a music therapy space before any kind of meaningful communication could take place and be developed. They suggested that this included being familiar with the practitioners themselves, the room, and the equipment that they used. They identified that repetition and session structure helped in that respect, so that there was a level of predictability to clients' routines. Initial sessions tended to identify what the aims of the remaining sessions would be, as they were a means to identify what the client's needs were. This suggests that a series of baselines sessions be incorporated into any future study, which has been identified as common practice in music therapy research, before the introduction of an intervention (Kern *et al.*, 2007; Villafuerte *et al.*, 2012; Edgerton, 1994a). This would allow analysis of each client's needs and an appropriate plan for the introduction of an intervention.

The practitioners implied that a new tool would have to be flexible enough for use within an individual or group scenario, provided there was a shared screen or projector. This also implies a shared means of inputting sound for visual feedback. They commented that community-based music therapy could be less controlled, as projects were dependent on available funding, which could determine the amount of available support staff. A staffing shortfall suggests that this could be unsuitable as a basis for a series of controlled sessions, with one-to-one sessions being more favourable for a prototype application.

The interviews highlighted the level of personal tailoring for individuals within each session, indicating a need for customisable technology, which could be facilitated by designing a number of user controls including colour and shape selection. A customisable interface may address interviewees' comments on the significance of ownership and control for clients with autism, which they indicated was key for developing independence. Interviewees implied that a lack of dexterity or musical skill should not disadvantage one client over another, and pointed out that expression in improvisational music was a key means to interactive communication. Previous research has shown that tangible user interfaces (SkoogMusic, 2018) and gestural interfaces (Ringland *et al*., 2014) can encourage space sharing and turn-taking whilst being accessible. However, some of the technologies identified in section 2.2.2 may have lacked simplicity in their set-up and their portability. Interviewees echoed these findings as they have suggested that any effective multimodal application would need to be simple to use, and accessible for both themselves and their clients. The practitioners' comments imply that an application should be useable without prior training, able to accommodate any acoustic or electronic musical instrument without interrupting their working practices.

The interviews highlighted the differing ways in which practitioners currently use technology within their practice. Some interviewees expressed reluctance to use technology, in favour of more traditional methods, reasoning that it could be a distraction from the music itself and would affect levels of communication. However, they also recognised their own lack of technical expertise, implying that they felt more comfortable working within familiar boundaries. Others interviewees mentioned that they were happy to use technology including iPad apps and music production software, dependent on their clients' abilities and desires. This comparison of technological uses is mirrored in a study by Cevasco and Hong (2011), which reported how students and therapists used technology in music therapy. The study pointed to therapists' lack of knowledge of available technology and their lack of training in its use. It also highlighted how interns' use of technology was greater, but that they lacked an understanding of how to incorporate technology into appropriate methodologies in practice. This suggests a need for balance in the way that established therapeutic music practitioners and new recruits view technology and appropriate methods for its use. In related research, Kern *et al.* (2013) surveyed the clinical practices and training needs for music therapy services that work with autistic clients. The authors highlighted that therapists have increasingly higher percentages of caseload, work with a broader age range of clients, and recognised a trend to serve clients at home and within community settings. It could be suggested then that there will be a greater need for a variety of methods to accommodate potential client needs, within a growing number of environments.

Through discussion with the interviewees, they have identified that cause-and-effect is a major factor for autistic users. It could be inferred that the sensitivity of client and therapist input, should mirror subtle and obvious changes in sound from a visual perspective within an application. Some practitioners expressed interest in the use of visual organic and symmetrical shapes, which implies that the use of Cymatics could be a basis for a stimulating audio-visual tool. Although interviewees indicated that music theory is not high on their priority list, they suggested that being able to show music through shape and colour could be a positive way to introduce musical ideas for clients in an accessible and stimulating way.

5 Prototype Development

The previous chapter discussed the findings from a series of interviews with therapeutic music practitioners, designed to generate an initial list of requirements for a prototype audio-visual application. The interviews outlined current practice for four practitioners, highlighted the ways in which they used technology, and indicated where potential lay for augmenting their working practices through innovation.

This chapter presents the design and implementation of *CymaSense,* a real-time interactive audio-visual application for the simulation of Cymatic shapes, comprising a user interface and output screen. Two versions of *CymaSense* are introduced. Version one was an implementation of the requirements analysis derived from literature reviewed and from the practitioner interviews. The design and implementation of version one is presented in sections 5.4 and 5.5 respectively. Early testing and demonstrations of version one with the supervisory team identified a number of design and implementation issues. The issues were addressed and solutions were implemented in version two, which are presented in section 5.6. Version two was subsequently used to test the audio-visual mapppings presented in chapter 6, and as the basis for intervention in a series of therapeutic music sessions over 12 weeks with autistic clients, presented in chapter 7.

The main motivations for this investigation are: (i) to explore appropriate models of interaction for effective audio-visual feedback for autistic users, and (ii) to develop meaningful audio-visual mappings of the therapist-client musical communication channel.

Section 3.1 of the literature review looked at research demonstrating cross-modal correspondences between audio and visual stimuli. The next step is to test whether these observed correspondences could be applied successfully to the design of an application. The following section discusses the reasons why simulation of Cymatic shapes would be a suitable method.

5.1 Rationale

Following exploration of a number of alternative methods of music visualisation in Chapter 3, current methods tend to fall into the following categories: (i) temporal graphical representation of musical structure; (ii) representation of audio signals; (iii) arbitrary and art-based representation of musical interactivity. These categories suggest that effective visualisation of music is dependent on its contextual use. One may consider which aspects of music are key, and how technology could facilitate appropriate representation for its intended use.

A number of graphical representations have been employed for identifying changes in musical structure. Piano roll style visualisations are based on musical notation, a visual representation intended for analysis and reproduction of music. Malinowski's Music Animation Machine (Musanim.com, 2011) used this concept but included colour to identify classes of pitch. Limitations of this system include the lack of discernible differences in major and minor chord, colour hues and its restriction to a 12-tone chromatic scale, which could hinder musical expression. Sapp's (2005) Visual Hierarchical Key Analysis used to colour to identify changes in key. However, as a basis for popular or improvisation styles of music within a therapeutic or group environment, it is likely the music would remain in a relatively stable key throughout, thus negating its main purpose.

In Chapter 3 it was found that untrained musicians tended to focus more on emotional aspects of musical interaction (Tan and Kelly, 2004a; Davidson et al., 1988). Music therapy studies have either identified participants as musically untrained (Dezfoolian *et al.*, 2013; Cibrian, Peña, *et al.*, 2017) or have made no mention of participants' musical background. Emotive and experiential visual feedback could therefore be considered the main aims of *CymaSense*, and could be facilitated by meaningful cross-modal correspondences.

Gao *et al.* (2007) concluded that chroma (the purity of the colour) and lightness were the most important factors on crossmodal colour-emotion association. Interview findings from practitioners in Chapter 4 highlighted the need to facilitate an emotional experience for their clients. It could be suggested then, that principal hues be used as a basis for the colour design of the potential application. In addition, individual colour choice could illustrate a connection between visual aesthetic and musical harmony, analogous to a form of synesthesia (section 3.1). Consideration should also be given to the use of colour lightness as a means of enhancing the levels of emotional feedback.

For autistic users within a music therapy environment, it could be assumed that music analysis or theory would not be a major consideration for the purposes of visualisation, as practitioners have identified the importance of improvisational techniques. The examples shown in section 3.3 for analysis of tonality, dynamics, and musical structure over time, would therefore seem unnecessary in *CymaSense*.

The majority of applications identified in Chapter 3 were designed for musical composition and employed some form of piano roll visualisation. Exceptions to these included: particle-based *Adive in Music* (Damien, 2018) which presented limited interactivity; *Loop Waveform Visualizer* (Chrome Experiments, 2015), which displayed music as a three dimensional waveform - however, it could be argued that the constant scaling from a central point limited viewing time, due to potential effects of nausea. World Stage (Wang *et al.*, 2011), a social-musical game, was designed to be used as an anonymous networked application that used emoticons to represent its users. Employing emoticons could be a useful approach in the participation of socially challenged people with autism, especially if language was a problem. However, it could be argued that if the goal was to become more socially interactive, a lack of verbalisation and remaining anonymous could further isolate users.

Lumisonic (Grierson, 2011) was designed for hearing impaired and autistic users, reacted well to harmonic changes in real-time, and accepted input from acoustic and electronic sources. The application was inspired by art-based visualisations and was effective in the visual representation of sound in a two-dimensional manner. A similar approach employing a more sophisticated and dynamic visualisation is recommended.

Utilisation of a variety of technologies (section 3.3) has allowed mappings of many kinds to develop over time, from Castel's *Ocular Harpsichord* (Popper, 1968) to *BendableSound* (Cibrian, *et al*., 2017). This can inevitably make it difficult to decide which sensory input to map to which visual output. Leman *et al.* (2010) highlighted the need for justified decisions concerning the types of mappings we choose in order to create more usable systems that have their roots in musical psychology. Alves (2012) argued that simple mapping techniques used by music visualisers were naive in visualisation, for example, corresponding one characteristic of audio like pitch, to another sensory characteristic, like colour. The author suggested more complex techniques were required to generate a greater emotional experience for the viewer.

Cymatics are unique in that they represent analogues of the geometry created by sound or music in a physical medium, and as such provide an artefact of sound as a physical imprint (Jenny, 1968). Water-based Cymatics currently provide an unpredictable but deterministic model of music visualisation when visualised using typical western musical scales (Sykes, 2015). This is evident when certain frequencies will create similar geometry, but with subtle differences due to changes in timbre of the instrument generating the sound. Sykes sought to develop a language between Cymatics and music rather than focus on the potential benefits of such. One aim of the current research, however, is to determine which approach would best represent music for people on the autism spectrum in a beneficial and meaningful way.

Multi-sensory audio-visual experiences establish perceptual links between sound and image. Research has shown that sensory integration therapy has encouraged development of independence amongst autistic people (Schaaf and Miller, 2005), and that multimodal applications have shown to be beneficial for autistic children (Cibrian *et al.*, 2017; Ringland *et al*., 2014). Autism researchers have noted the superior ability of some people with ASC in recognition of auditory and visual patterns (Mottron *et al.*, 2006). Lim (2010) identified that children with ASC perceive information through principles of pattern perception. Fletcher-Watson *et al.* (2016) identified a common interest in geometric patterns in autism, and utilised the idea within an iPad app designed for autistic children as a reward mechanism, which resulted in no obsessive behaviours (Figure 5-1).

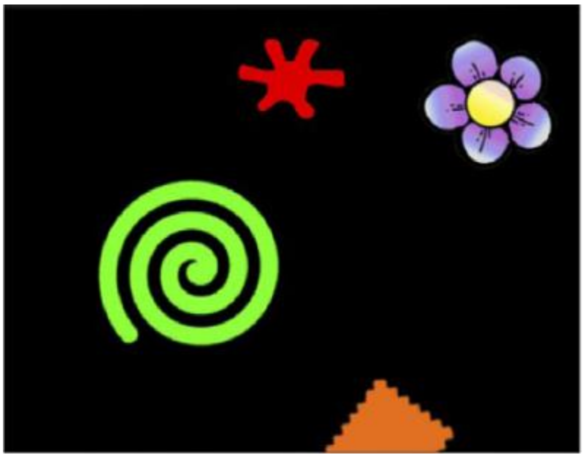


Figure 5-1: Example screenshot of a reward token for the iPad app (Fletcher-Watson et al., 2016)

It is suggested that the symmetry found in Cymatics creates recognisable patterns that may aid in the identification of musical sounds for people on the autism spectrum. Physics informs us that sound travels in three dimensions, while Telfer's (2010) bubble experiments have demonstrated that harmonicity affects the shape of 3D objects, created in the medium in which sound propagates. Additionally, water-based Cymatic images display quasi-3D elements, through the periodic wavelets on the surface and sub-surface of water (Cymascope.com, 2018d). The creation of three-dimensional Cymatic shapes, viewed from a number of perspectives, may be a novel and meaningful way to visualise sound for people with ASC. It is proposed that a new interactive application based on the aesthetics of Cymatics could increase audio-visual exploration, that will further a sense of agency for the client within therapeutic music sessions.

CymaSense is primarily interested in increasing the level of communicative behaviours within participants with ASC, via the aesthetic of resultant patterns created by sound. One aim of the application is to generate a real-time feedback loop that will encourage further musical experimentation though a sense of play within its users. An overview of the prototype design characteristics of *CymaSense* is described in Table 5-1.

Overview of *CymaSense* Prototype Design Characteristics
Designed to create a meaningful experience for autistic users, through its ability to demonstrate clear audio-visual causation, and customisation of visual output
Designed to visualise 3D Cymatic shapes, as a reflection of the true nature of sound travelling through a medium like air or water - many of the current methods are based on augmented 2D or quasi-3D representations of the amplitude of sound waves (see section 3.6)
Inspired by the aesthetic properties of Cymatics whose underlying principles of periodicity are ubiquitous in nature (Jenny, 1968), and which display geometric properties analogous to other organic objects (Cymascope.com, 2018d)
Designed to allow the manipulation of sound to be visualised in real-time
Affords the implementation of various audio-visual mappings that would adapt to changes in frequency, amplitude and timbre

Table 5-1: Overview of the prototype design characteristics of *CymaSense*

5.2 The proposed model of interaction for audio-visual synthesis

Music therapy utilises the skills of a therapist to encourage musical communication with an individual or group of clients via any number of potential acoustic or electronic instruments, including the human voice. Music therapy can also use existing electronic interfaces, like *iPads* (Future Publishing Limited, 2017) or *Lauchpad* (Novation, 2018), and self-built interfaces using affordable technology like *Makey Makey* (JoyLabz, 2018). The model of interaction focuses on the use of *CymaSense* as a musical medium to encourage and develop communication between the client and the therapist. The *CymaSense* interface would require sufficient flexibility to sample the output of any acoustic or electronic musical instrument, and the human voice. It should also adapt to other existing assistive technologies and DIY tangible interfaces, like the *Skoog* (SkoogMusic, 2018). An additional accessible mode of interaction could be based on tangible user interfaces (TUIs). Literature has indicated the positive aspects of using TUIs for people with ASC (see section 2.2.2). For example, TUIs embed computer technology in graspable objects and have been shown to improve social interaction and play in people with ASC (Farr *et al.*, 2010). *CymaSense* could be adapted as an interactive surface, where a simple microphone or electrical circuit could detect and process vibration, with subsequent visual output of Cymatic shapes.

The ability to inspire musical communication and interaction between a music therapist and a client, or group in music therapy necessitates a minimum of a single-user and two-user version of the proposed tool. This would aim to improve verbal and social communication through sharing of an interface. Previous research into the use of shared interfaces has indicated improvements in turn-taking and eye contact amongst participants with ASC (Villafuerte *et al.*, 2012).

Other forms of interaction for *CymaSense* were considered: (i) gestural control could be a more accessible way to interact with sound – there are advantages for those who do not have musical skill, or for those who have limited movement or dexterity (Cross, 2014); (ii) Virtual Reality Technology (VRT) as a form of immersive interaction was considered. Research has shown both positive and negative potential in this area (see section 2.2.2). Parsons and Mitchell (2002) suggest it would be too discomforting and could encourage further isolation rather than social interaction, while Murray (1997) argues that VRT augmented practice with a therapist, parents or other group members, becomes a socially interactive situation. Both of these forms of interaction will be considered for a future version of *CymaSense*.

5.3 Requirements of *CymaSense*

Music therapy practice can utilise any number of musical instruments, from drums, guitars, piano, electronic keyboard, voice and so on. A proposed system has to be capable of converting acoustic audio waves and electronic musical signal data into real-time visual components. An appropriate approach would be to provide the user with the option of choosing an electronic instrument or an acoustic instrument as input. Therefore, the capabilities of the system for processing and mapping appropriate audio information to the visual domain have to include firstly, MIDI (musical instrument digital interface) data; and secondly, the conversion of analogue sound into the digital domain. The system also calls for the creation of an application interface to allow end-users the choice of audio input and visual output, for single or multi-user interaction.

Beyond the literature reviewed, previous work by the researcher has explored the idea of sound visualisation in a Master's Degree short film animation, *Holographic Music* (McGowan, 2014). The project introduced the concept of sound simulated as three-dimensional bubbles, based on Cymatic shapes. Within the film, sound was shown propagating through air within a variety of scenarios, implemented as a visual effects project for a general audience. The processes involved within the production may have represented a basis for a potential method of the real-time implementation of an application. User comments from the film indicated the appeal of the idea and contributed towards its potential as a basis for an interactive application (view the film using this URL: https://www.youtube.com/watch?v=BtXYzj-iDRs). The 3D graphics rendered for the film used a combination of layered particles (see Figure 4-1) that were emitted from models created in Maya (Autodesk Inc., 2018). Particle systems model an object as a cloud of primitive particles that define its volume, and have been used as a technique in computer graphics since the 1980s (Reeves, 1983). The dynamics of particle systems result in models that represent motion and changes of form that are not possible with surface-based animations. Particle animations enhanced the level of detail of the visualisation within the Masters film. Subsequent requirements of a real-time 3D audio-visual application would include the use of particle systems to create the dynamic animation of detailed shapes more effectively than surface-based 3D geometry.

A review of software indicated that no identifiable single development environment was available to meet the criteria necessary for *CymaSense*. The main criteria for development included: processing of MIDI data and audio; ease of use via its programmability; high quality graphical output through use of real-time 3D rendering and particle systems; portability between alternative computer operating systems; integration with other systems; licence fees; and minimum system requirements (see Table 5-2 below). To render 3D Cymatic shapes with suitable clarity and quality for projection in environments with varying sizes of screen, the development environment required high-resolution bitmapped graphics in real-time. A suitable environment would include particle system capabilities, to allow generation of finer details, as well as the ability to render 3D graphics. Max (Cycling '74, 2018a) was considered as the sole development environment due to its capabilities as a useful tool for prototyping and quickly building user interfaces. However, it lacks high quality 3D rendering or particle system capabilities within its graphical output component, Jitter. Nonetheless, Max's sound processing capabilities make it an ideal tool for audio analysis and to provide a means for a visual interface.

Software	Description	Ease of Use	Particle System	Portability	Integration	Fees	Audio Processing
Unity (2018)	Good for proto-typing, good quality graphics	Easy	Yes	Cross platform	3D packages, OSC, Max	No	Limited
Unreal Engine 4 (Epic Games, 2017)	Good for proto-typing, good quality graphics	Difficult	Yes	Cross platform	3D packages, OSC, Max	No	Limited
Touch Designer (Derivative, 2017)	Designed for projection mapping, interactive visualisation	Neutral	Yes	PC	Audio, I/O & gesture controlled devices	Yes	Limited
CryEngine (Atlassian Confluence 5.4, 2017)	Good quality graphics	Very Difficult	Yes	PC	Audio	Yes	Limited
Max (Cycling '74, 2018a)	Max-Unity Inter-operability, MIDI integration, multi-channel audio, graphics quality not as good as Unity, UE4 or TD	Easy	Yes	Mac / Windows	Transcoding, audio, video, graphics, and control data	Yes	Yes
Magic (Color & Music, 2016)	VJ'ing software	Neutral	No	Mac / Windows	Audio, video, gesture controlled devices	Yes	Limited
Quartz Composer (Apple Inc., 2017c)	Development tool for processing and rendering graphical data, easy to use, not as functional as others	Neutral	No	Mac	Video, MIDI	Yes	No

Table 5-2: Development Environment – Comparative Features

The Unity games engine (Unity Technologies, 2018) provides the necessary real-time capabilities for creating suitable visual output. Unity employs high quality particle systems and provides the functionality required to use 3D meshes exported directly from Maya (Autodesk Inc., 2018). The animations in Unity are based on particle emissions from the vertices of 3D Cymatic shapes, which are modelled in Maya (Figure 5-2). The Open Sound Control (OSC) protocol provided the appropriate data communication channel between the two environments.

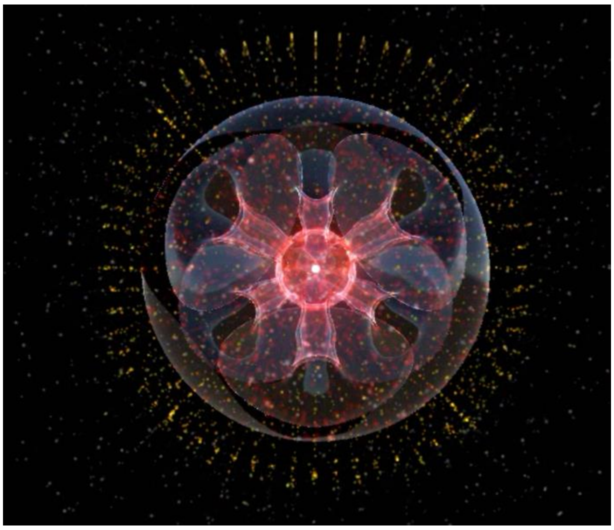


Figure 5-2: *CymaSense* Output Window – Single User Example

5.4 *CymaSense* Version One: Design

CymaSense aims to augment current therapeutic music practice through visualisation of the musical communication that takes place between a therapist, or music tutor, and a client. The application visualises specific Cymatic shapes dependent on the frequency or note being detected. The mapping of audio variables (amplitude, pitch and timbre) to visual qualities (scale, shape, colour saturation, colour lightness, rotation) have been identified through literature in Chapter 3. Therapeutic music practitioner interviews identified that appropriate mapping of these elements could encourage a sense of agency within clients with autism. This was expedited through cause-and-effect, accessibility and customisation (refer to sections 2.1.3 and 4.2.5). To facilitate greater communication and social interaction, a single and two-user version of the tool was recommended.

CymaSense works by analysing audio and/or MIDI input (see Figure 5-3): if MIDI input is chosen, both MIDI data and audio is analysed by the system – MIDI data can include note number, velocity, note on/off and bend. Detection of MIDI data allows several Cymatic shapes to be played at once, for example a chord, enabling polyphonic visualisation. Acoustically based input is detected through the use of a microphone to convert the sound waves into audio signals. Microphone input visualises only one set of audio frequencies at a time, which facilitates a monophonic visualisation. The audio is analysed for its fundamental frequencies, its partial (or harmonic) frequencies and the amplitude of the signal.

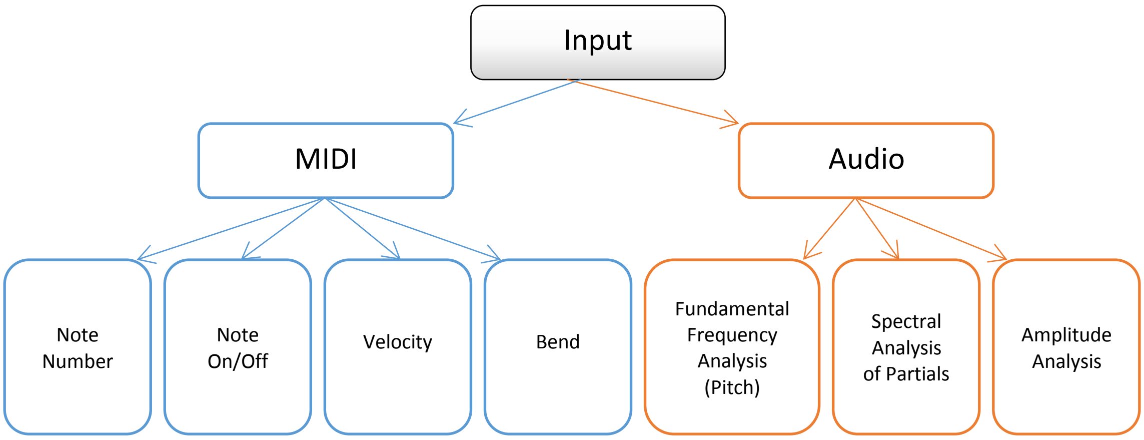


Figure 5-3: Audio Input Analysis

Figure 5-4 shows the main user interface for the single-user version one of *CymaSense*. Designed for practitioner and autistic client, the interface options include: MIDI instrument ‘in’ and ‘out’; input selection of microphone or line-in input; audio on/off and level controls; colour and rotation controls for the Cymatic shapes and background colour; and a ‘reset keys’ button (see section 5.6). The interface was designed to sit below the Unity output window to allow access to controls and customisation at any time. A standard Arial sans serif font (size 12pt) was chosen as the basis for the labelling of buttons and general functionality, in order to comfortably fit all user interface elements on screen.

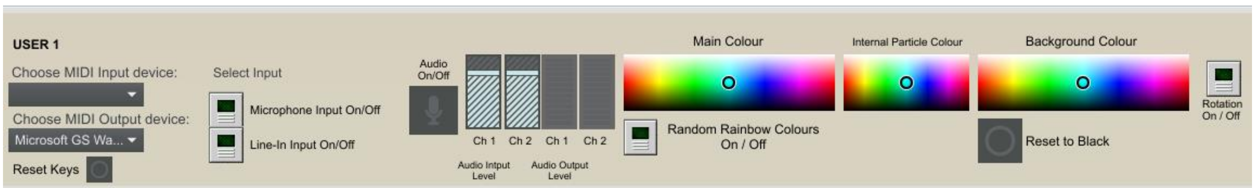


Figure 5-4: *CymaSense* interface controls for single-user, designed for practitioner and client

The two-user version includes the same controls as the single-user with the exception of only one option for background colour, as both sets of Cymatic shapes will be presented within the same output window. Figure 5-5 shows a section of the two-user-interface including the record and playback controls.

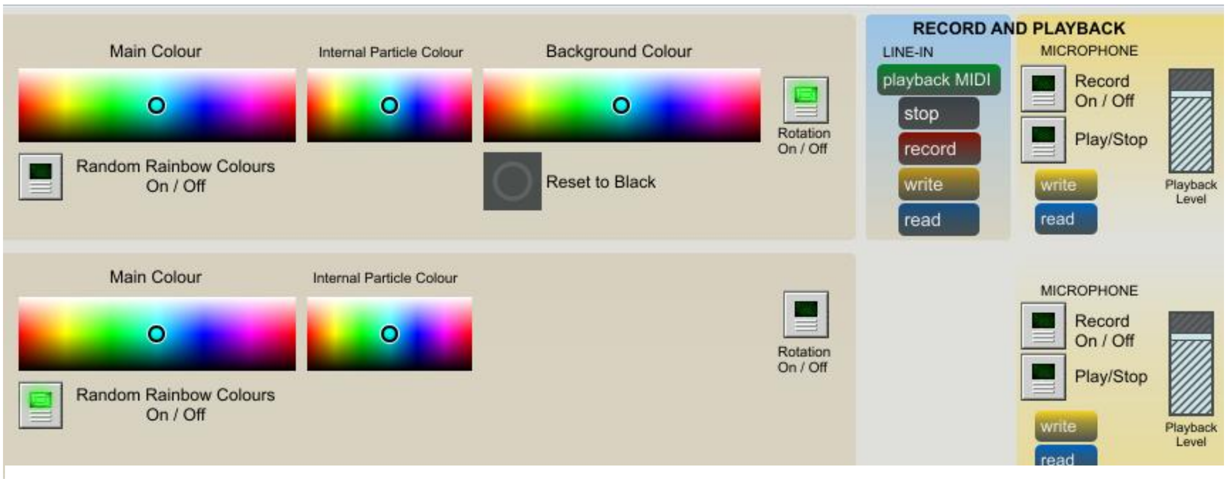


Figure 5-5: A section of the *CymaSense* two-user version interface

5.4.1 Determination of Mapping Audio to Visual

Mapping amplitude to scale is commonly referred to in literature (Küssner, 2014; Smith and Williams, 1997). The majority of the reviewed research indicated a relationship between loudness of input sound with the size of its associated visual output. A similar approach was employed here. Amplitude of the audio signal is detected though the audio input of the instrument used, and is mapped to the scale of the Cymatic shape, the particle size, and the amount of bloom. Within the Unity games engine, bloom is an optical effect where light from a bright source (such as a glint) appears to leak into surrounding objects (Unity Technologies, 2018). The effect was applied to the *CymaSense* shapes to augment the visual appeal. By scaling shape, particle size and bloom, a consistent proportion is maintained allowing clear visualisation of the shape, regardless of its amplitude (Figure 5-6).

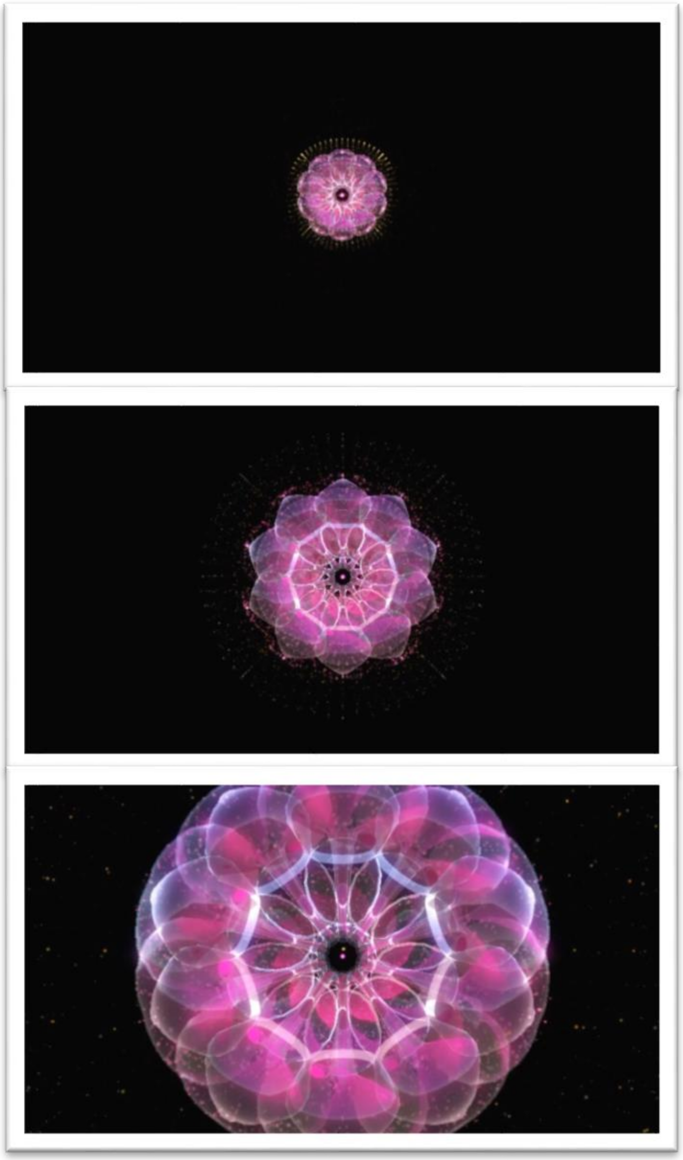


Figure 5-6: An example of a low (50 dBC), medium (66 dBC) and high amplitude signal (83 dBC) represented by its associated visual scale (top to bottom).

The Cymatic shape is represented by the main geometry; particles are seen as small dots surrounding the shapes. Bloom is represented by the general brightness of the particles themselves that increases relative to the shape scale.

Section 3.6 has shown that sounds vibrated through different mediums can create specific Cymatic shapes, determined by their frequency. Literature has also indicated that pitch has commonly been visually represented through changes in vertical position (Küssner and Leech-Wilkinson, 2014; Pietrowicz and Karahalios, 2013), or through changes in scale (Marks *et al*., 1987; Mondloch and Maurer, 2004). However, Cymatic shapes have been prioritised as a means of identifying changes in pitch from an aesthetic perspective, and in recognition of the abilities in pattern recognition of some people with autism. Sykes (2015) commented that western-based tuning (Equal Temperament) has shown harmonic inconsistencies and that the Pythagorean-based Just Intonation (JI) has shown greater and more consistent visual symmetry (see 3.4.2). This has also shown to be true through experimentation with audio visualisation in water. To represent all notes in a western scale efficiently (as commonly used by therapeutic music practitioners), 12 Cymatic shapes that represented the 12 semitones of a musical octave were created.

The twelve 3D meshes that were created for *CymaSense* (see Figure 5-7) were based on high resolution images of piano notes (A3 up to and including G#3) visualised in water (Cymascope.com, 2018b). Vertical positioning was also considered, but would have required considerable scaling down of all shapes to allow visualisation of a suitable range of notes within a single visual field. Implementing changes in vertical height for each note would also require users to follow the animated path of each note from a visual perspective. Jarrold and Scott-Samuel (2005) reported that individuals with ASC may process motion atypically at a very low perceptual level and may react atypically to biological motion (Blake *et al.*, 2003). It was decided, therefore, to keep shapes in a central position, reflecting the way that water-based Cymatic images are created. It would also allow focus on the detail of individual shapes in relation to their corresponding frequency as a mode of visual representation.

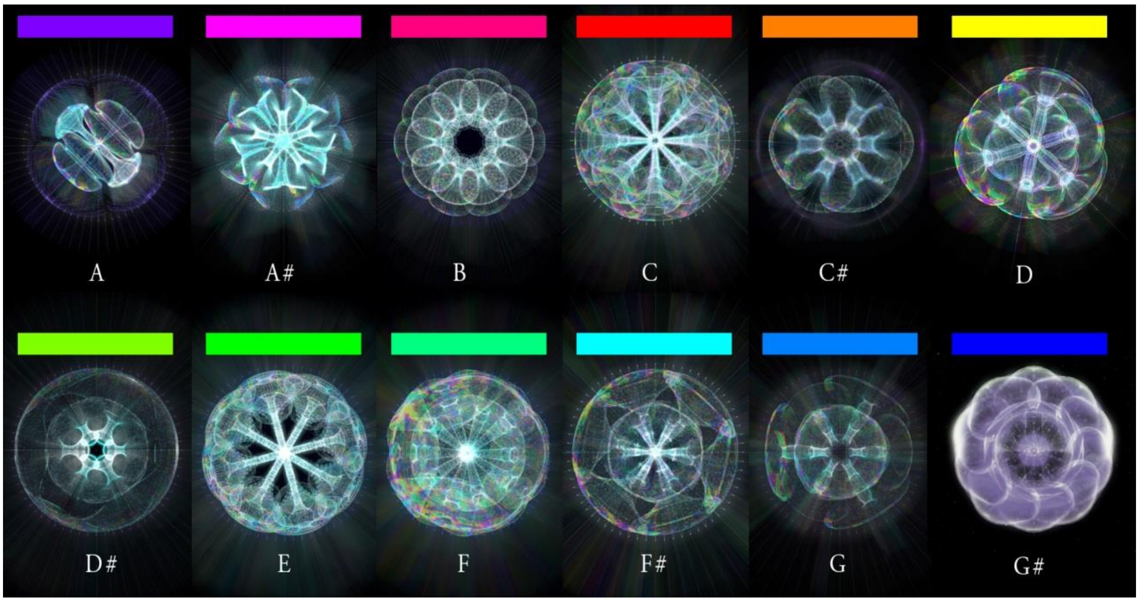


Figure 5-7: The 12 Cymatic shapes above were created for *CymaSense,* one shape for each semitone on the musical scale, displaying associated note names and default colour

Colour was identified in literature (Ciuha *et al*., 2010a) and through interviews with practitioners (section 4.2.5), as key to empowering clients in relation to facilitating their own choices. Literature in Chapter 3 also referred to chroma and colour lightness being the most important factors on colour-emotion association. Subsequently, choice of hue is provided for *CymaSense* users. These include an outer material colour of the main shape, main particle colour and internal particle colour. Two sets of particles are created to facilitate user choice for numerous colour combinations; however, a default colour spectrum is also made available. Lightness of colour is applied to the Cymatic shapes to differentiate between octaves, facilitating a pitch-to-lightness correspondence, referred to in synesthesia and cross-modality literature (Whitelaw, 2008; Marks and Pierce, 1975). The higher the note, the lighter the visual component is.

Smith and Williams (1997) state that timbre is the most difficult characteristic of tone to describe. It is also referred to as a potentially useful tool in audio-visualisation by practitioners for therapeutic use (see section 4.2.5). Literature reviewed in Chapter 3 indicated that timbre has been represented by changes in shape (Adeli *et al*., 2014), through pattern (Walker, 1987), or with colour (Fahlenbrach, 2008). Fales (2002) identified timbre as the perceived quality of relative intensities of harmonics within a tone, visible as 2D waveforms within a spectrogram (see 3.4.1). Observation of Cymatic shapes in water has shown a change in complexity and detail of shape, affected by the change in timbre in vocalised vowel sounds (soundhealingresource, 2011).

It was proposed that Cymatic shape simulation extend to the visualisation of timbre in a similar manner as water-based Cymatic shapes. This implied that the details of each of the 12 shapes be modified in real-time, dependent on the timbre of the sound source. The findings of Adeli *et al.* (2014) were used as a basis for changes in Cymatic shape surface quality, where soft sounds have been associated with rounded shapes and harder sounds associated with sharper shapes.

CymaSense aims to facilitate changes in timbre by deforming the shape structure. This technique is known as blend shape deformation in 3D applications (see Figure 5-8), where the location of vertices within a 3D mesh can be moved to alter its surface shape (Autodesk Inc, 2018). In *CymaSense*, the extracted tonal values of the audio would allow real-time visual representation of changes in timbre by altering the surface of the Cymatic shapes.

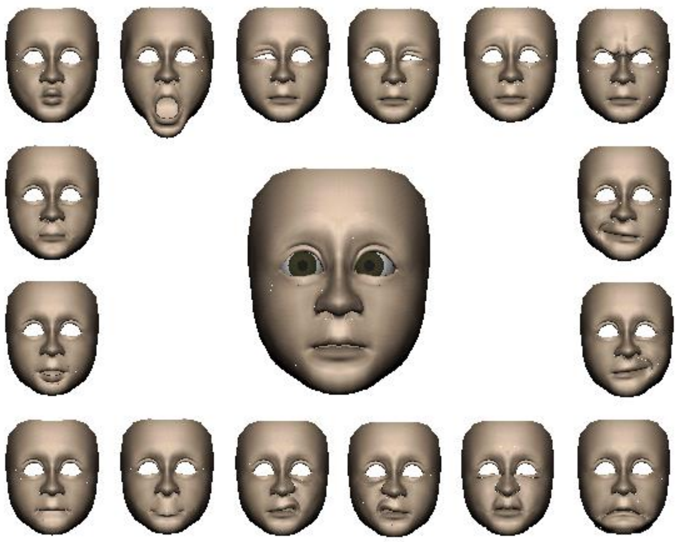


Figure 5-8: Example of blend shapes typically used for facial animation (Autodesk Inc, 2018)

Through observation of a video of Cymatic shapes created in water available from Cymascope.com (2018b), it was noted that in addition to changes in shape dependent on frequency, subtle rotation occurs. Subsequently, the design should also allow the end-user to control rotation of the shapes.

Table 5-3 illustrates the features associated between audio and visual stimuli. The analysis was aimed at the ontology of the features and their potential actions.

Interface Features		
Visual Features	**Ontology**	**Potential actions**
Colour Intensity	Texture Energy	Dark - Bright
Scale/Particle Size	Energy	Small - Large
Bloom Intensity	Energy	Dark - Bright
Shape Surface Quality	Texture Energy	Round - Sharp
Rotation Value	3D Spatial Distribution	Slow - Fast
Audio Features		
Audio Features	**Ontology**	**Potential actions**
Amplitude	Energy	Quiet – Loud
Timbre	Harmonic Distribution	Dull - Bright
Pitch	Energy Frequency	Low - High
MIDI Note Bend	Frequency Modulation	Down - Up

Table 5-3: Analytical cataloguing of the visual interface and the audio features, in terms of parameters, domains and potential actions

Identifying the ontology and potential actions of each parameter is an essential and informative way of determining any cross-modal associations between the audio and visual elements. In both audio and visual features, the repetitive themes of energy indicate the connection between musical input and associated visual output. Causation has been discussed in section 3.5 as a perceptive aid in interaction design, and was identified by therapeutic music practitioners in section 4.2.5 as being key for people with ASC, as a means to facilitate a sense of agency. Colour, bloom intensity, and particle size relate to the amplitude and pitch of an audio signal. The system attempts to make this connection implicit for the user, simplifying the interface to allow focus on the act of musical creation and immediate visual feedback.

The mapping of the version one of *CymaSense* was based on creating an interactive 3D Cymatic representation of sound, by employing aspects of established audio-visual correlations from a psychological perspective (Whitelaw, 2008). It can be summarised as follows in Table 5-4, while the implementation of the associated mapping is discussed in section 5.5.

Property Identified	**Mapping**	
	Audio	**Visual**
Sense of Agency (Through Cause-and-Effect)	Amplitude	Scale / Particle Size
	Pitch	Cymatic Shape / Colour Lightness
	Timbre	Expansion of Shape / Detail of Shape
Communication / Social Interaction	Amplitude, Pitch and Timbre (as above) for Single or Two User Version	One or Two sets of Cymatic shapes implemented (as above) to encourage interaction
Customizability	Instrument Choice of User	Shape Rotation
		Cymatic Shape Colour
		Background Colour

Table 5-4: Overview of *CymaSense* Mapping Techniques

5.4.2 Interactive Surface

Based on the literature reviewed and therapeutic music practitioner feedback, the design of a simple interactive surface was considered as an alternative and accessible means to trigger Cymatic shapes for autistic users. A simple surface or object can detect vibration, allowing users to use their hands or any available implement with which to strike it. A contact microphone connected to a sound module allows generation of a range of electronic sounds, dependent on the force with which the surface is played. An audio connection from the sound module to the *CymaSense* application would then visualise the sounds via a screen, or by projecting the shapes onto the surface itself. This could add to the efficacy of a multimodal experience where the surface itself becomes the visualising medium (Figure 5-9).

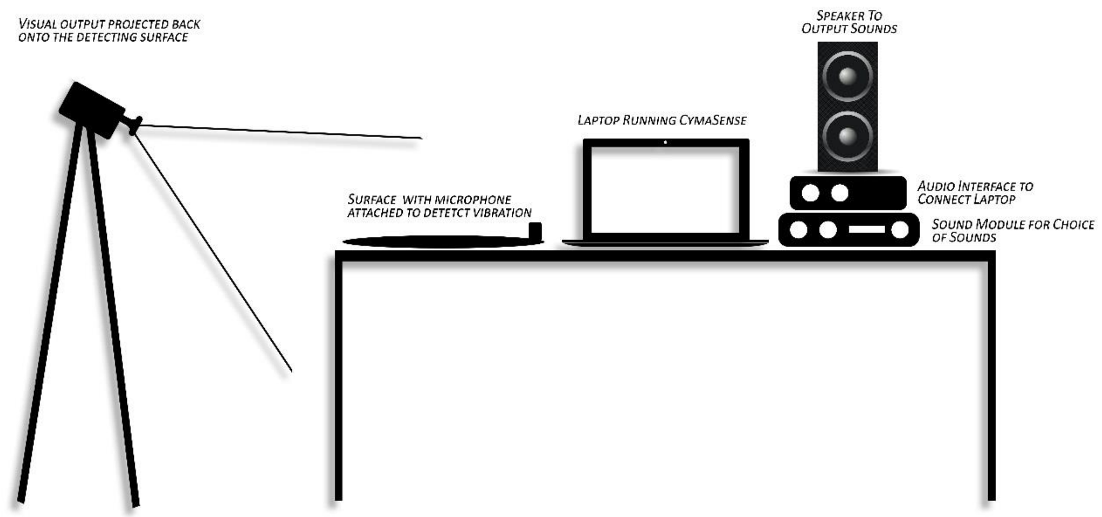


Figure 5-9: Overview of the design of a simple interactive surface that uses a microphone to detect vibration, a sound module to generate electronic sounds, and a projector to send visual output back onto the surface itself

5.5 Implementation

Amplitude to Scale of Cymatic shape – In *CymaSense*, the amplitude is monitored by a noise gate in Max and will only allow the signal to pass if it is above a specified threshold of 0.5% of the signal's maximum potential. This global setting reduces the noise floor within the system before the audio signal is routed to a User Datagram Protocol (UDP) port.

The monitored raw audio signal lies in a range of values between 0.001 and 0.1 and is scaled up 1000% by a Max meter~ object to a range of between 0.01 and 1.00, so that the signal can be viewed within the interface through a VU meter (Figure 5-10). This value is further scaled up 10000% by a Max scale object where its resultant range of values lie between 0 and 100. The final value is transferred to Unity and assigned to the X, Y and Z-axis scale parameters within a corresponding C# script that scales the 3D meshes to a value of between 0 and 100%. 0% represents no scale and 100% represents maximum scale where the shape fills the screen (refer to Figure 5-6).

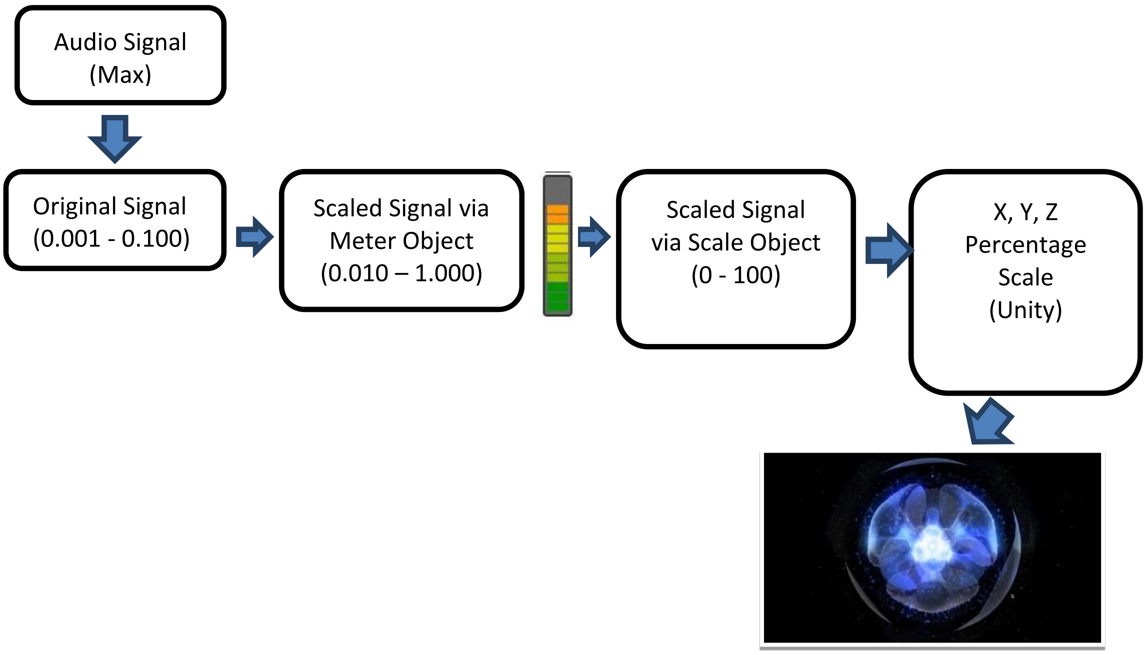


Figure 5-10: The audio signal in Max is scaled up on two levels before being sent through to Unity

UDP ports allow a data connection between two programmes to be established, facilitating transfer of audio from Max to Unity. Once transferred over to Unity, C# scripts associated with each Cymatic 3D model filter and apply the data to the appropriate Cymatic shape which is updated every frame. The approximate frame rate is 60 frames per second (See Pitch to Cymatic shape section below for details of Cymatic shape selection). As noted in section 3.1, sensory afferent delays are shorter for auditory stimuli compared to visual stimuli by about 40ms (Pöppel *et al*, 1990). Assuming auditory latency is less than 80ms and the distance between user and screen is less than 30 metres, real-time audio to scale mapping latency is negligible from a visual perspective (Eagleman, 2018).

Amplitude to Particle Size – In the same manner to the Amplitude to Scale of Cymatic Shape process above, amplitude of the input instrument is also mapped to particle size within Unity. This maintains a visual consistency of scale with the perceived mass of internal particles emitted compared with the expanding and collapsing of the external Cymatic shape material. Figure 5-2 and Figure 5-6 show examples of output shapes with external semi-transparent material and internal particles, coloured red and pink respectively.

Pitch to Cymatic shape – Frequency evaluation and subsequent Cymatic shape selection was employed by identification of the MIDI note number, or analysis of the fundamental audio frequency, to retrieve the appropriate mesh from a library of 3D models. This has been accomplished in two ways using Max and Unity:

(i) A MIDI line-in input option in Max directly detects MIDI information, including note number, which is filtered and routed to an appropriate UDP port number before being sent to Unity for analysis and visual output. The detected notes cover six octaves on a MIDI keyboard ranging from C1 to C7, which translates as MIDI note 24 up to and including MIDI note 96 (Figure 5-11).

Note	Octave										
	-1	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
C	0	12	24	36	48	**60**	72	84	96	108	120
C#	1	13	25	37	49	**61**	73	85	97	109	121
D	2	14	26	38	50	**62**	74	86	98	110	122
D#	3	15	27	39	51	**63**	75	87	99	111	123
E	4	16	28	40	52	**64**	76	88	100	112	124
F	5	17	29	41	53	**65**	77	89	101	113	125
F#	6	18	30	42	54	**66**	78	90	102	114	126
G	7	19	31	43	55	**67**	79	91	103	115	127
G#	8	20	32	44	56	**68**	80	92	104	116	
A	9	21	33	45	57	**69**	81	93	105	117	
A#	10	22	34	46	58	**70**	82	94	106	118	
B	11	23	35	47	59	**71**	83	95	107	119	

Figure 5-11: Grid referencing musical note name against octave number and associated MIDI note value

(ii) A microphone input option converts the fundamental frequency to an approximate quasi-MIDI key number value of the audio signal using the pitch detection object Sigmund~ (GitHub, 2018). The returned value includes a fractional part (which does not exist in true MIDI) for greater specificity of pitch evaluation. Each output from the Sigmund object is filtered to allow a tolerance of +0.4 and -0.4. For example, values greater than 47.6 and less than 48.4 are assigned to the MIDI note 48, the equivalent of C3 (see Figure 5-11). Furthermore, between each range of values, a 0.2 buffer was created to allow triggering of an intermediate default spherical shape that would allow a clearer distinction of the transition between notes created via the microphone. For example, values greater than 48.4 and less than 48.6 are assigned to the default spherical shape. This filtering pattern continued for all remaining values, so that the next range of values of 48.6 and 49.4 are associated with C#3 (MIDI note 49) and so on, up to and including B6 (MIDI note 95). The range of notes for microphone input goes from G2 (MIDI note 43 or 98Hz) up to B6 (MIDI note 95 or 1975Hz), considered as a suitable range for vocal input or acoustically recorded mid-range instrument (Sound Engineering Academy, 2018).

The rounded MIDI note number is then routed to its associated UDP port in Max before transfer to Unity. The received data at the Unity end of the OSC protocol is routed to a C# script dependent on MIDI note number for MIDI-based input, either directly from the midi note played in from a MIDI instrument, or in the case of a microphone, from the converted fundamental frequency to its associated MIDI note number. The particular C# script associated with each note number determines which associated Cymatic shape, out of 12 possible shapes, is triggered while audio determines scale. For example, MIDI notes 26, 38, 50, 62, 74, or 86, would trigger the Cymatic shape associated with the note D (see Figure 5-11).

Cymatic Shape Colour Choice - Colour hues can be selected directly from a colour swatch on the *CymaSense* interface, which identifies the RGB values associated with the selected hue (Figure 5-12). The chosen RGB colour values are sent via a UDP port directly to a C# script where they are analysed and implemented within the chosen Cymatic shape's material and main particle colour (selected via the main colour selector), or its internal particle colour. The default colour spectrum can be selected via a button named *Random Rainbow Colours,* implementing the colours shown in Figure 5-13. The RGB colour values represented by each shape can also be referred to in Figure 5-13.

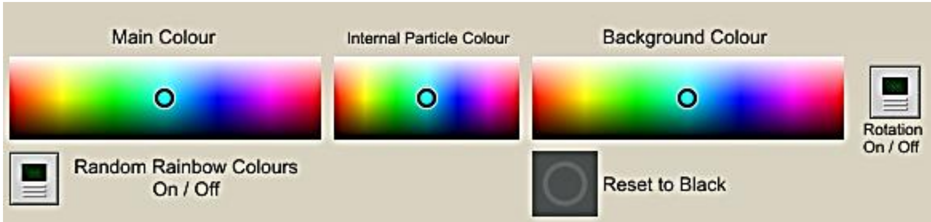


Figure 5-12: *CymaSense* interface colour swatches for main, internal and background colour choice

Background Colour Choice – to provide the user with additional options for colour customisation, background colour selection is also made available. Similar to the process described above, RGB values are selected from the interface and sent to a C# script attached to the camera's background colour in Unity for implementation (Figure 5-12). It was noted in section 2.2.2 that colour has been used in a number of ways for people with ASC. For example, as a means of reinforcing the organisational needs of an autistic child within a learning environment (Bredek *et al.*, 2014), as a means of improving attention skills (Taheri *et al.,* 2015), or to facilitate communication (Wainer & Ingersoll, 2011). Background colour choice could thus be a more relevant option for the user, due to the entire screen behind the visualised shapes being changed to the users' chosen colour. An initial default black colour is implemented to allow clear views of the Cymatic shape colours. A button is also provided to reset the background colour to black.

Pitch to Colour Lightness – Implemented on the 12 notes of the chromatic scale from red through to the magenta end of the spectrum, Figure 5-13 demonstrates the default red, green and blue (RGB) colour values assigned to each note within the musical scale (see also Figure 5-7). Twelve Cymatic shapes were designed for use within the initial version of the prototype, to allow user recognition of the same note shape across several octaves, and to reduce load on computer processing (see 5.5.1).

Colour lightness is determined by analysis of the relative MIDI note or audio frequency, implemented via the same process of identifying MIDI note numbers described in Pitch to Cymatic Shape. Identification of the MIDI note determines RGB value based on the default RGB settings of note values seen in Figure 5-13.

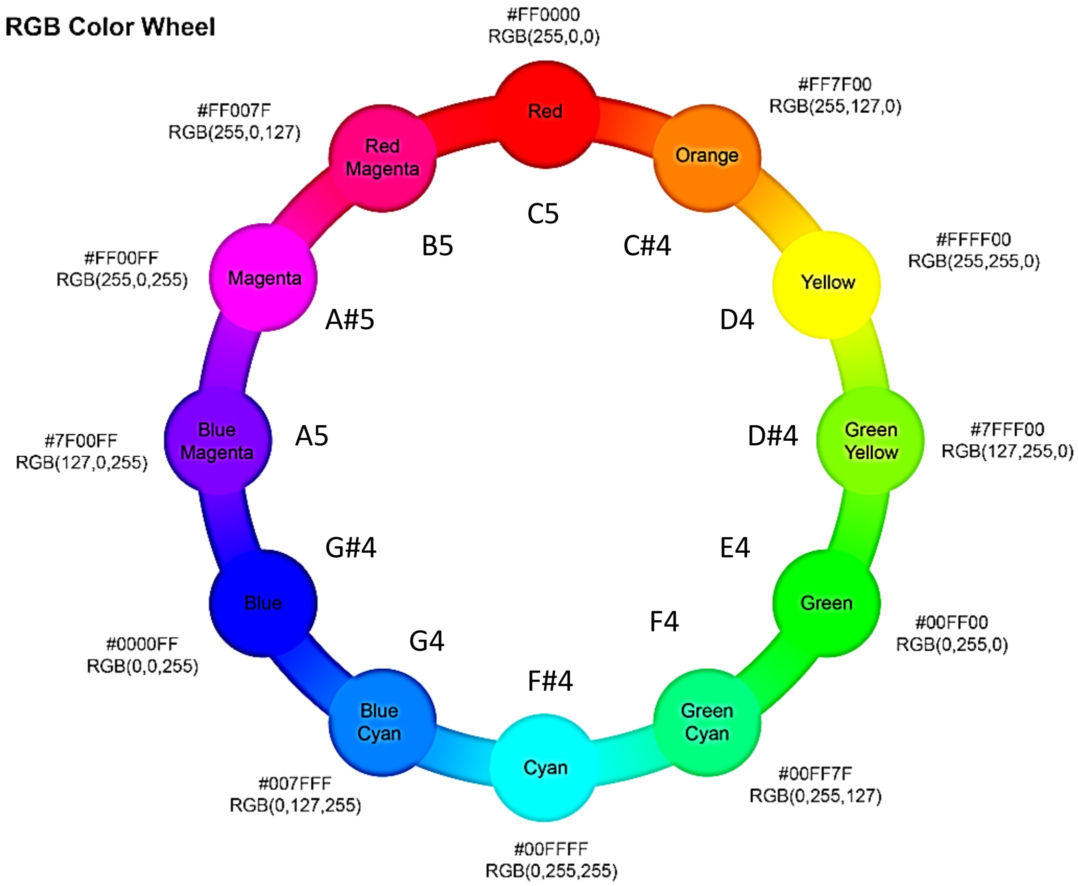


Figure 5-13: Colour wheel indicating the RGB values associated with musical notes, used as the default colour scheme used in *CymaSense* (modified colour wheel, original source Van De Vall, 2013)

In this mapping, the RGB colours are first converted into hue, saturation and lightness (HSL) colour values by a separate patch within Max. The MIDI note number is converted to a lightness value over a range of between 0% and 100%. For example, C4 (MIDI note value 60, colour red, RGB value of 255, 0, 0) has been assigned the associated lightness value of 50% (see Figure 5-14). Table 5-5 shows the range of lightness percentages for notes C1 to C7.

Note Name	C1	C2	C3	C4	C5	C6	C7
Lightness %	0	17	33	50	66	83	100

Table 5-5: Sample assignment of Lightness values for notes C1 to C7

Lightness values are calculated based on their relation to the assigned default RGB values. The lightness value is then converted back into RGB values and applied to the Cymatic shapes.

Name	Color	RGB	HSL
white		rgb(255,255,255)	hsl(0,0%,100%)
silver		rgb(192,192,192)	hsl(0,0%,75%)
gray		rgb(128,128,128)	hsl(0,0%,50%)
black		rgb(0,0,0)	hsl(0,0%,0%)
maroon		rgb(128,0,0)	hsl(0,100%,25%)
red		rgb(255,0,0)	hsl(0,100%,50%)
orange		rgb(255,165,0)	hsl(38.8,100%,50%)
yellow		rgb(255,255,0)	hsl(60,100%,50%)
olive		rgb(128,128,0)	hsl(60,100%,25%)
lime		rgb(0,255,0)	hsl(120,100%,50%)
green		rgb(0,128,0)	hsl(120,100%,25%)
aqua		rgb(0,255,255)	hsl(180,100%,50%)
blue		rgb(0,0,255)	hsl(240,100%,50%)
navy		rgb(0,0,128)	hsl(240,100%,25%)
teal		rgb(0,128,128)	hsl(180,100%,25%)
fuchsia		rgb(255,0,255)	hsl(300,100%,50%)
purple		rgb(128,0,128)	hsl(300,100%,25%)

Figure 5-14: Comparison of RGB (Red, Green, Blue) and HSL (Hue, Saturation, Lightness) values (Color-Hex.org, 2018)

Timbre to Detail of Shape – To implement a timbre-to-shape mapping, audio input data is analysed in Max for its tonal value by employing a Fast Fourier Transform (FFT) spectral analysis tool. The Iana~ object (IRCAM Forumnet, 2017) uses an algorithm to determine the spectral centroid, which is a measure used in digital signal processing to characterise the psycho-acoustic importance of a sound (Figure 5-15). It indicates where the 'centre of mass' of the spectrum is located. Perceptually, it is associated with the impression of 'brightness' of a sound (Grey, 1978). Spectral centroid values are output in the range of 0.01 to 1.00, which are scaled up within Max to within a range of 0 to 100, in a similar manner to the process described for amplitude scaling. The spectral centroid values are sent to Unity and used to determine the level of change of the mesh shape. Animating changes in timbre was addressed by firstly creating alternative versions of each 3D mesh, known as blend shapes. Blend shapes allow animation of a 3D mesh by morphing the coordinate points of the original shape, known as vertices, to its remodelled version (Autodesk Inc., 2018)

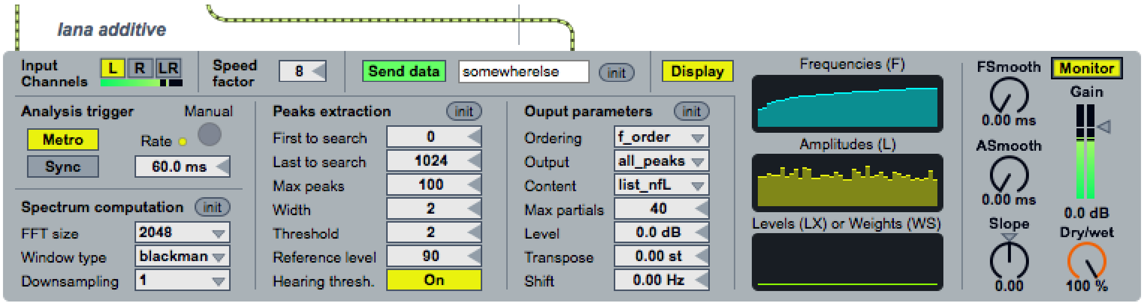


Figure 5-15: Iana~ FFT audio analysis object interface (IRCAM, 2018)

As every acoustic or electronic instrument has its own unique timbre, two interpretative approximations of each of the 12 3D mesh shapes were created to represent the ‘softer’ and ‘harder’ ends of the tonal spectrum. Using the FFT analysis from the audio input (Figure 5-15), the PW value was sent to Unity where ‘softer’ tones were applied to more rounded versions of each of the original models, whilst ‘harder’ tones were applied to the more pointed versions of the models, thus facilitating a real-time animation of tonal changes. Figure 5-16 shows three versions of the same Cymatic shape, visualised by a soft tone (PW value of 0), a mid-tone (PW value of 50), and a hard tone (PW value of 100). A future version of the prototype may seek to exaggerate and clarify this process for the user from a visual perspective, dependent on results from initial studies.

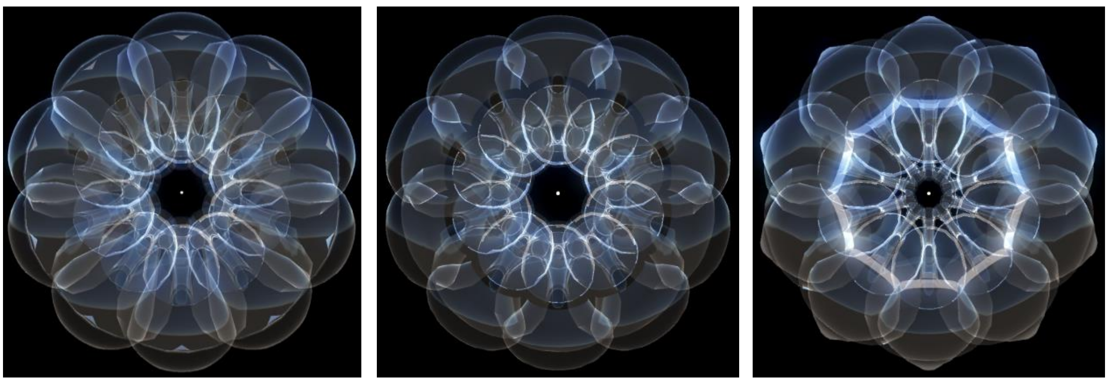


Figure 5-16: *CymaSense* example demonstrating three versions of timbre applied to the same Cymatic shape: (left) soft tone; (centre) mid tone; (right) hard tone

Cymatic Shape Rotation – The decision to include a simple on/off button for no or random rotation values was deemed sufficient for the initial version to simplify the interface implementation (Figure 5-12). Rotation can be turned on or off directly from the interface – when turned on, change in frequency or MIDI note detected in Max triggers a random quaternion rotation on all three axes between a value of -1 and 1 (Shoemake, 1985). This is equivalent to a plus or minus 90-degree random rotation applied to the X, Y and Z-axis (Figure 5-17). This value is sent to Unity where the currently selected Cymatic shape is rotated, thus providing immediate but subtle audio-visual feedback.

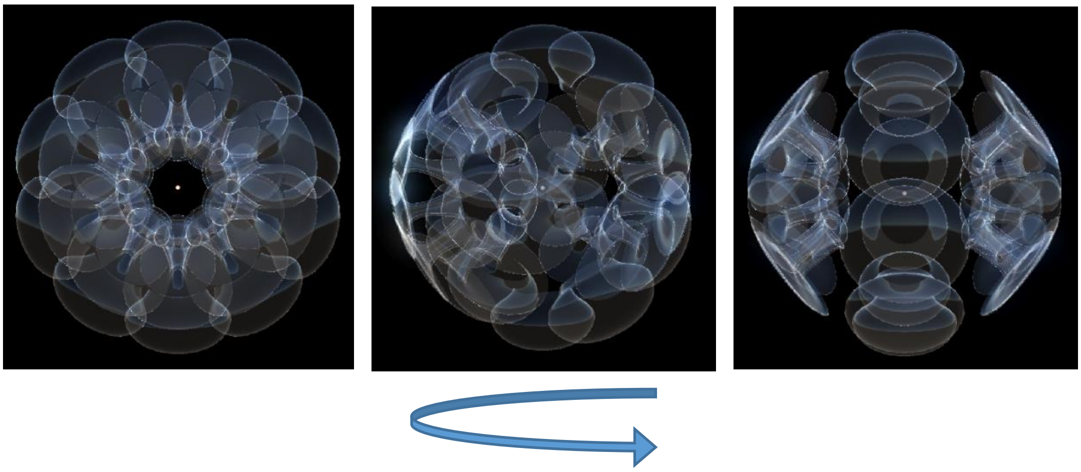


Figure 5-17: 3D Cymatic shape displaying an example positive rotation around the vertical Y-axis with values of 0, 0.5 and 1 quaternion left to right respectively

Recording and Playback – Recording and playback functions were implemented via the record~, buffer~, and play~ objects in Max respectively. The record~ object was assigned a named buffer space where audio was placed on a temporary basis. The duration of the audio sample recorded could be set any millisecond value. In this case 30000ms (30sec) was set as a default buffer space. Read and write functions allowed archiving and retrieval of the audio files for playback via the play~ object. Audio from the buffer was routed through the system in the same way that live audio or MIDI was processed, allowing visualisation of the saved data. Potential changes to sample duration or to functionality would be dependent on user testing of the prototype, and will be discussed in chapter eight.

5.5.1 System Architecture

Requirements of the application demanded that both MIDI and acoustically-based input would be offered to practitioners and clients. MIDI-based electronic instruments use a combination of audio output and MIDI connection via USB to the computer running *CymaSense*. The general architecture of *CymaSense* facilitates the visualisation of Cymatic shapes based on 3D meshes created in Maya. An advantage of this architecture lies in its ability to support other types of visualisation, where the system can utilise any 2D image or 3D mesh in the same way. A disadvantage of the architecture, from a Cymatics perspective, is the inability to mathematically synthesise Cymatics in real-time based on the physics of sound waves. However, the modelling of complex wave refractions based on multiple frequencies is beyond the scope of the current research.

An issue within any system that aims for real-time interactivity, is that the overall system can become overloaded from a computational point of view. Latency can be an issue with any audio-visual system and can be more noticeable when central processing unit (CPU) processes are high in number (Abdelkrim et al., 2009). This is notable due to the first version of *CymaSense* being a combination of two environments: the audio analysis and visual control components in Max; and the rendering of 3D meshes and particle animations within Unity.

During development there were noticeable delays, in MIDI notes being played and corresponding visual output being displayed, of approximately 0.5 seconds. Subsequently, a number of modifications were identified that could improve the system efficiency: (i) removal of any graphical representation of audio analysis within Max, which were default within the FFT object, as this could increase unnecessary processes which were not required by the user for audio analysis during runtime; (ii) reduce the number of separate Max patcher windows by embedding code and connections within one patcher window; (iii) reduce the particle emission rate to a minimum for each of the Cymatic shapes, at the expense of creating more defined particle shapes, as this reduced load on the CPU.

Figure 5-18 illustrates the general architecture of *CymaSense* for a single user. The interface, which provides the audio and visual control, was designed using Max components. Audio input is divided into microphone or MIDI-based line-in inputs: microphone input audio is analysed for its fundamental frequency, partial frequencies for timbre analysis, and amplitude; MIDI-based line-in input analyses MIDI note, velocity and bend, while amplitude and timbre analysis of the audio signal is simultaneously processed, in the same manner as the microphone signal. The analysed and processed audio, MIDI and interface data, is sent through to the Unity games engine using the Open Sound Control (OSC) protocol (Linux Journal, 2015). This is implemented through the UDP communication protocol, by establishing send and receive ports within Max and Unity respectively.

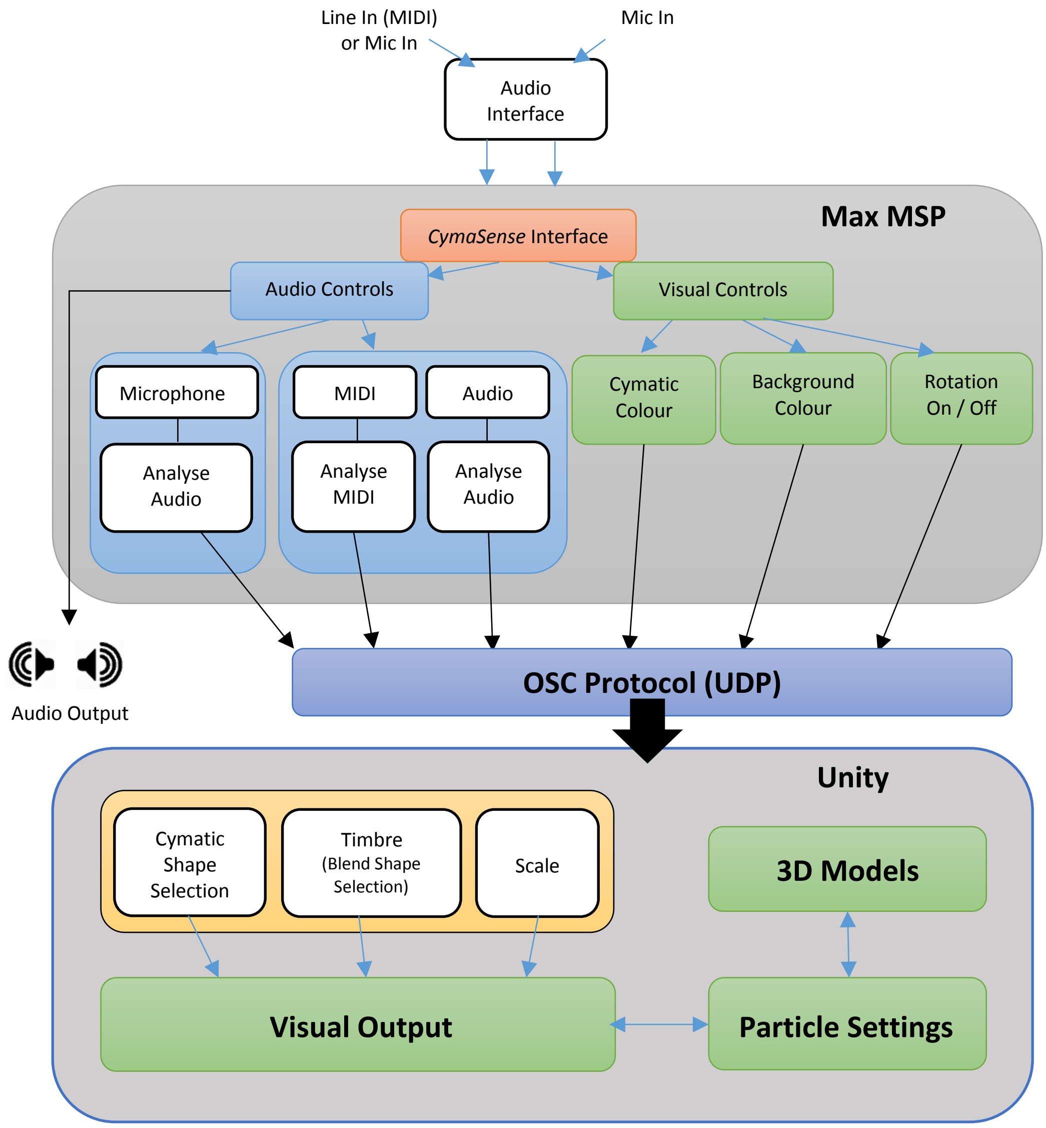


Figure 5-18: System Architecture Overview for *CymaSense*

Resolution of the visual output window is determined by the capabilities of the system running it; however, variations of window size are presented to the user via the executable program file created in Unity (Figure 5-19). The user interface is presented to the user on opening the Max file that opens in presentation mode showing only the necessary controls as seen in Figure 5-4. Figure 5-2 illustrates one Cymatic shape from the single-user version of *CymaSense*, output via the Unity environment.

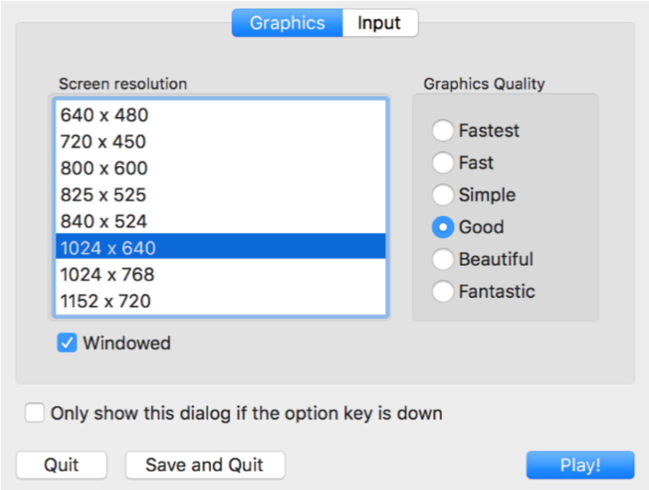


Figure 5-19: Resolution options presented to the end-user in Unity

5.5.2 Interactive Surface

A 14-inch diameter black rubber drum silencer was chosen as a simple prototype interactive material that could be placed on any table or surface (Figure 5-20). This allowed the use of hands, drumsticks, or other implements to be used as tools for triggering sounds. A contact microphone (Creative Field Recording, 2018) was used as means of detecting vibration, which was connected to a sound module for playing back electronic sounds (Roland Corporation, 2018). The module sounds were routed through *CymaSense* and projected back onto the drum silencer with minimal latency, thus implementing an audio-visual interactive surface. The sounds were played through a speaker for audio feedback.

Figure 5-20: Prototype interactive rubber surface detecting vibration through a contact microphone. The signal is routed through CymaSense and projected back onto the surface.

5.6 *CymaSense* Version Two

CymaSense version one was an implementation of the requirements analysis derived from literature and from the practitioner interviews. Frequent supervisory meetings and demonstrations of the development stages of the prototype identified a number of design and implementation issues, which are discussed below. These have been addressed within *CymaSense* version two.

5.6.1 Design Issues in Version One

The *CymaSense* prototype incorporates a library of 12 three-dimensional Cymatic shapes (see Figure 5-7). The 3D shapes, modelled using Maya software (Autodesk Inc., 2018), are based on original high resolution images filmed from water-based Cymatics known as the Cymascope (Cymascope.com, 2018a). The 12 models relate to a particular semitone and MIDI note value on the musical scale, and are employed over several octaves, but differentiated by changes in colour lightness. Figure 5-21 demonstrates a comparative range of MIDI note numbers (21 to 108), note names (A0 to C8), and frequencies (27.5Hz to 4186Hz).

MIDI number	Note name	Frequency Hz
21	A0	27.500
22		29.135
23	B0	30.868
24	C1	32.703
25		34.648
26	D1	36.708
27		38.891
28	E1	41.203
29	F1	43.654
30		46.249
31	G1	48.999
32		51.913
33	A1	55.000
34		58.270
35	B1	61.735
36	C2	65.406
37		69.296
38	D2	73.416
39		77.782
40	E2	82.407
41	F2	87.307
42		92.499
43	G2	97.999
44		103.83
45	A2	110.00
46		116.54
47	B2	123.47
48	C3	130.81
49		138.59
50	D3	146.83
51		155.56
52	E3	164.81
53	F3	174.61
54		185.00
55	G3	196.00
56		207.65
57	A3	220.00
58		233.08
59	B3	246.94
60	**C4**	**261.63**
61		277.18
62	D4	293.67
63		311.13
64	E4	329.63
65	F4	349.23
66		369.99
67	G4	392.00
68		415.30
69	**A4**	**440.00**
70		466.16
71	B4	493.88
72	C5	523.25
73		554.37
74	D5	587.33
75		622.25
76	E5	659.26
77	F5	698.46
78		739.99
79	G5	783.99
80		830.61
81	A5	880.00
82		932.33
83	B5	987.77
84	C6	1046.5
85		1108.7
86	D6	1174.7
87		1244.5
88	E6	1318.5
89	F6	1396.9
90		1480.0
91	G6	1568.0
92		1661.2
93	A6	1760.0
94		1864.7
95	B6	1975.5
96	C7	2093.0
97		2217.5
98	D7	2349.3
99		2489.0
100	E7	2637.0
101	F7	2793.0
102		2960.0
103	G7	3136.0
104		3322.4
105	A7	3520.0
106		3729.3
107	B7	3951.1
108	C8	4186.0

Keyboard

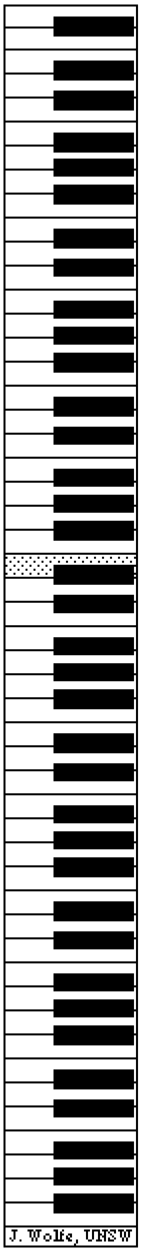


Figure 5-21: Comparison of MIDI note number, note name and frequency (Wolfe, 2011)

The audio-visual mapping of pitch to shape, and timbre to detail of shape, were motivated by the observation of water-based Cymatic visualisation. In order to accurately simulate this within a computerised environment, mathematical calculations involving wave propagation, refraction, and surface reflections within a given environment, would need to be analysed. The current design of the application is concerned with the use of the aesthetics of Cymatics in a therapeutic scenario rather than a mathematically accurate simulation of the propagation of sound waves. Version one's design strengths lie in its ability to visualise pre-modelled shapes based on recognition of audio frequencies in real time, however, this requires a high computer processing overhead. Future development of *CymaSense* aims to identify and implement a suitable algorithm that would provide a more efficient means to simulate Cymatic shapes based on harmonic analysis.

Consideration was given to the representation of a pitch-to-vertical position audio-visual mapping, however, it was decided to implement a central positioning of all shapes for the version one (see 5.4.1). This was due to the potential difficulties in identifying shape detail, due to their movement on the vertical axis. This may be implemented as an option in a future version of *CymaSense*.

Initial system trials with the supervisory team indicated potential issues with the user interface design, as users may have found difficulty in identifying and choosing a colour from the swatches. The interface was initially designed to sit below the Unity output window for ease of access to user controls at any time during its use. However, this design decision forced the colour swatches to be small in size, and potentially confusing to the user as to which colours were on offer. As suggested by Frauenberger *et al.* (2013), in regard to interface design for the autistic, it was decided to create a larger version with limited colour choice for autistic users thus reducing the complexity of the design (Figure 5-22). Additionally, the default colour selector was relabelled *Default Colour Spectrum*, for the purposes of simplification. These have been implemented into version two of *CymaSense*.Incorporating both the interface and the Unity output window within the same screen, was revised to allow the interface to remain available on one screen (for example, a laptop), while the Unity output window would be projected onto another screen (for example, the wall). This would allow users to focus more clearly on the *CymaSense* output, and reduce potential distraction from the interface during play.

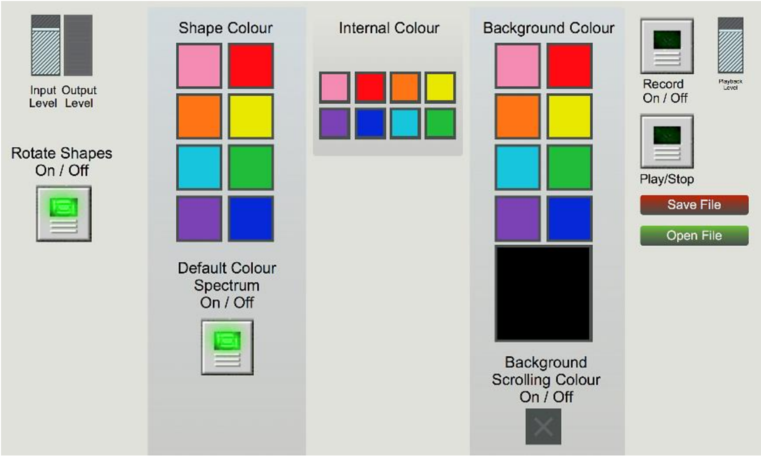


Figure 5-22: The revised *CymaSense* user interface with limited colour choices, larger buttons and reduced options in version two of *CymaSense*

Another issue related to whether audio input should be monophonic or polyphonic, and subsequently how that would affect the visual output and general system efficiency. A monophonic approach was adopted in order to facilitate a more robust system by visualising one shape at a time. A polyphonic approach would allow each Cymatic shape triggered by MIDI input to be visualised simultaneously, thus allowing the layering, and greater visual complexity, of Cymatic shapes. Early tests indicated that user input may be restricted as a result of monophonic MIDI input. The playing of chords, for example, would only visualise the last MIDI note detected by the system, which may not promote intuitive audio-visual feedback. However, it could also be argued that overly complex shapes would seem unintuitive and potentially distracting to musically untrained users. The decision was to enable both polyphonic MIDI input and monophonic microphone input. However, particle animations within Unity are processor intensive, and a two-user version that employed both polyphonic MIDI and monophonic microphone input would be subject to further system testing.

These design issues may have been avoided if an alternative participatory design approach was adopted. The IDEAS (Interface Design Experience for the Autistic Spectrum) method described by Benton *et al.* (2012), may have created a more usable design by facilitating the collaboration of high-functioning autistic participants through testing a series of paper-based prototype screens. A series of sessions mirroring the IDEAS method may have included team building, context setting, generating ideas, design development, design refinement, and evaluation of the experience. Team building would involve therapist-led structured activities assigning roles to each participant to assist in supporting social difficulties. Context setting may involve discussions over participants' previous experience with audio-visual music technology to establish a basis for understanding of the topic. Generating ideas could employ some of the previously used music technology to demonstrate alternative visualisations and prompt participants to use their imaginiation to draw on paper what they would like to see. Design development would then collect the ideas together and present them, while encouraging participants to decide which they preferred and how it may be animated. Prior to the next session, design refinement, a prototyped animation of the groups decisions would be created and presented for further discussion and clarification. The final session would then involve reflection and evaluation of the prototype animation and of the experience as a whole.

5.6.2 Implementation Issues in Version One

CymaSense line-in input utilises a polyphonic approach where multiple MIDI messages are processed and implemented simultaneously. This, however, led to UDP port exhaustion within Unity. This is a problem created within an application that opens and closes too many UDP ports for Windows to process, thus resulting in a four minute time delay, while the system resets (ComputerTechBlog, 2017). This issue occurred when implementing the two-user version, due to the number of C# scripts (relating to each of the Cymatic shapes) opening and closing within a short time period. It was thus decided to reduce the second user option to microphone input only, as it was not possible to accommodate the running of two polyphonic input options simultaneously. A future version aims to have a monophonic option for keyboard in addition to microphone input.

Interactive Surface

Through testing of the initial interactive surface with the supervisory team, feedback indicated that the surface area was too small for group or shared play, and incapable of visualising all potential colours hues because of the black colour of the surface itself. In addition, audio feedback was limited to one chosen sound from the sound module at a time, which restricted playability. This suggested that a larger playing area was required with the ability to trigger a variety of sounds based on the dynamic input of the user. The solution was to construct a bespoke table, based on an interactive table design by Sinclair (2018), who granted permission for reuse of the design. This was incorporated for *CymaSense* version two. The table top, measuring approximately 1.5 metres by 1 metre, incorporates an inset for a semi-transparent Perspex surface to be placed. Four notches were cut to allow available space to place contact microphones on the underside of the surface, for detection of vibration (Figure 5-23). Legs attached to the table top allow access for seating or for wheelchair access.

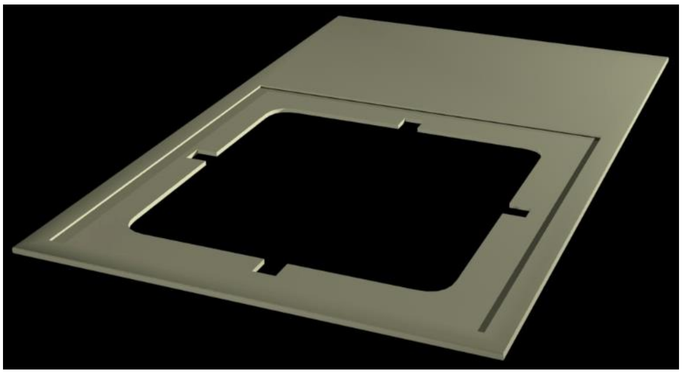


Figure 5-23: A 3D rendering of the interactive table top for *CymaSense* version two, showing inset for the Perspex surface and notches for contact microphones

Sinclair's table was originally designed to pick up vibrations and project 2D visuals on the underside of the Perspex, based on visual output from a video synthesiser (Critter & Guitari, 2018). The video synthesiser visuals were based on manipulation and colouration of audio waveforms (Figure 5-24).

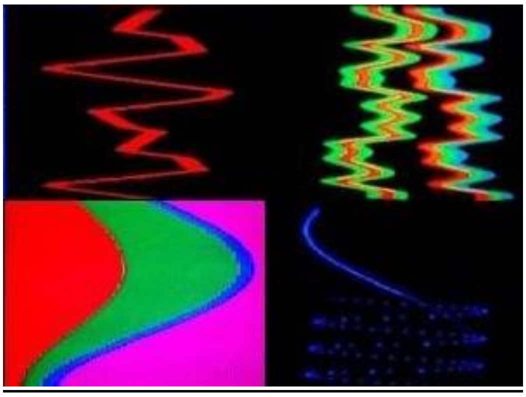


Figure 5-24: Sample visual output from the video synth (CritterGuitari, 2014)

Back projection of Cymatic shapes on to a semi-transparent Perspex surface enables full-colour visualisation of *CymaSense*, and a larger playable surface area for greater accessibility (Figure 5-25). To address the issue of restricted choice of sounds, an iPad application called *Impaktor* is used to generate a variety of percussive synthesised sounds (Apple Inc., 2017a). This allows users to use their hands or beaters to play the surface, resulting in a variety of electronically generated sounds based on their dynamic input. An adapter for an iPad (IK Multimedia US, 2017) was required as an interface between a contact microphone and an iPad. The generated sounds are sent to a small amplifier for audio feedback.

Figure 5-25: The interactive table played using beaters and showing *CymaSense* version two back-projected on the Perspex surface

5.7 Conclusions

In this chapter, the design and implementation of *CymaSense,* an interactive audio-visual application based on the aesthetics of Cymatics, was presented. It was argued that visual references to musical structural, analysis of audio signals, or composition, would not be a suitable approach for autistic users. *CymaSense* was developed with Cymatics as a novel form of visual output due to their aesthetic qualities. It was suggested that pattern recognition of Cymatic shapes may be a useful aid in identification of musical notes as a learning aid for people with autism.

Mapping decisions were made based on literature reviewed and therapist feedback, to link audio to visual features including volume with scale, pitch to shape detail, and timbre to variations in shape detail. User control is provided via a graphical user interface, where choice of particle and shape colour, background colour, and rotation of shape are made available. A default colour spectrum is also made available to the user, while colour brightness is implemented as a means to differentiate repetition of shape use over several octaves. Functions to record, playback and store audio are provided as a means of immediate playback within the session, or to archive client session data. *CymaSense* version one interface was revised to make it more accessible for autistic users by enlarging buttons, and simplifying available choices, in line with recommended design guidelines for the autistic.

CymaSense is designed to analyse input from any acoustic or electronic source with minimal disruption to music session practice, and is processed through the Max programming environment (Cycling ’74, 2018b). Max also acts as the means for the creation of the user interface. Processed audio signals are sent to the Unity games engine which acts as the visualising engine for a library of 12 three-dimensional Cymatic shapes, triggered dependent on the input frequency. Advantages of the system were highlighted, including its ability to visualise any 2D image or 3D mesh. Disadvantages included latency issues, due to excessive load on the CPU when using particle animations.

The application has two modes available – one for single-use, where one set of Cymatics shapes are projected based on either microphone or MIDI input; the other, a two-user version where two sets of Cymatic shapes are projected side-by-side, designed for therapist and client (Figure 5-26).

Figure 5-26: A therapist and client use microphones for the two-user version of CymaSense with two sets of shapes being projected on the wall

An interactive surface design was implemented as an alternative means to use the *CymaSense* application. The version one design was revised to allow greater accessibility, sharing of a playable surface, and to allow greater visual feedback. This was accomplished through the creation of a bespoke interactive table design, implemented in the final iteration of the prototype, *CymaSense* version two.

6 End-User Testing of *CymaSense* Audio to Visual Mappings

Chapter 5 detailed the design of the initial prototype and the decisions made determining the audio to visual mappings for *CymaSense*, derived from reviewed literature and interviews with therapeutic music practitioners. However, no contributions had yet been made by autistic clients concerning the design of the application. Makhaeva *et al.* (2016), stated that by promoting meaningful participation of autistic participants, their creative potential can be allowed to unfold. To facilitate a limited participatory design, a survey was designed to gather feedback from high functioning autistic (HFA) and neurotypical (NT) end-users, based on version two of the prototype. It was important that NT therapeutic music practitioners could facilitate appropriate music making decisions with autistic clients in mind, as well as fully understand and contribute to the design of the related visual output of *CymaSense*.For autistic participants, it has been noted in literature that the condition may affect sensory awareness and cognitive processing (DePape *et al.*, 2012; The National Autistic Society, 2016; Morris and Picard, 2009). Ludlow *et al.* (2014) hypothesised that colour obsession in autism may be related to hyposensitivity and this may have an effect on perceived audio-visual correspondences. Additionally, researchers identified that synesthesia was diagnosed in almost three times as many participants with autism as NT participants (Simon Baron-Cohen *et al*., 2013). Subsequently, there may be unpredictable multimodal effects, dependent on particular audio or visual attributes presented to participants. A comparison of experiences between the two groups would aid in highlighting the strengths of a shared understanding of the audio-visual mapping, and potential limitations of the design.

As discussed in chapter 3, the manner in which musically-trained individuals visualise music may be influenced by their learning experiences. For example, musical notation provides a linear structure that associates melody and rhythm with vertical height and horizontal division of physical space (Honing, 2001). Music producers and hobbyists, familiar with contemporary production software like GarageBand (Apple Inc., 2018) or Pro Tools (Avid, 2017), may associate amplitude and timbre with waveforms (see Figure 3-38). Tan and Kelly (2004) have shown that musically trained individuals tended to visualise elements of intra-musical properties, like musical themes, repetition, and changes in pitch (Figure 3-6). Non-musically trained participants visualised external sensory and emotive factors as metaphor, through fleeting images or the creation of stories (Figure 3-7). Data collected from musically trained and non-musically trained participants would be correlated with the survey results to determine its level of influence in the degree of perceived correspondence of the audio-visual mappings.

6.1 Hypotheses

Four primary research questions were investigated:

> Q1: Will the perceived audio-visual correspondences of participants differ from the currently designed mappings?
>
> H1: Respondents will perceive that: increasing and decreasing changes in amplitude will correspond to increasing and decreasing changes in visual scale; the 12 notes of the musical scale will correspond to the 12 individual Cymatic shapes; increasing changes in pitch will correspond to increasing colour lightness; and changes in timbre of the same note value, will correspond to changes in detail of the same Cymatic shape.
>
> Q2: Which of the designed audio-visual correspondences are perceived as being the most effective?
>
> H2: Volume to scale, and pitch to colour lightness, will return the highest matched responses; pitch to shape and colour, and timbre to blend shape, could yield conflicting results.
>
> Q3: Will the degree of perceived correspondence of the audio-visual association differ between the neurotypical and high-functioning autistic groups?

H3: Differences in perception, due to a wide range of altered neurological conditions for high-functioning autistic participants, could yield conflicting results for audio-visual mappings.

Q4: Will the degree of perceived correspondence of the audio-visual association differ between musically trained and non-musically trained groups?

H4: Participants with a musical background will provide a greater number of answers that match the researcher's design, due to a higher degree of previous audio-visual associations, compared to non-musical participants.

6.2 Method

High functioning autistic and neurotypical participants were asked to participate in an audio-visual survey to assess the effectiveness of version two of the *CymaSense* prototype. Both groups were asked to play with the application for a minimum of five minutes using a MIDI keyboard, sound module and laptop, prior to completion of a series of video-clip based questions. Participants were given a brief demonstration of the prototype (see 6.2.4), but were not provided with details concerning the audio-visual mapping. The survey was designed to evaluate the effectiveness of the audio to visual mappings within the context of playing the prototype for a period of time. An understanding of the mapping of the application, following participants' use, would then be tested. It was anticipated that the results would aid in the clarification of the design of *CymaSense* before testing in an extended study within a therapeutic environment (Chapter 7).

6.2.1 Participants

The survey was run with both neurotypical (NT) and high functioning participants on the autism spectrum (HFA). It was decided only to invite HFA end-users to participate, rather than lower functioning autistic end-users, as the tasks and time taken to participate within the survey may have been considered too stressful. As noted in section 2.1, challenges with autism include problems in communication, social interaction, and issues relating to hypersensitivity or hyposensitivity. Schuler *et al.* (1997) recognise people with ASC can perceive their environment as chaotic and confusing, and therefore require a level of routine and predictability of interactions, and of their surroundings. Low functioning autistic participants would require a greater level of assistance and a more familiar environment in which to run the survey. This would raise the need for ethical approval due to considerations for their well-being. At this stage of development, it was unknown as to the level of functioning of potential users of the application. It has to be noted that by only employing HFA participants, there may be limited suitability in providing results that would inform the optimium design for participants on the lower end of the spectrum. However, as an addition to knowledge in the field, this could also be of interest in a wider context regarding future studies.

The survey was organised within the University, within an acoustically controlled environment, notifying participants beforehand what was involved, of the equipment set-up, and of its location. This was intended to minimise any potential stress or discomfort involved within an unfamiliar environment. Participants were invited to participate through email, posters, or personal invitation at a drop-in centre for HFA adults in Edinburgh (Autism Initiatives UK, 2017). In total, 47 participants volunteered for the survey. Thirty participants were neurotypical (NT) while the remaining 17 indicated that they had been diagnosed as high functioning autistic (HFA). Participants were not asked about impairments prior to their involvement in the survey. During the experiment two NT participants reported having hearing impairments, with one NT and one HFA participant disclosing a form of visual impairment. One participant from the neurotypical group reported a colour blindness visual impairment, while one of the autistic participants reported having Iren syndrome, a perceptual processing disorder. Data from both participants were discarded due to their direct relationship to the perception of the mappings presented. Seventeen NT participants and nine HFA participants had a musical background, either through playing an instrument or through formal training. Table 6-1 provides an overview, with further details available within the results section (6.3).

Attribute	NT	HF Autistic
Total participants	30	17
Gender	19 male, 11 female	16 male, 1 female
Age Range	18 - 64 years	18 - 54 years
No. of Nationalities	7	3
Impairments	2 hearing, 1 visual	1 visual
Musical Background	57%	53%
Non-musical background	43%	47%

Table 6-1: Mapping Survey Demographic Data

6.2.2 Materials

The survey was run within the Auralisation Suite in Edinburgh Napier Merchiston Campus. An Auralisation suite is an acoustically controlled environment suitable for running listening tests. The following equipment was utilised: an Apple MacBook Pro laptop (Apple Inc, 2018), an audio interface (Focusrite, 2018), a MIDI keyboard, a sound module (Roland Corporation, 2018) and fully enclosed headphones (Beyerdynamic, 2018). The hardware was placed on a desk with an adjustable chair for participants (see Figure 6-1). Participants were presented with a printed participant information sheet detailing the research background and what the study involved (Appendix D – Mapping Survey Information Sheet for Potential Participants). The researcher was seated on a chair behind participants to be able to assist without visually distracting anyone.

Figure 6-1: Mapping Survey Equipment Set-Up

6.2.3 Design

To test the effectiveness of the AV mapping, participants were presented with a series of sounds, and for each sound, with three videos. Out of the three videos, one had been created with *CymaSense* (target) using the associated sounds, the other two were not (distractors). The rationale for the choice of sounds and distractors is presented in the next section. For each sound and associated videos, participants were asked to choose which video they thought matched the sound best. The mappings were broken down into audio and visual attributes as indicated in Table 6-2 below. Results were based on the level of agreement of participants with the designed audio-visual mappings. The question order was randomised.

Q	Audio Attribute	Audio Duration	Notes Played	Visual Attribute	Three Possible Visual Responses
1	Static Volume Level, 50 dBC	2 secs	1	Scale (Static)	Same shape with small, mid and large, approx. 20% (target), 50%, 80% of screen size (Figure 5-6)
2	Static Volume Level, 66 dBC	2 secs	1	Scale (Static)	Same shape with small, mid and large, approx. 20%, 50% (target), 80% of screen size
3	Static Volume Level, 83 dBC	2 secs	1	Scale (Static)	Same shape with small, mid and large, approx. 20%, 50%, 80% (target) of screen size
4	Fast Volume Attack Level: 83 dBC after 0s	3 secs	1	Scale (Dynamic)	Same shape scale 0-80% of screen size after 0s (target), 0.8s, and 1.5s
5	Mid Volume Attack Level: 83 dBC after 0.8s	3 secs	1	Scale (Dynamic)	Same shape scale 0-80% of screen size after 0s, 0.8s (target), and 1.5s
6	Slow Volume Attack Level: 83 dBC after 1.5s	3 secs	1	Scale (Dynamic)	Same shape scale 0-80% of screen size after 0s, 0.8s, and 1.5s (target)
7	Fast Volume Decay Level 83 to 0 dBC	1 secs	1	Scale (Dynamic)	Same shape scale 80-0% of screen size after 1s (target), 2s and 4s
8	Mid Volume Decay Level 83 to 0 dBC	2 sec	1	Scale (Dynamic)	Same shape scale 80-0% of screen size after 1s, 2s (target) and 4s
9	Slow Volume Decay Level 83 to 0 dBC	4 sec	1	Scale (Dynamic)	Same shape scale 80-0% of screen size after 1s, 2s and 4s (target)
10	Static Low Pitch (note C3)	4 sec	1	Lightness (Static)	Same shape with for low (33%) (target), mid (50%) and high lightness (66%) values
11	Static Mid Pitch (note C4)	4 sec	1	Lightness (Static)	Same shape with for low (33%), mid (50%) (target) and high lightness (66%) values
12	Static High Pitch (note C5)	4 sec	1	Lightness (Static)	Same shape with for low (33%), mid (50%) and high lightness (66%) (target) values
13	Changing Pitch (Ascending notes C3, D3 and G3)	8 sec	3	Shape and Colour	**1**: colour, shape and lightness (target) **2**: mismatched colour, mismatched shapes, mismatched lightness; **3**: matched shape, mismatched colour, mismatched lightness
14	Static Dark Timbre	2 sec	1	Blend shape (Static)	Low (target), mid and high blend shapes (see Figure 6-4)
15	Static Mid Timbre	2 sec	1	Blend shape (Static)	Low, mid (target) and high blend shapes (see Figure 6-4)
16	Static Bright Timbre	2 sec	1	Blend shape (Static)	Low, mid and high (target) blend shapes (see Figure 6-4)
17	Dynamic Timbre (spectral glide audio effect)	3 secs	1	Blend shape (Dynamic)	**1**: increasing and decreasing scale 30-100-30%; **2**: increasing and decreasing lightness values 17-83-17%; **3**: changing detail of blend shape and returning to original, (target)

Table 6-2: Audio Visual Mappings for Survey Video Clips

Literature on mapping amplitude to scale was reviewed in section 3.1, where loudness was mostly represented with larger scale, by size in drawings, and by various mapping strategies. These included gestures such as height, size and muscular energy (Smith and Sera, 1992; Walker, 1987; Küssner, 2014). This was determined as the basis for representation of levels of volume in *CymaSense* in section 5.4.1.

The UK workplace safety requirements for an eight hour working day set the maximum decibel (dB) levels at 85 dBC (Bennett, 2006). The ambient sound pressure levels within the Auralisation Suite were approximately 43 dBC. Participants were wearing headphones with a 16 dB level of acoustic isolation. The subsequent ambient sound pressure levels were thus 29 dBC. The volume levels of questions 1, 2, and 3, were set at approximately 50 dBC, 66 dBC, and 83 dBC for low-volume, mid-volume and high-volume sounds respectively, where high sounds would always fall at least 2 dBC below the maximum. Questions 1-3 tested static volume levels (low, mid and high) against three sizes of the same Cymatic shape. For example, Question 1 played the same low-volume two-second sound clip, which was presented to the participant within three separate video clips; one large in scale, the second medium in scale, and the third small in scale (see Figure 6-2). The participant then had to choose which they considered the best audio-visual match.

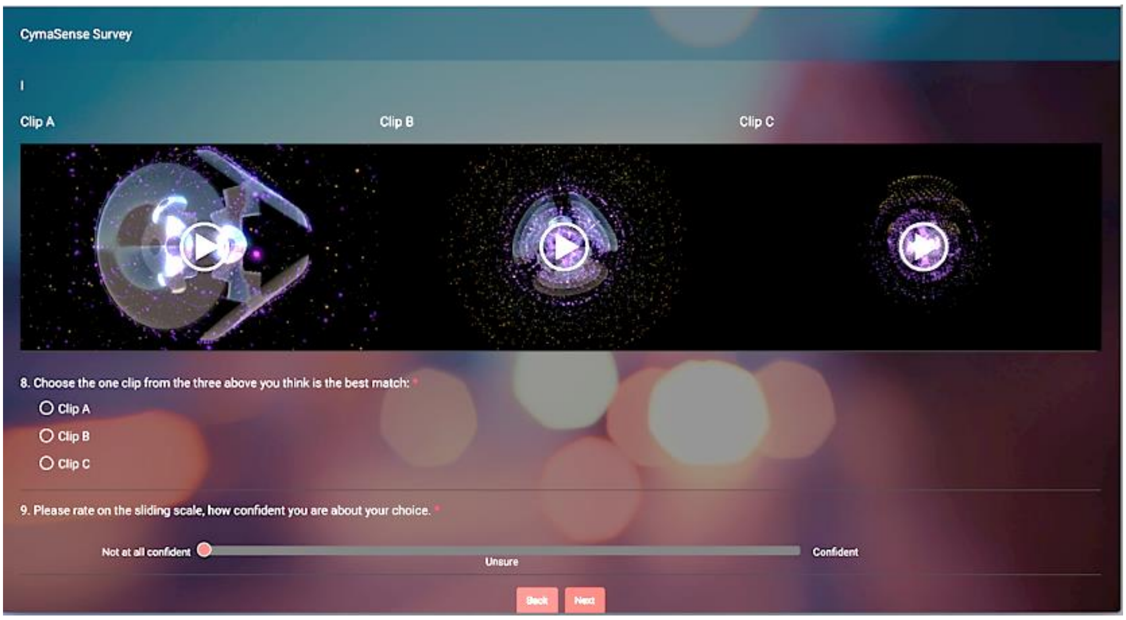


Figure 6-2: *CymaSense* mapping survey screenshot

In section 3.4 on temporary representation of audio signals, it was recognised that peak programme meters (PPM) display variations in the amplitude of audio signals by visually indicating increasing or decreasing dB levels. Similarly, waveforms (see Figure 3-38) trace sound pressure variations over time and are seen as graphs of amplitude, in the vertical axis, over time in the horizontal axis. Attack, decay, sustain and release, (ADSR) is an amplitude envelope used to shape some synthesised sounds (Figure 6-3).

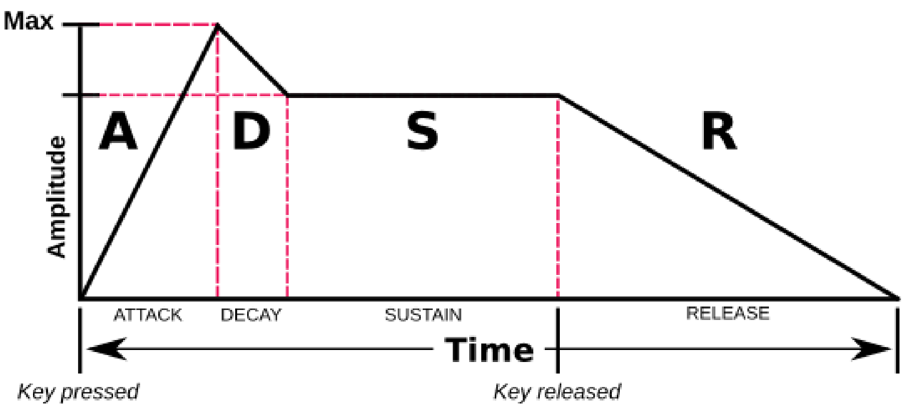


Figure 6-3: An ADSR envelope, which stands for attack, decay, sustain and release, is an amplitude envelope used to shape some synthesized sounds (Libre Music Production, 2018)

The volume attack levels refer to the initial amplitude of an audio signal, seen in Figure 6-3 as the time it takes for ‘A’ to reach the maximum level, which would be seen as a peak on a PPM. Audio decay refers to the tapering of amplitude over time, seen as ‘D’ in Figure 6-3, and can be seen as a falling PPM level. Sustain level refers to the volume level that the sound sustains at as long as the synthesiser is triggered. Release time describes how long it takes for the volume to fade once the synthesiser has been released. Representations of volume attack and decay levels were tested by the scaling up and down of the Cymatic shapes, corresponding to the changing levels in volume. For example, a fast attack level can be described as an immediately loud sound with a short attack time that gradually fades (starting at 83 dBC and fading to 50 dBC); a mid-attack level would describe a sound with a longer attack time where the peak of the volume would be midway between the start and end of the audio clip (starting at 50 dBC, building to 83 dBC in the middle, and falling to 50 dBC at the end); while a slow-attack sound gradually builds from an initial low volume to becoming louder at the end (starting at 50 dBC and building to 83 dBC).

Questions 4, 5 and 6 tested the audio volume attack levels (fast, mid and slow attack levels) against three versions of the same Cymatic shape displaying differing changes in time taken to reach maximum size. In a similar manner as described above, questions 7, 8 and 9 tested volume decay levels for fast, mid and slow decays against three versions of the same Cymatic shape displaying differing changes in size diminishment over time (see Figure 5-6 for a comparison of audio levels against scale of Cymatic shape).

In Chapter 3, a study by Kaya and Epps (2004) on colour-emotion associations revealed that principle hues including red, yellow, green, blue and purple, comprised the highest number of postive emotional responses at approximately 80%. For intermediate hues, the majority of emotional reactions (64.5%) were positive. For achromatic colours, white returned a positive response at 61.2% compared with 19.4% and 7.1% for black and gray respectively. Additionally, interview findings from practitioners in Chapter 4 highlighted the need to facilitate an emotional experience for their clients through colour choice. It was determined that principal hues be employed as a basis for the colour design of the application, and colour lightness be implemented within *CymaSense* to visually differentiate between the same notes over several octaves (refer to section 5.5 for details of implementation). Subsequently, Questions 10, 11, and 12 tested the combinations of low, mid, and high audio pitches, against low, mid, and high levels of colour lightness. Higher pitches of the same note created lighter colours the higher up the musical scale they are played. For example, C3 would be a dark shade of red, C4 would be a lighter shade of red than C3, and C5 would be the lightest of all three versions (Figure 6-4). However, the system does function from C1 up to and including C7. The levels used for low, mid and high lightness, were 33%, 50% and 66% respectively (refer to Table 5-5).

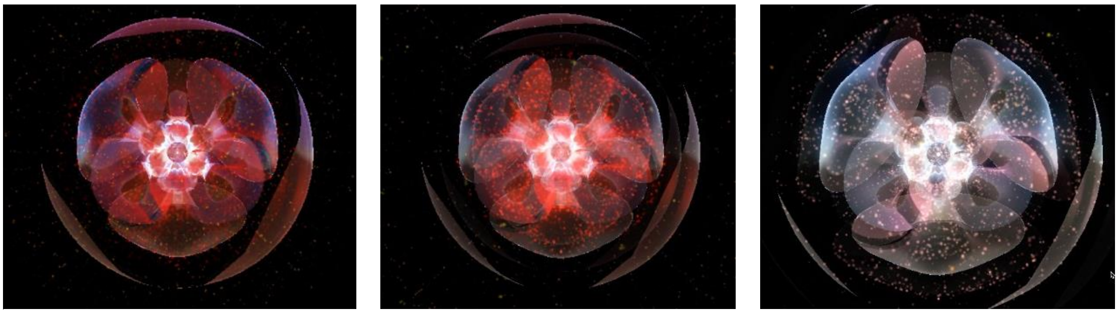


Figure 6-4: Notes C3, C4 and C5 (left to right) showing differences in colour lightness

CymaSense was designed to allow colour selection by the end-user, in which a chosen colour would be applied to all Cymatic shapes, regardless of their pitch, but differentiated by changes in colour lightness. Ludlow *et al.* (2014) hypothesised that colour obsession in autism may be related to hyposensitivity, while colour phobias may be related to hypersensitivity, in the affected regions of colour space (section 2.1.4). End-user colour choice could potentially minimise obsessive behaviours or discomfort for ASC participants with hyposensitive or hypersensitivity issues. However, a default colour spectrum was also implemented to allow differentiation of pitch through colour (section 5.5). The default colour scheme (red, orange, yellow, green yellow, green, green cyan, cyan, blue cyan, blue, blue magenta, magenta, and red magenta) was used within the survey. This was used as a basis for evaluation of changes in colour that corresponded to changes in pitch (see Figure 5-13).

Cymatics was identified in section 3.6 as a way of engaging people through its novelty. Interviews with practitioners further indicated an interest in the symmetry and organic nature of Cymatics as a form of visualisation in Chapter 4. Practitioners commented that the use of organic and natural geometry was a source of inspiration for their clients. It was noted in Chapter 5 that autism researchers identified a common interest in geometric patterns by people with ASC, thus influencing the decision to use Cymatics as a basis for a new visualisation paradigm. It was identified in section 5.4 that efficient representation of all notes in a western scale (as commonly used by therapeutic music practitioners), required the creation of 12 Cymatic shapes that represented the 12 semitones of a musical octave (see Figure 5-7).

Question 13 tested audio pitch against cymatic shape and colour by using different combinations of colour, shape and lightness to test participants' colour and shape association. The same three-note ascending audio sequence was used for all three video clips. One clip presented the chosen shape, colour, and colour lightness, based on the design decisions outlined in Chapter 5 for *CymaSense* version two. The other clips displayed a combination of alternative shape, colour, and colour lightness.

Questions 14, 15 and 16 tested audio timbre against the alternative low, mid and high blend shapes that are triggered by static dark, mid and bright audio tonal qualities. Research by Adeli *et al.* (2014) highlighted the association between hard (or bright) sounds being perceived as more pointed, and dark (or softer) sounds being perceived as more rounded (see section 3.1). This led to the implementation of blend shapes within *CymaSense*, which was detailed in section 5.5. Blend shapes allow animation of a 3D mesh by morphing the vertices' coordinates of the original shape to its remodelled version (Autodesk Inc., 2018). In this case, low blend shapes represented a darker tonal quality with high blend shapes representing brighter tonal qualities (see Figure 6-5). Finally, question 17 tested the blend shapes against dynamically changing audio tonal qualities. A sweeping bandpass filter effect was used as a means to alter the audio envelope over a period of three seconds, increasing and decreasing the amplitude of different frequencies. A wide-band filter began at the low end of the frequency spectrum around 30 Hz at the start of the sound, swept through to the high end of the spectrum around 5 kHz at 1.5 seconds, and then returned to its starting point at 3 seconds. This effect alters the harmonic relationship between audible frequencies, which in turn changes the perceived timbre of the sound. This process could be described as spectral glide effect. The target video clip displayed the appropriate change from a darker tone to a brighter tone and back again, via blend shapes (Figure 6-5). The remaining two distractors displayed increasing and decreasing changes in size: starting at 30% of the screen size, expanding to 100%, then returning to 30%; and increasing and decreasing changes in colour lightness: beginning with 17% lightness before growing to 83% then returning to 17%.

The questions were categorised into three audio-visual mapping groups (Table 6-2). Questions 1 to 9 were composed of the volume to scale questions, questions 10 to 12 included pitch to colour lightness associations. Question 13 referred to pitch to shape and colour correspondences, whilst questions 14 to 17 related to the timbre to blend shape associations.

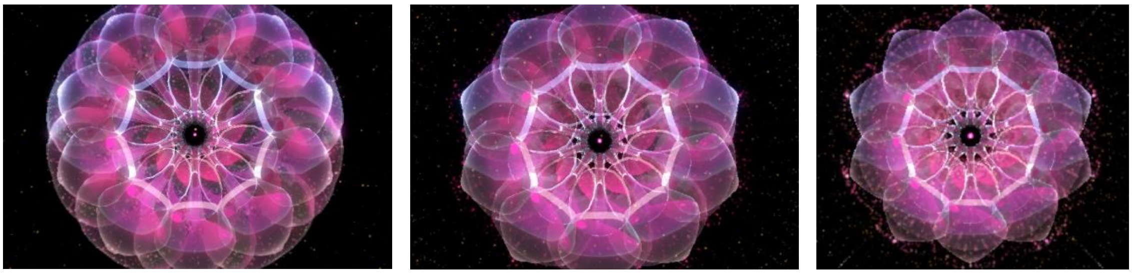


Figure 6-5: A comparison of the tonal differences of the same note value - a low 'darker' tone (left), a mid-tone (centre), and a higher 'brighter' tone (right)

On completion of the video clip survey questions, participants were invited to add any additional comments. This question was used as a basis for any resulting qualitative feedback (6.3.5).

The audio-visual mapping survey was developed using Survey Gizmo (2017) allowing side-by-side formatting of video clips and randomisation of pages, which should reduce potential bias of predictability of structure within the results (Schulz & Grimes, 2002). The survey was designed to include feedback from both NT and HFA end-users. Appropriate ethical approval forms, participant information sheets and consent forms were developed in keeping with Edinburgh Napier University guidelines for working with vulnerable groups (see Appendices D, E, F and G).

6.2.4 Procedure

Prior to the survey, an email was sent to all research students and staff at Edinburgh Napier University, informing them about the study and inviting participation. Following a brief verbal description of the research, which reiterated the printed participant information (Appendix D – Mapping Survey Information Sheet for Potential Participants), participants were given a brief demonstration and invited to test the prototype themselves. The demonstration involved the researcher pressing alternative keyboard keys for a few seconds, using varying amounts of pressure, which resulted in the animated scaling of corresponding shapes on screen. Participants were shown how to alter the note range of the keyboard to play lower or higher notes and select a few random sounds from the Roland sound module.

The testing process involved participants playing on the MIDI keyboard and selecting a variety of sounds from the sound module for a minimum period of five minutes. Participants were asked not to adjust the volume of the sound module or the laptop, unless they found the volume levels uncomfortable. All participants were happy with the volume levels. Both the sound module and the video clip audio were set at an average level of 83 dBC, which is 2 dB below the UK workplace safety requirements for an eight-hour working day. The resultant images were displayed on the 13-inch laptop screen, whilst participants could hear the associated sounds via the fully enclosed headphones. Following the testing period, the researcher launched the survey on the laptop to allow the participants to complete the questions. Questions were asked relating to gender, age, nationality, existing known aural or visual impairments, musical background, and experience with audio equipment (Appendix F – Mapping Survey - *CymaSense* Survey Questions).

Participants then proceeded to play the randomised audio-visual clips and select which clip they thought to be the best match for each question. After each selection, participants indicated the level of confidence of their choices by controlling an on-screen slider (a numeric sale from 0 to 100, where 100 represented complete confidence). Collins (2003) states that confidence rating is a method that aims to provide results that are valid, reliable, unbiased and complete. The chosen method was also used in an audio-visual mapping survey by Tsiros and Leplâtre (2017), where participants were asked to rate their level of assuredness in matching a correct source image to its associated audio clip.

In the present research, participants were presented with 17 sets of three audio-visual clips for the survey. The order in which the stimuli were presented to each participant was randomised to minimise selection bias (Suresh, 2011). Participants could play back the clips as many times as they wished. The tasks took approximately 30 minutes to complete. The researcher was available at all times to provide any assistance needed, which occurred on two occasions when participants requested assistance in selecting the sounds from the module. Some participants provided qualitative feedback via a comment box in the final survey question. The comments are detailed in section 6.3.5. Upon completion of the survey, a brief discussion concerning participants' use of the prototype, and any issues concerning the survey questions, provided informal feedback. Any informal feedback was not recorded.

6.3 Results

The survey data were analysed and presented in relation to each of the hypotheses. The survey results confirmed H1, that out of the potential permutations of volume to scale, pitch to Cymatic shape, pitch to colour lightness, and timbre to detail of shape, the results would show the highest number of matches with the designed *CymaSense* mappings (6.3.1). The second research question was related to the degree of difference of perceived audio-visual correspondences between the designed audio-visual mapping groups. The results have shown a high percentage of matches for volume to scale, pitch to colour lightness, and pitch to shape and colour. Timbre to blend shape returned the lowest pecentage of matches (6.3.2). The third research question was concerned with the degree of perceived differences between the NT and HFA groups, in relation to audio-visual association. The results have shown that there were no significant differences (6.3.3). Hypothesis 4 stated that participants with a musical background would answer a greater number of questions matching the designed mappings, due to a higher degree of previous audio-visual associations, compared to non-musical participants. This was rejected, as results indicated an improvement in the scores of participants with a non-musical background (6.3.4).

6.3.1 Research Question 1

The first research question addressed whether the perceived audio-visual correspondences of participants would differ from the currently designed mappings. It was hypothesised that increasing and decreasing changes in amplitude would correspond to increasing and decreasing changes in visual scale; the 12 notes of the musical scale would correspond to the 12 individual Cymatic shapes; increasing changes in pitch would correspond to increasing colour lightness; and changes in timbre of the same note value, would correspond to changes in detail of the same Cymatic shapes.. An overview of percentages of matched answers for high functioning autistic participants (HFA), neurotypical participants (NT), and their combined mean score percentages are presented in Figure 6-6. The maximum matched response from both groups was 100% for questions 5 and 6 related to volume attack levels. The minimum correspondences were considerably lower, at 38% for the HFA group for questions 16, and 45% for the NT group for question 17. Both questions were related to changes in timbre. For the combined groups, the mean response of percentages for all 17 questions was 81%. The majority of the combined results fell between 67% and 100% for questions 1 to 15, with two questions (16 and 17) falling below this at 51%.

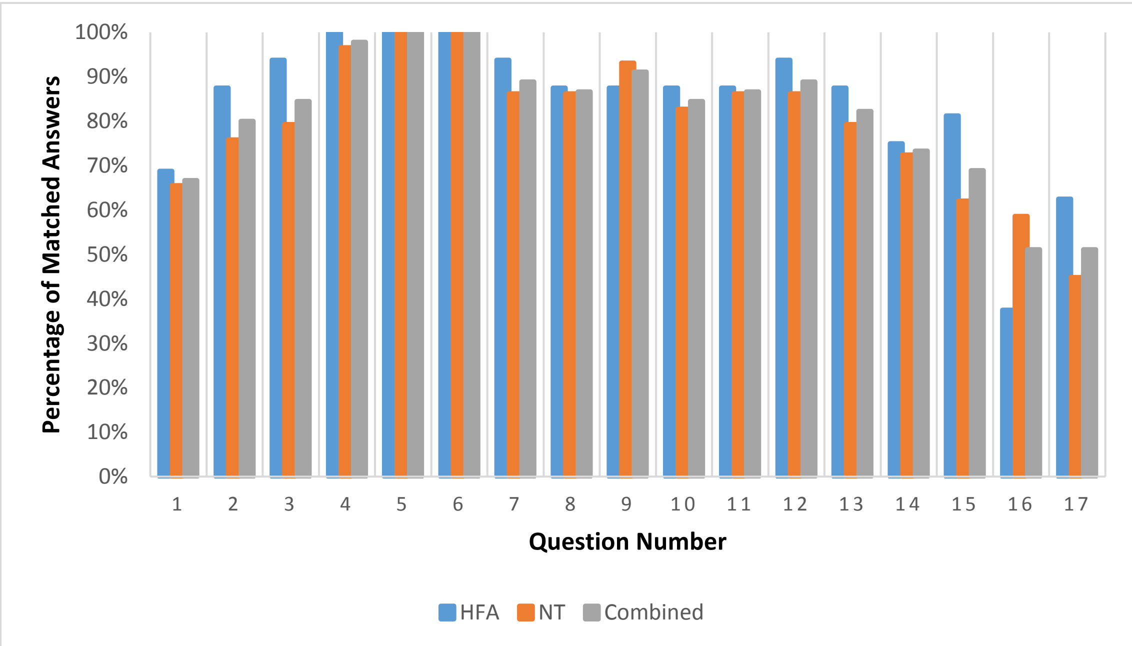


Figure 6-6: Percentages of matched answers for each question for HFA, NT and combined

One-sided binomial tests have been shown to be effective for statistical results in small sample sizes (Statistics Solutions, 2018; Influentialpoints.com, 2015). A binomial test indicated that the proportion of matched answers were higher than the expected value of .333 for questions 1 to 15 inclusive, for both HFA and NT participant groups. The proportion of matched answers for HFA participants in question 16 of .375 were not significant when compared to the expected value of .333, p = .452 (1-tailed). The binomial test indicated that the proportion of matched answers for NT participants in question 17 of .448 were not significant compared to the expected value of .333, p = .132 (1-tailed). All remaining questions indicated significant results. The p-values for all questions can be seen in Table 6-3.

Question	HFA Binomial p-value	NT Binomial p-value
1	0.004	0.000
2	0.000	0.000
3	0.000	0.000
4	0.000	0.000
5	0.000	0.000
6	0.000	0.000
7	0.000	0.000
8	0.000	0.000
9	0.000	0.000
10	0.000	0.000
11	0.000	0.000
12	0.000	0.000
13	0.000	0.000
14	0.000	0.000
15	0.000	0.001
16	**0.452**	0.004
17	0.016	**0.132**

Table 6-3: Binomial p-values for each question for HFA and NT participants. Non-significant results are **bold** and highlighted in **red.**

6.3.2 Research Question 2

Results were grouped for analysis in accordance with the Hypothesis 2, which suggested that volume to scale, and pitch to colour lightness, would return the highest matched responses. Additionally, pitch to shape and colour, and timbre to blend shape could yield conflicting results (see 6.1). The mean matched answers per question group show that volume to scale mapping questions have the highest percentage of matched responses at 90% for combined participant groups. Pitch to colour lightness returned a mean percentage of 87%, while pitch to Cymatic shape and colour demonstrated an 81% mean matched response. The lowest group of matched responses belongs to the timbre to blend shape mapping, with a mean return of 62%. An overview for each participant group and their combined mean percentages are presented in Figure 6-7. The majority of the matched responses for combined groups fell between 81% and

90% for the volume to scale, pitch to colour lightness, and pitch to shape and colour mapping questions. The timbre to shape blend questions fell below this at a mean of 62%. The maximum difference in results between HFA and NT groups in each of the questions groups was 5%.

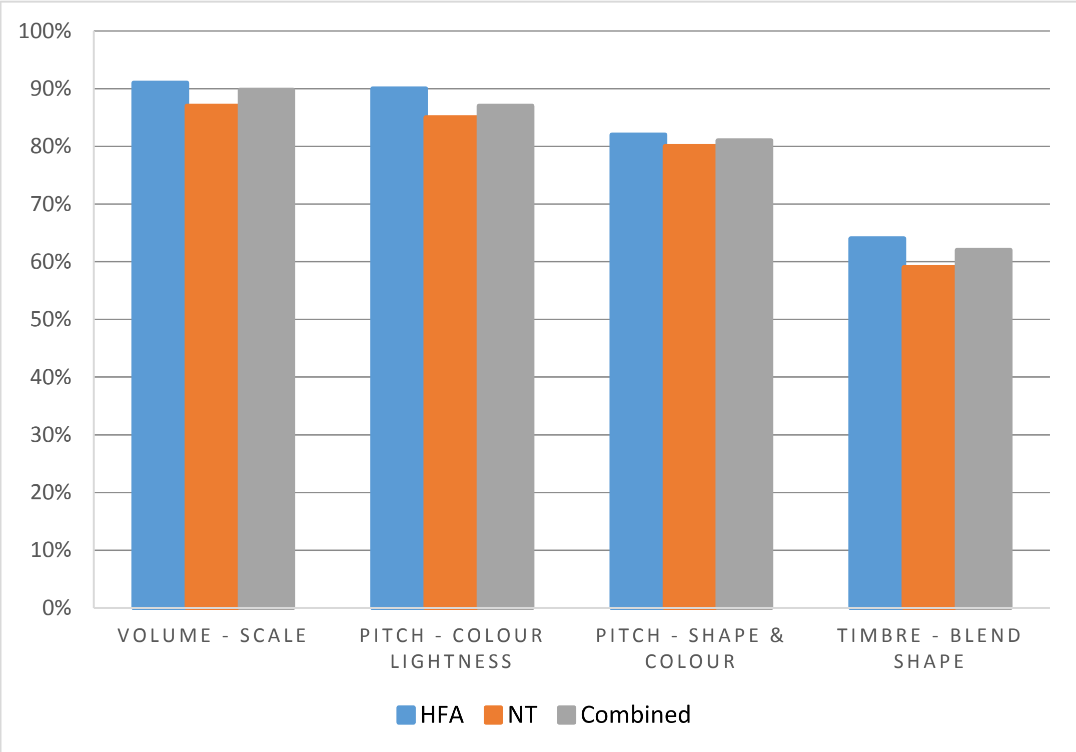


Figure 6-7: Mean matched answers per question group

Confidence ratings per question group (see Figure 6.8) indicated that volume to scale mapping had the highest combined mean at 85.52, followed by pitch to Cymatic shape and colour at a mean of 75.96. Pitch to colour lightness returned a mean of 73.67 with timbre to blend shape returning the lowest confidence rating mean of 65.17. An overview of the mean confidence ratings can be seen in Figure 6-8. The average differences between HFA and NT confidence levels were approximately 9.16. The maximum difference between groups was in the pitch to colour and shape category at 14.57, while the minimum difference was 0.92 in the pitch to blend shape category.

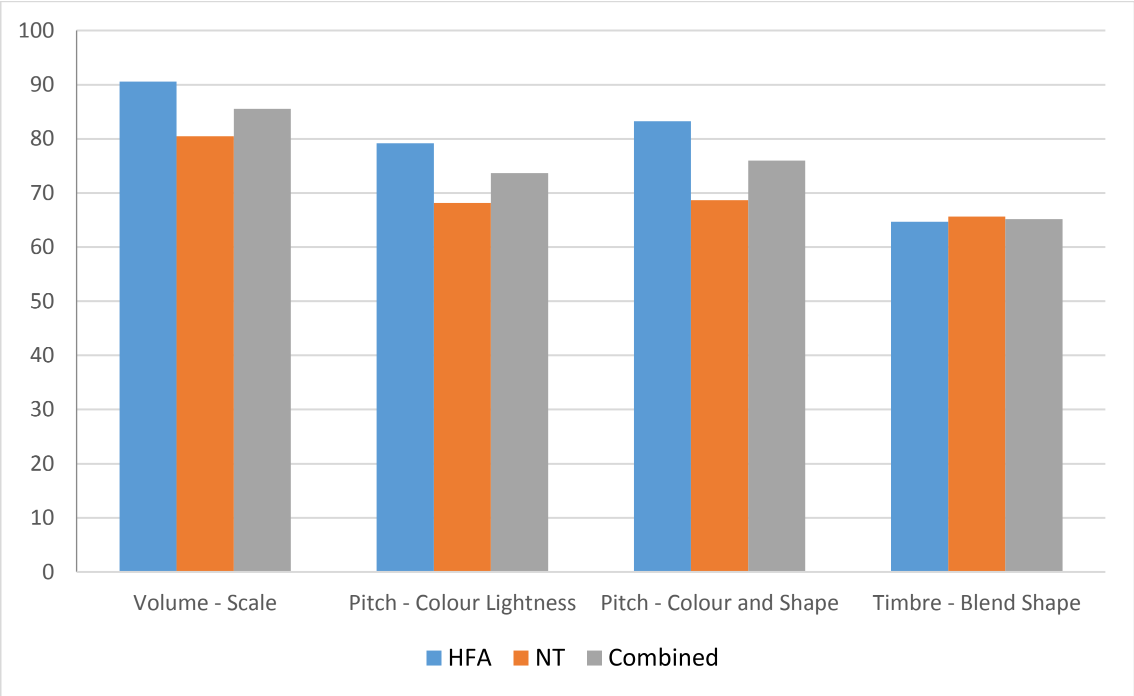


Figure 6-8: Confidence ratings per group

6.3.3 Research Question 3

Research Question 3 addressed whether the degree of perceived correspondence of the audio-visual association differs between the NT and high functioning autistic groups. Pearson chi-square was used to explore if there were differences between the choices made by high functioning autistic (HFA) and neurotypical (NT) participants for each question. All results were shown to be non-significant which indicates no significant differences between the two participant groups. Table 6-4 provides an overview of the results. No measures of association were computed for the cross-tabulation in questions 5 and 6, as the calculations were constant and could be considered non-significant.

Question No:	Pearson Chi-Square	p-value
1	0.048	0.826
2	0.873	0.350
3	1.637	0.201
4	0.564	0.453
5	N/A	N/A
6	N/A	N/A
7	0.594	0.441
8	0.015	0.903
9	0.400	0.527
10	0.176	0.674
11	0.015	0.903
12	0.594	0.441
13	0.473	0.492
14	0.035	0.851
15	1.770	0.183
16	1.841	0.175
17	1.289	0.256

Table 6-4: Pearson chi-square and p-values for comparison of HFA and NT participant groups for each question

When the confidence rating for the two participant groups were compared, the autistic group showed a higher overall mean of 81.99 compared to the neurotypical group at a mean of 74.06. Independent sample t-test was used to compare the difference between HFA and NT participants' groups for their mean confidence rating scores. The results indicated a significant difference [$t(41.482) = 2.298$; $p = 0.027$] in favour of HFA participants mean confidence levels (mean confidence rating = 81.99; SD = 7.00) against NT confidence levels (mean confidence rating = 74.06; SD = 16.01).

6.3.4 Research Question 4

Research Question 4 addressed whether the degree of perceived correspondence of the audio-visual association differed between musically trained and non-musically trained groups. Results indicated an improvement in the scores of participants with a non-musical background, at a combined mean of 88%, compared to participants with a musical background who resulted in a combined mean of 78%. This does not support the hypothesis that musically trained participants would have scored higher due to previous audio-visual associations. Details can be seen in Table 6-5.

	Group	Mean Score	Mean %
Musical Background	HFA	13.11	77
	NT	13.31	78
	Combined	13.21	78
Non-Musical Background	HFA	15.86	93
	NT	13.92	82
	Combined	14.89	88

Table 6-5: Comparison of overall question scores and between participants with a musical and non-musical background

Independent sample t-tests were used to compare the difference between musical and non-musical background mean scores for HFA and NT participant groups. The results for both groups showed no significant difference: the NT group [t(27) = -0.613; p = 0.545] ; the HFA group [t(14) = -1.879; p = 0.81].

The confidence ratings of each group from a musical background perspective show that NT participants with a non-musical background had a higher mean score of 77.14 compared to NT participants with a musical background who had a mean score of 70.96. HFA participants with a non-musical background had a minor gain in mean scores over the musical background HFA participants with scores of 82.27 and 80.85 respectively. Combined mean confidence ratings for each group indicated an advantage for the HFA group over the NT group with scores of 81.99 and 74.06 respectively. There were no significant differences in mean confidence rating scores between the groups regarding musical background (Figure 6-9).

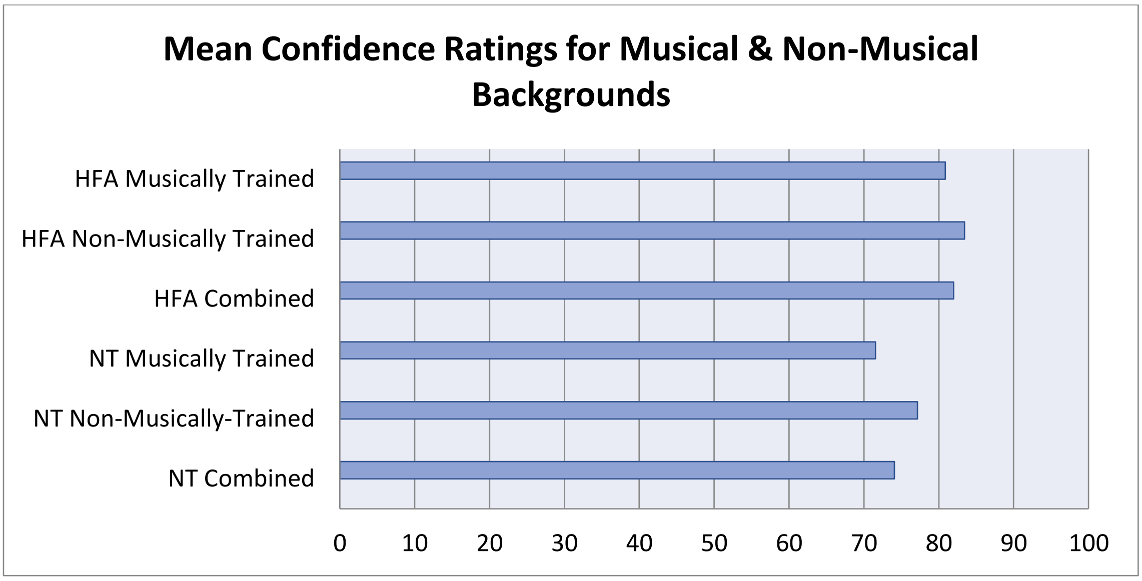


Figure 6-9: Mean confidence ratings for musical and non-musical backgrounds per participant group

The mean confidence ratings for each question are shown for the HFA group, the NT group and as a combined mean in Figure 6-10. The average differences between HFA and NT confidence levels for all questions were approximately 9.79. The maximum difference between groups was noted as 18.94 in favour of HFA participants for question 3 relating to volume and scale. The minimum difference was reported as 2 in question 2, in favour of NT participants, again related to volume and scale. The maximum confidence ratings were 97.63 and 87.1 for HFA and NT groups respectively, whereas the minimum ratings were recorded at 60.63 for HFA, and 59.41 for NT.

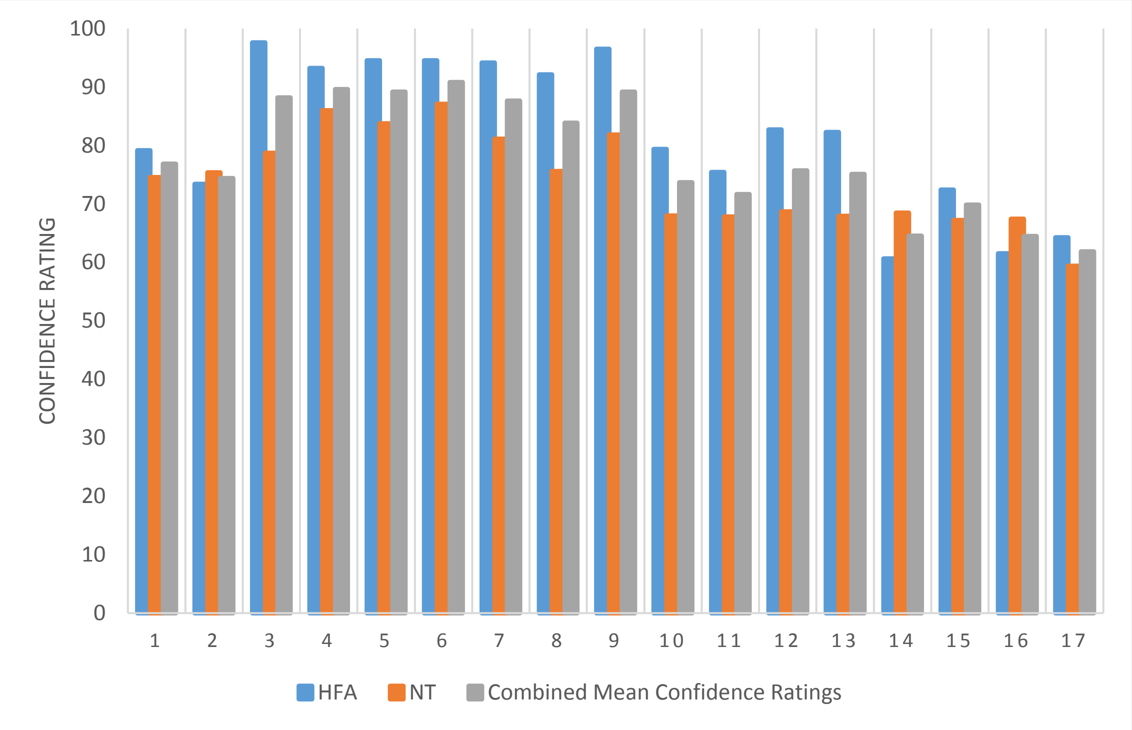


Figure 6-10: Mean confidence ratings per question for HFA, NT and combined groups

Finally, a comparison of combined mean confidence ratings per question against mean scores for each question is shown in Figure 6-11. The average difference between the combined groups mean confidence ratings, and mean question scores, was reported as 7.91. The maximum difference was 13.37 in favour of the mean question scores in question 11, while the minimum difference was reported as 1.82 in favour of the confidence ratings in question 15.

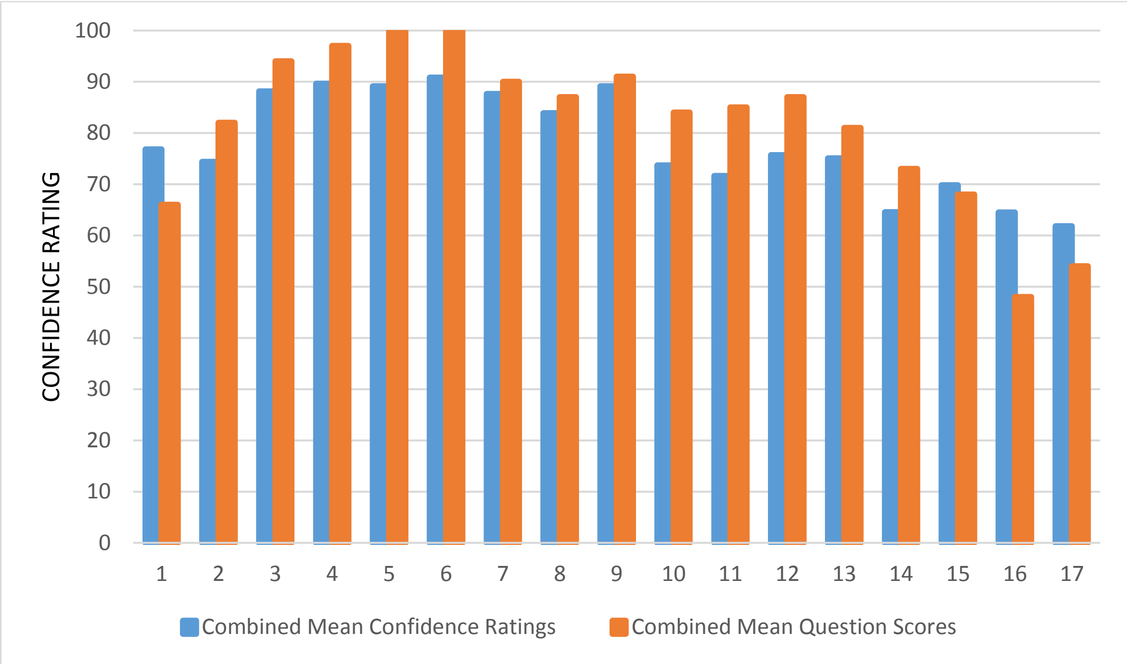


Figure 6-11: Mean confidence ratings compared against mean question scores for each question

6.3.5 Qualitative Feedback

In total, 18 written additional comments were left by participants, 14 by NT participants, and four by HFA participants. The feedback has been grouped into three themes that are described in Table 6-6 below. HFA and NT participants' feedback is identified as HFA01-x, and NT01-x for the purposes of anonymization.

Theme	**Description**	**Participant Contribution**
Sense of Play	Participants expressed their emotional reactions through experimentation with *CymaSense*	NT06, NT07, NT16, NT22, NT27, NT28, NT29, NT31, NT32, HFA10, HFA15, HFA17
Audio-Visual Integration	Opinions on the successes and limitations of the audio-visual mappings	NT07, NT13, NT17, NT27, NT31, HFA11, HFA17
Alternative Uses	End-user suggestions and comments for improvements and further use	NT13, NT20

Table 6-6: Participants' comments themes and descriptions

<u>Sense of Play</u>

The majority of the end-user comments suggested that they found the survey a pleasurable experience, as they either expressed that it was 'enjoyable' (NT06, NT16, NT22, HFA17), or that it was 'fun' (NT07, NT27. NT28, NT29, NT31, NT32). Participants inferred that the interactive experience was entertaining by commenting that they 'enjoyed playing with it' (HFA15) or '… playing the keyboard and watching the visuals' (HFA10).

Audio-Visual Integration

Participants commented that the audio-visual mappings worked well for the most part – 'Most of the visuals seem to fit well with the audio sounds being play[ed] back' (NT07). They indicated that the clearest mapping seemed to be volume to scale – 'I mostly looked at the size of the visualisation' (NT13), 'The temporal mapping between the sound loudness and the visual size was straightforward to understand' (NT32). However, they suggested that associating pitch with colour, and pitch with shape, was more problematic – 'I found it difficult to associate colours with sounds' (NT13), 'mapping between different pitches and colour as well as geometry were more difficult to assess' (NT32). Another participant implied that pitch to shape correspondence was a little confusing – 'Sometimes I have found more than one [suitable] graphic for the sound' (HFA11).

Some participants pointed out the challenges associated with the tonally based questions – 'the tough questions were the ones with changing tones' (NT27), 'tonally based questions were the most difficult' (HFA17). One participant highlighted their efforts to identify the best match association - 'I played the videos 2-3 times usually to really try to notice the difference on the more subtle ones' (NT17).

Most of the video clips represented only one note played at a time. One participant suggested that multiple note phrases may have made the audio-visual mappings easier to understand - 'personally [I] felt that there should have been more various choices of notes being played … [I] only seemed to find one or two examples of multiple notes being played' (NT07). However, they also added that they enjoyed the experiment – 'the audio-visual integration is great' (NT07).

Alternative Uses

One participant stated that *CymaSense* could be used for other groups as a means of artistic expression – '… this could be a very useful tool not just for people with autism and other disabilities. It could be useful for regular people too as another expressive tool' (NT20). They went on to suggest that additional effects could enhance the end-user experience – 'perhaps some visual effects happening behind the shapes in the middle of the screen' (NT20).

Regardless of the fact that all sounds were centrally positioned in the stereo spectrum, one participant commented that visual location and audio panning position could alter audio-visual perception – 'I would have expected the position of the visualisation on the screen somehow to correspond with the direction the sound was coming from, but that didn't seem to be the case' (NT13). Overall, participant feedback suggested that the audio-visual mappings were generally effective, and that *CymaSense* was enjoyable through its multimodal interactivity.

6.4 Discussion

Data from the survey indicates that the audio-visual mappings chosen for *CymaSense* can be considered effective. The results support the findings from other studies into cross-modal correspondences for volume to scale, pitch to colour lightness, and timbre to shape (Küssner, 2014; Gao *et al.*, 2007; Adeli *et al.*, 2014). The survey differs through its association of pitch to shape, as an effective audio-visual mapping. Participant feedback is in accordance with Hypothesis 1, as the *CymaSense* designed mappings were the dominant matched audio-visual associations within the survey.

The results suggest that the most intuitive mapping for participants was volume to scale, with a combined mean of 90%, which backs up previous research where loudness was mostly represented by larger scale and relative size in drawings (Smith and Sera, 1992; Walker, 1987; Küssner, 2014). Subtle changes in volume in electronic sounds, such as vibrato or modulation effects, were detected and visualised in real time that supported the volume to scale relationship. Participant comments confirmed this idea – 'I mostly looked at the size of the visualisation and if it vibrated with the sound' (NT13), which implied a causal relationship. Questions 5 and 6 returned a response rate of 100% best match, which related to volume attack levels. These results may have been related to the researcher's initial briefing that showed participants how to use the audio equipment and view the associated shapes on screen. Studies in motion perception have shown that when motion is difficult to perceive visually, for example, in dark or occluded environments, sound and touch can convey information that can contribute to a more accurate perception of motion (Shams and Kim, 2010). Within the present research, participants' observations of the demonstration and subsequent experimentation with the audio-visual equipment involved tactile, auditory and visual modalities. This may have emphasised the perceived scaling motion of the shapes. Although vision is typically the dominant sense over auditory or tactile (Soto-Faraco *et al.,* 2003), studies have reported that visual motion perception itself can also be influenced by other modalities (Meyer and Wuerger, 2001).The majority of participants may have understood the volume to scale correspondence immediately, and reinforced the audio-visual association through their own experimentation.

Pitch to Cymatic shape and colour mapping demonstrated a high level of responses matching the *CymaSense* design decisions, suggesting that an association of pitch to pattern may be a means of enhancing musical memory for some autistic participants. This notion is reflected in research by Mottron *et al.* (2006), Lim (2010), and Fletcher-Watson et al., (2016), who support the idea that some people with autism have a heightened visual perception for pattern recognition. This ability could be a beneficial means of identifying musical pitch for some end-users. Nonetheless, one NT participant indicated problems in identifying pitch through geometry, while another NT participant suggested that there should have been more multiple note example phrases. These comments implied difficulties in correspondence between pitch and shape. It could be argued additional multiple note-based questions may have created a deeper understanding of the pitch to shape relationship.

Research into cross-modal influences on visual perception has highlighted that a brief sound presented simultaneously with a colour change of a visual target can also decrease detection time when searching for a visual target (Burg *et al.,* 2008; Shams and Kim, 2010). The use of primary hues for each pitch, within the pitch to shape and colour mapping, may have augmented the identifiable changes in pitch and geometry in question 13, decreasing detection time and aiding in returning a mean response rate of 82%.

With a combined mean of 87% matches, pitch to colour lightness mapping results support previous research that pitch can be represented through changes in lightness (Marks, 1974, 1982, 1987; Hubbard, 1996; Melara, 1989; Ward *et al.,* 2006; Ward *et al.*, 2008; Pouris and Fels, 2012). However, the MIDI keyboard used in the demonstration, which had 24 keys, may have been too few for ease of playability and appreciation of changes in lightness (see Figure 6-1). Participants were shown how to alter the note range of the keyboard to play lower or higher notes. However, a higher rate of matches may have resulted from the use of an 88-key keyboard, which represented all of the available MIDI notes, allowing participants to visualise the differences between the lowest and highest notes more easily. This may have clarified the pitch to colour lightness correspondence. Nonetheless, future versions of the application would require an alternative means of pitch representation for end-users who have visual impairments, including colour blindness. This could be accomplished through vertical movement or by changes in brightness, and is discussed in Chapter 8.

Results from mapping timbre to shape supports previous work by Adeli *et al*. (2014). However, questions 16 and 17 (related to changes in timbre) resulted in the poorest percentage of matches, in accordance with Hypothesis 2. In the Adeli 2014 study, all graphical stimuli were static and two-dimensional (see Figure 3-8). In the present study, the visual stimuli were dynamic and three-dimensional, arguably increasing the complexity of the graphics and the difficulty in identifying the best match. Timbre to blend shape mapping may not have been as effective due to the differences between alternative blend shapes for each note being too subtle (see Figure 6-5). A number of participant comments highlighted the difficulty in identifying the visual changes in timbre. It could be suggested that by exaggerating the blend shapes more the timbre to blend shape mapping would be more visibly obvious, and could provide greater real-time feedback. The question grouping mean scores reflect the consistency of trends between matched answers and confidence ratings (62% combined mean matched answers, combined confidence ratings mean of 65).

The third research question addressed differences between the responses of the neurotypical and autistic groups. Although no differences were found between their performances, HFA participants had a higher overall confidence rating than NT participants. This could be partially due to a reduced level of conscientiousness, recognised within people on the autism spectrum. Studies have shown that once the initial confidence levels of HFA participants were selected, their remaining choices were set at a consistent level (Wakabayashi *et al.*, 2006; Fortenberry *et al.*, 2011). Moreover, a study by Farmer *et al.* (2017) indicated that people with ASC, when compared with NT control participants, demonstrated a reduced sensitivity to contextual stimuli in many perceptual and cognitive tasks. The authors established that control participants' preferences between pairs of similar consumer items switched when a third decoy item was introduced, but this tendency was reduced among individuals with ASC. This indicated that their choices were more consistent and conventionally rational than those of control participants, despite the presence of the decoy item.

The use of headphones within the survey may also have affected how participants perceived sound. Headphones were used within the survey as a means to reduce ambient noise from external sources. However, it is unlikely that headphones would be used within a music therapy environment as traditional acoustic instruments are customarily used (Hunt *et al*., 2004). Electronically generated sounds are typically amplified through speakers in music therapy (Cibrian *et al*., 2017). Sounds from headphones attenuate potential reverberation from surroundings, decreasing stimulation and increasing isolation from the outside world. This could be described as creating a more immersive experience than using speakers. In a study by Kallinen and Ravaja (2007) comparing the use of headphones and speakers, emotional and psychophysiological responses were analysed by participants listening to news via a computer. The authors indicated that participants preferred headphones to speakers. Headphones elicited more positive emotional responses and higher attention, as indexed by shorter pulse transit times, than speaker listening did. However, speaker listening prompted more attention among subjects scoring high on sociability and activity personality scales. Speaker listening also elicited higher physiological arousal. This suggests that using headphones facilitates more focused immersive experiences, while speakers may better facilitate more communication-based social environments. Headphones have also been shown to be effective in helping people with ASC-based hypersensitivity issues with auditory stimuli (Ikuta et al., 2016). In a survey by Lipkin *et al.* (2016), regarding auditory sensitivity issues, 57.6% of children with ASC reported wearing headphones regularly to listen to music. The comfort levels of HFA participants may have been affected by regular use of headphones, and contributed to confidence ratings. However, information regarding participants' headphone use was not recorded within the present survey.

Contrary to Hypothesis 4, participants with a non-musical background displayed a higher score than those with a musical background. It could be suggested that non-musical participants reacted more positively to pictorial-based imagery, as they had fewer preconceived ideas concerning musical representation. This backs up research by Tan and Kelly (2004) who have shown that musically trained individuals tended to visualise elements of intra-musical properties rather than metaphorical or emotively-driven images. In addition, Davidson *et al.* (1988) suggest that the more cognitively developed the participant is from a musical perspective, the less likely they are to represent music pictorially. The use of interactive 3D graphics may also have been a distractive influence rather than a reinforcing one for musically trained individuals. One could argue that autistic clients become musically trained as therapeutic sessions continue, thus musical associations may become dependent on having the visual stimuli present. It could be suggested that non-musically trained participants have been less exposed to musical stimuli, therefore, have had no previous association, and would be more open-minded concerning audio-visual mapping. Trained musicians also tend to look up from their instruments rather than observing visual changes because of what they play. Focusing on visual stimuli may have been an unnatural way to experience music, which affected the results in favour of non-musicians, who may not have experienced the same conflict. Although there is no statistically significant difference between the groups, there may be a trend approaching significance.

Although NT participants left the majority of comments, both groups used positive remarks to describe their experiences. The survey results suggest that both high functioning autistic and neurotypical end-users share an understanding of the audio-visual correspondences. However, it could be argued that the design of the survey could have been improved through greater integration of demonstration and response and recording of participants' sounds choices. Use of multi-sensory integrative technology has been shown to encourage interaction and independence for people with ASC through the use of tactile, auditory and visual senses (Schaaf & Miller, 2005). Ringland *et al.* (2014) and Cibrian *et al.* (2017) have also demonstrated sensory stimulation within multi-sensory environments, regarding their respective *SensoryPaint* and *BendableSound* interventions for children with ASC. The demonstration phase and the video clip based survey used a tri-sensory and bi-sensory experience respectively, where the experimental phase included touch. Demonstration of differences in each of the mapping groups (volume to scale, pitch to colour and shape, timbre to blend shape), with the participants prior to the survey questions, may have highlighted the audio-visual correspondences more effectively. For example, participants could have been asked to play alternative sounds from the module on the same MIDI key demonstrating how the shapes altered due to timbre, regardless of the same pitch and volume. Immediately afterwards, they may have been asked to answer a timbre to blend shape question. Restricting the choices made available to the participants to the same sounds used within the video clips, may have standardised the experiment for all. Alternatively, sounds chosen by participants could have been recorded for comparison against the results, to identify any trends between the two. These changes may have provided a more consistent set of results amongst all mapping groups. Nonetheless, demonstration of the application was designed to be minimal, to allow participants to make unbiased selections and provide impartial qualitative feedback.

A limited participatory design approach was used via the input from the study participants, with neurotypical practitioners and autistic clients representing the target audience. It is difficult to represent all potential target users of *CymaSense* with ASC, as literature has identified the difficulties in providing general guidelines for studies based on autistic participants, given the nature of the spectrum condition (section 2.3). However, the data gathered suggests that the designed mappings displayed no negative effects, and provides a positive basis for evaluation of the application within a practical therapeutic environment.

The size of the visual display used within the survey may have been an influential factor in positive matching of the shapes. Our central vision uses an area densely packed with light sensitive cells, where more neurons will analyse a stimulus picked up by our central vision compared with the same stimulus picked up by our peripheral vision (Scientific American, 2018). This leads to a colour-sensitive, high-resolution central vision and a fast-working, movement-sensitive peripheral vision. The amount of noticeable detail between central and peripheral vision may have been affected by focusing on a 13-inch laptop screen, rather than being projected as a larger image on a wall. If the projected image had been larger, end-users may have noticed broader changes in the geometry of the shapes but paid less attention to the finer details.

It is suggested then, that the audio-visual mappings effectiveness may be improved by using larger visual projections. Speakers may aid in projecting electronic sounds in a shared musical environment in comparison to headphones, however the 50 dBC clips might have been difficult to discern. More time could also be spent in demonstrating the audio-visual mappings to enhance understanding of the associations. In addition, remodelling of emphasised blend shapes may augment appreciation of the timbre to shape relationship.

6.5 Conclusions

Four primary research questions addressed *CymaSense*'s audio to visual mappings, evaluating the feedback from both HFA and NT participants. It was necessary to investigate and validate the chosen mappings from the design in chapter 5, based on literature reviewed, practitioner interviews and innovation, prior to further testing within a therapeutic music session. Previous studies have highlighted accepted correlations between volume and scale (Küssner, 2014), and pitch and lightness (Hubbard, 1996). However, no evidence of testing pitch against Cymatic shape had been discovered at the time of writing, whilst timbre and has shown limited evaluation from static 2D shapes (Adeli et al., 2014), but not from animated 3D shapes. Findings that demonstrated a significant lack of matching participant responses would necessitate a redesign of the audio-visual correspondences. Results from the survey suggest that the overall audio-visual mappings derived from Chapter 5 were effective, and appropriate for testing with end-users within a therapeutic environment. Strong correlations between volume and scale; pitch and colour lightness; and pitch and shape have been demonstrated within this study, with the relationship of timbre to blend shape to a slightly lesser degree. The survey results confirmed Hypothesis 1 (6.1).

The results partially confirmed Hypothesis 2, demonstrating the strongest correlations in volume to scale and pitch to colour lightness, and the weakest in timbre to blend shape. The data for the pitch to shape and colour mapping suggests a robust correspondence. By grouping the audio-visual correspondences, it was interesting to evaluate the degree of difference in level of matched responses. The data indicates which parings were more intuitive, and which were limited in their effectiveness. Confidence ratings also highlighted the level of assuredness between mapping groups. Although there were no significant findings, it is interesting to note the lower number of matches for the timbre and blend shape category. The findings could indicate potential changes in the design for future studies.

The third research question examined whether the degree of perceived correspondence of the audio-visual association differed between the NT and autistic groups. The aim of this question was to investigate any potential mismatch in multimodal correlations between autistic users and neurotypical practitioners. As discussed within literature, autistic users' audio-visual associations may be affected by sensory awareness and cognitive processing. Any findings which highlighted significant differences would imply that a redesign of the mappings would be required prior to testing in music sessions. However, the results indicated a non-significant difference between the groups, suggesting that the designed mappings would be acceptable for further evaluation within a series of therapeutic music sessions. The results have indicated that there appears to be no observable difference between the NT and high functioning autistic groups who took part in this study. Further testing of the application may help identify the efficacy of *CymaSense* with autistic participants who have greater support needs. This will be evaluated in the next chapter. However, it was noted that HFA participants scored higher in levels of confidence, compared to NT users. This could be due to traits in the consistency of their decision-making, rather than based on evaluation of each of the questions on their own merits.

Research question 4 asked whether the degree of perceived correspondence of the audio-visual association would differ between musically trained and non-musically trained groups. The question's aim focused on how musical training may influence the effectiveness of the audio-visual mappings, in particular, identifying Cymatic shapes with pitch. Literature has identified how trained musicians tend to visualise intra-musical elements and that non-musically trained participants tend towards visualisation of emotive metaphor through images or stories. Although there were no significant differences, the data indicated a tendency toward favouring non-musically trained participants. This implies a level of accessibility for potential users who are not trained in music. This suggests that the current design may be suitable for use in music sessions where participants would most likely not be musically trained. However, long term use of the application has yet to be evaluated. Hypothesis 4, favouring participants with a musical background, was rejected in favour of non-musically trained participants. The data suggests a lack of musical training has a greater level of success in identifying the audio-visual correspondences, which could be beneficial for participants with no musical training. Whether this suggests that the initial benefits of using the application will diminish over time, as therapeutic music sessions may passively develop musical training, will only be known through further testing.

The effects of using *CymaSense* within a therapeutic environment will be evaluated in the following chapter, and will employ qualitative and quantitative methods to test its capabilities with autistic participants over a number of weeks.

7 An Investigation of the Use of *CymaSense* within Therapeutic Music Sessions

The *CymaSense* prototype was developed through a series of semi-structured interviews with therapeutic music practitioners (see Chapter 4), which provided a set of requirements for users of the application, including autistic clients and practitioners. A subsequent series of design guidelines were discussed in Chapter 5 and tested in the Mapping Survey (Chapter 6). This chapter discusses the development and organisation of a study involving eight participants with autism, using CymaSense as an intervention within a series of therapeutic music sessions. The study took place over three separate phases at a charity-run centre for people with a variety of disabilities, including autism, called TouchBase (Sense Scotland, 2017b). Phase 1 refers to an eight-week series of music sessions, comprising two non-intervention weeks, followed by the introduction of *CymaSense* over the subsequent six-week period. After a break of seven weeks, Phase 2 comprised two weeks of intervention-based music sessions, one withdrawal week of the intervention, and a final week of intervention. The sessions were aimed at observing and analysing changes in communicative behaviours of the participants. Phase 3 details a series of semi-structured interviews with parents of the participants, and the music tutor involved in the study, to gather background information on the participants involved and how their behaviours may have changed during, and as a result of the study.

7.1 Introduction

Section 2.2 discussed the benefits of music therapy in improving communication and social interaction for people with autism. The intention of the TouchBase study was to test the efficacy of *CymaSense* in improving musical interaction between client and therapist within a therapeutic musical environment. In addition, non-musical communication skills outwith the sessions were examined. Analysis of the sessions was facilitated through a combination of video observation and a post-study survey. A Communicative Responses and Acts Score Sheet (CRASS) allowed detailed analysis of each session (Appendix H - Communicative and Acts Response Sheet (CRASS)), where the number of occurrences of musical and non-musical behaviours was totalled each week and used for comparative purposes. Some of the behaviours included participating in rhythmic give and take, matching a beat, creating a verbal response or establishing eye contact (see Table 7-4 for a definition of CRASS behaviours). The use of CRASS was based on Edgerton's (1994a) method of determining the effectiveness of improvisational music therapy on communicative behaviours. A post-study behavioural change survey with the participants' parents/guardians, care workers and tutor gathered information concerning observable musical and non-musical behaviours of the subjects outside of the sessions (Appendix G – Behaviour Change Survey).

7.2 Hypotheses

This research was designed to test the following hypotheses:

(1) There is a significant improvement between the number of musical and non-musical communicative responses demonstrated by the autistic participants. The number of communicative responses will be significantly higher in the final week of the intervention than at the beginning.

(2) There is a significantly higher number of musical and non-musical communicative responses demonstrated by the autistic participants between their last non-intervention and first intervention sessions.

(3) There are changes in the communicative, social and musical behaviours of the autistic participants observable by parents, care workers or tutors at the conclusion of the study.

7.3 Method - Phase 1 and 2

Autistic participants were asked to take part in an initial eight-week study, Phase 1, which employed *CymaSense* as an audio-visual tool within the sessions. The sessions were video recorded and analysed using quantitative and qualitative methods. Phase 1 could be considered an AB design method, whereby A represents the non-intervention weeks followed by B, representing the intervention (see 7.3.4). Following the completion of the initial eight sessions, a four-week follow up series of sessions, Phase 2, was employed to assess the effect of a long withdrawal phase. In addition, it would allow the inclusion of a reversal design method (BAB) used in previous music therapy intervention studies (Carnahan *et al*., 2008; Goldsmith and Leblanc, 2004; Pasiali, 2004). Geist and Hitchcock (2014) point out that with a secondary demonstration of an effect of intervention (through reversal design), alternative explanations such as regression to the mean, history, maturation, history etc. become far less plausible explanations for the change in behaviour of autistic participants.

7.3.1 Music Tutor

The music tutor running the therapeutic sessions has been working with children and adults with additional support needs in Sense Scotland (2019) since 1999. He has developed a range of ideas to enable individuals with disabilities to find alternative ways of communication and self-expression through improvisational musical approaches, and has worked previously with all but one participant in the present study. His usual practice involves using a variety of acoustic, electronic instruments and voice, within scheduled therapeutic music sessions, using structured and improvisational techniques tailored to individual clients' needs (see 7.3.5). The tutor was not previously involved in the development of *CymaSense*.

7.3.2 Participants

Six adult males and two adult females, who have been clinically diagnosed as being on the autism spectrum, were recruited from Scottish Autism (Scottish Autism, 2017) and Sense Scotland (Sense Scotland, 2019) for the 8-week study. All participants, with the exception of one newly referred client, had formerly taken part in therapeutic music sessions within TouchBase. All of the participants' parents or guardians were contacted directly by the music tutor several weeks prior to the study for approval. One of the males and one female worked together as a group (G1), while the other six participants took part in one-to-one sessions with the music tutor (P1-P6). Participants' diagnosis of autistic impairment ranged from severe to mildly impaired. Deficits in communication skills were common to all participants. None of the participants had visual or aural deficiencies. Four participants demonstrated non-verbal skills, and two participants demonstrated limited functional language skills. Parents or guardians provided informed consent for their children to be involved in the study. All participants were between the ages of 18 and 28 years. Table 7-1 provides an overview of the participant details.

Participant	Age	Communicative Abilities	Musical Abilities	Comments
P1	Late teens	Non-verbal skills, uses facial expression, gesturing and pictorial methods	Preference for percussion	Prone to verbal outbursts and body rocking
P2	Late 20s	Non-verbal skills, uses facial expression, gesturing, body language and objects of reference	Turn-taking rhythmic activities on the keyboard or electric guitar	Hypersensitive to loud noises or boisterous environments, seeks out quieter areas
P3	Mid 20s	Non-verbal skills	No preference	Often displayed a sense of detachment, withdrawal and non-participation
P4	Late 20s	Non-verbal skills, uses vocal and facial expression, gesturing and pictorial methods	Preference for percussion and stringed instruments	Known to have an interest in computers
P5	Mid 20s	Non-verbal skills, uses vocal expression	Use of voice	Emotional expression through use of microphone
P6	Early 20s	Functional language skills	Use of voice and keyboards	Spontaneous verbal communication and improvisation through keyboard and singing
G1	Both in Mid 20s	One non-verbal skills and one with functional language skills	One prefers percussion and strumming guitar, the other singing and playing percussion	Childhood friends, both quite fluent with the use of computers

Table 7-1: Overview of participant details

7.3.3 Materials

The music sessions took place in a large room and had the following musical instruments available: acoustic and electric guitars; microphones; an assortment of acoustic and electronic percussion; a harp; electronic keyboard (Figure 7-1). All instruments could be height adjusted to suit each participant either sitting or standing. Chairs were available for both participant and tutor. A variety of beater and drumsticks were also available. In addition, two video cameras were installed to record the sessions (GoPro, 2016): one mounted on top of a cymbal stand in the corner of the room; another placed on a small stand near the entrance to the room.

Figure 7-1: TouchBase Music Room

The *CymaSense* prototype was run on a laptop (Apple Inc, 2018) connected to an audio interface (Focusrite, 2018), placed at the side of the room. The laptop also provided access to the user interface for music tutor and participants, allowing customisation for each user, including control of colour schemes (see 7.3.4). The prototype was used in three distinct ways, detailed in Table 7-2.

#	Prototype Use	Description
1	One Room Microphone	1 microphone processes room audio, 1 set of projected shapes
2	Two Microphones	2 microphones process 2 audio inputs, 2 sets of projected shapes
3	Interactive Table	*CymaSense* interactive surface creates sound and projects shapes beneath its surface when played

Table 7-2: Participants' use of the prototype within the study sessions

The three alternative ways were tailored to the needs of each autistic participant, which were monitored prior to, and during, the intervention sessions (see 7.5.2). Firstly, a microphone on a stand was used to capture all sounds that were audible within the room. The microphone was placed near the wall beside the laptop, behind participants and out of their line of sight. This allowed the tutor to use any instrument within the room and minimise changes to the established routine for the participants.

A tripod-based projector (AAXA Technologies Inc., 2017) on one side of the room projected the visual output from the laptop onto a screen of approximately five feet in length by four feet in height (See Figure 7-2)(McGowan, 2017a).

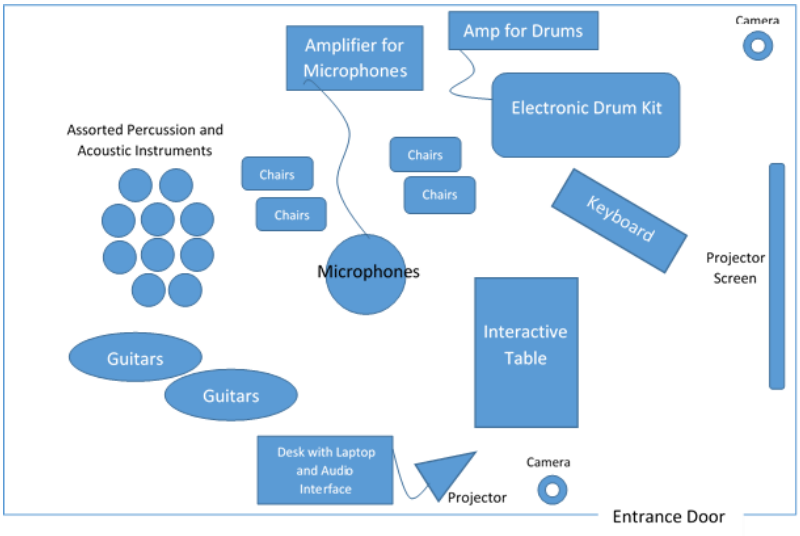


Figure 7-2: Music Room Overview

In the second scenario, two microphones captured audio inputs for the 2-user version of the prototype, allowing the tutor and participant to control their own set of shapes using their voice or chosen instrument. The 2-user version was also projected onto the screen with each set of Cymatic shapes positioned side by side (McGowan, 2017b). Lastly, an interactive table was used as an alternative means of using the prototype, presented as a tangible user interface within the room. The extent of the interactivity would be restricted to playing the table in a percussive manner with hands or beaters for participants' or the music tutor. Tapping or striking the table would activate sounds from an electronic percussive synthesiser in addition to simultaneous projection of the *CymaSense* application on the underside of the table. This facilitated the needs of those participants who were less capable of eye-hand coordinated activity – playing an instrument and looking at the screen – as well as those who were driven by rhythm-based activities (McGowan, 2017c).

The table design comprised of a Perspex transparent surface; a contact microphone to pick up audio vibrations; an interface adapter for an iPad (IK Multimedia US, 2017); an iPad application called Impaktor to generate percussive synthesised sounds (Apple Inc., 2017a). It also employed a small audio amplifier and a projector to visualise the

Figure 7-3: Music tutor and a participant using the *CymaSense* Interactive table

CymaSense prototype on the underside of the table surface (see Figure 7-3)(McGowan, 2017a; McGowan, 2017d). The music tutor was alone in the room with the participants with the exception of a few unanticipated interruptions from other members of staff, and on occasion when the researcher's help was required with the prototype, which occurred on average once a week.

7.3.4 Design

Phase 1

Single subject case design (Aldridge, 2003) has been used within a number of music therapy case studies and within related intervention studies with Autism (Reichow *et al.*, 2011; Geist and Hitchcock, 2014; Villafuerte *et al.*, 2012). Single case study designs were chosen as a suitable approach for this audio-visual multimodal intervention as they are the primary source of music therapy research (Accordino *et al.*, 2007). They allow changes in the relationship with the therapist and with other family members to be detailed using a variety of research methods (see 2.3.3). Changes in emerging phenomena, such as new intervention, can be detailed and new models can be created. The structure of the design is dependent on the individual clients; however, in general a baseline stage (A) is determined over a period of several sessions. Following this, an intervention stage (B) will introduce the intervention to be tested. Subsequent permutations and combinations may include no intervention baseline (BA), the reintroduction of a withdrawal session (ABA – known as basic withdrawal), which can be free time for the client to do as they will, reversal design (BAB), or the introduction of a (C) stage etc. (ABAC).

People with autism can exhibit considerable distress when exposed to unfamiliar situations, changes in routine, or changes in environment (American Psychiatric Association, 2013). Therefore, a phased approach for the introduction of *CymaSense* would minimise the effects of stress on each participant. Designed to identify and agree upon each participant's communication and musical abilities, a short interview with the music tutor confirmed the most appropriate way to customise and introduce the intervention (Appendix M - David McCluskey Interview - 06/02/2017).

For the initial eight-week study, a two-phased approach was used: (A) a baseline stage was established over two sessions; (B) the intervention was introduced and tested over a subsequent six-week period. This is the same protocol used by Yang *et al.* (2003) to examine social behaviour in 7-to-9 year old children with ASC, by Hutchins and Prelock (2006), and Norris and Dattilo (1999), researching the effects of Social Stories on autistic children.

<u>Phase 2</u>

After a seven-week gap, four-weeks of follow-up sessions employed a BAB reversal design consisting of three phases: (B) a two-week continuation of the intervention from the Phase 1 study; (A) a reintroduction of the baseline stage for one week; and finally the intervention (B) for one final session. A reversal design has been used by Edgerton (1994b) and others in the evaluation of interventions with autistic children (Simpson and Keen, 2011; Pasiali, 2004). The two phases could also be evaluated as one larger study with a break between sessions (ABAB) (see Figure 7-4). This will be discussed in 7.5 and 7.6.

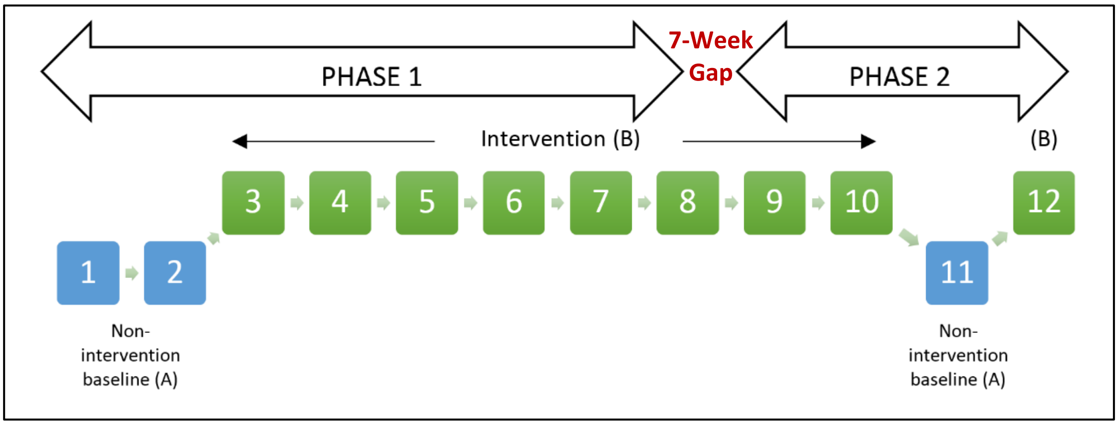


Figure 7-4: Overview of the 12 weekly TouchBase study sessions

7.3.5 Procedure

Each participant was scheduled for a 30-minute session per week, for both Phase 1 and Phase 2, with the exception of the group who were scheduled for a 60-minute session each week. Within TouchBase, regular one-to-one weekly sessions are 30 minutes long whilst group sessions are normally 60 minutes. Due to illnesses and unforeseen circumstances, such as external commitments, not all the participants were able to attend all the sessions. On average, the attendance over the two phases was 83%. During the non-intervention baseline stage (A) the music tutor used a number of improvisational musical techniques, such as playing guitar, the drum kit or percussion, the electronic keyboard and/or singing. The techniques were aimed at establishing contact with and facilitating responses from the participants and development of their musical and rhythmical abilities. The music tutor played, and provided each participant with the opportunity to do the same. Lazar *et al.* (2016) discuss ways to empower adults with cognitive impairments through art therapy via the Third Hand technique, where the therapist draws on and enables the skills of the client, builds on previous sessions and provides support. Similarly, the tutor made every attempt to be sensitive to the desires, goals, and emotions of the clients, by providing support intent on minimising the imposition of meanings, ideas, or preferences onto their work.

In designing creative spaces for people with ASC, Makhaeva *et al.* (2017) highlighted that the common contradictory misconception between autism and creativity, generated by those outwith autism and therapy, can be overcome through subtle interplay and space that allows meaningful participation. By combining a well-known activity with familiar, but slightly modified elements, they indicated that participants felt free to appropriate them in original ways. They employed a Play Partner and Active Observer, which contributed to facilitating a creative process. Adopting this approach prior to the intervention stage (B), a discussion between the music tutor (as Play Partner) and the researcher (as Active Observer) took place, allowing a review of each of the participants needs. The discussion was formalised through a short interview (Appendix M - David McCluskey Interview - 06/02/2017) and is discussed in more detail below.

Ringland *et al.* (2014) and Cibrian *et al.* (2017) discuss the importance of natural user interfaces to support body awareness and sensory stimulation within multi-sensory environments, regarding their respective *SensoryPaint* and *BendableSound* interventions for children with ASC. Similarly, the participant's natural body interactions with the tutor from a musical perspective were taken into account. For example, P1 preferred a sitting position leaning slightly forward for rhythmic play, while P5 liked to lean back whilst sitting with a microphone to make use of his voice more effectively.

The intervention phase (B) was introduced gradually within a session, once each participant was identified as being comfortable, which would generally take around five minutes. The intervention involved projecting the visualisation of the sound produced by the instruments chosen by participants and music tutor, either on a 3m x 2.5m screen, or using an interactive table measuring 1.5m x 1m (see Figure 7-3).

The laptop interface was introduced to the majority of participants by the music tutor in week 5, with the exception of one (P4) who showed interest in exploring the interface on the introduction of the intervention in week 3, by using the mouse to select and change colours. In general, during weeks 3 and 4, the music tutor introduced *CymaSense* using the default colour scheme (Figure 5-13). In week 5, the music tutor encouraged physically capable participants to use the mouse and select different colours, and then would indicate the visible changes by pointing towards the screen or table to demonstrate the results to participants. For participants who remained in their chairs or would not show interest in coming over to the laptop, the music tutor would initially encourage them to indicate approval or disapproval through gestural and verbal means for different colour schemes. For those participants who did not show interest in engaging, the default colour scheme was selected.

The TouchBase music room was designed for use by clients with a variety of disabilities, including people on the autism spectrum who are hypersensitive to light (section 2.1). The music tutor was thus provided with the ability to alter the lighting levels in the music room over the session, using adjustable roof blinds to allow control of available light (ranging from complete darkness to daylight). He could also adjust window aperture to control the amount of air entering the space (Figure 7-1). This allowed the participants to become more comfortable, aware and engaged with the audio-visual interaction (McGowan, 2017b). During the intervention phase, the music tutor continued to attempt to respond to each participant's individual needs (in the same manner as the baseline stage), based on the amount of gestural, verbal, vocal and musical responses and acts within each session.

The sessions were customised for each participant (see Table 7-3: Overview of participant use of *CymaSense*), however, a general set of structured activities were as follows: (1) Directed activity – the tutor began sessions with an introductory welcome and interaction with a chime bar. He would continue with personalised interaction with the participants' chosen instruments and/or voice. At the end of the sessions, conclusory activities included simple breathing and stretching exercises. (2) Free activity – the music tutor would identify favoured instruments for each participant and encourage them to initiate interaction during the sessions. Independent play was also encouraged with the tutor being on-hand whenever the participant required assistance or encouragement.

The researcher was sat in the control room next door to the music room for technical support when required througout the sessions, but was not monitoring or reviewing the activites as they took place.

At the end of the sessions the tutor would have informal chats with the participants as they were preparing to leave, concerning what they thought of the *CymaSense* application. He asked questions concerning the shapes and colours used or chosen, and their general feelings using the application. The verbal and gestural reactions of the participants were recorded visually and aurally through the video recordings.

Participant	Use of *CymaSense*
P1	Played interactive table with hands and beaters, rhythmic improvisation with tutor playing drums or other instruments.
P2	Turn taking on the interactive table, also improvised along with tutor on drums.
P3	Limited tapping of the interactive table for with hands/fingers.
P4	Played the interactive table, placed other percussive instruments, which would be visualised via the table as well. Changed colour schemes on the user interface.
P5	Preference for vocalising with the 2-user version of *CymaSense* using a microphone to improvise with the tutor.
P6	A room microphone visualised keyboard playing and singing; played the interactive table; vocal interaction with the tutor using the 2-user version.
G1	A single microphone for visualisation of room sounds or solo voice; played the interactive table; one member of the group also took frequent control of changing colour schemes.

Table 7-3: Overview of participant use of *CymaSense*

7.4 Data Analysis

A composite variable method was employed, as used by Villafuerte *et al.* (2012), based on social interaction when evaluating the *Reactable* tangible user interface for children with ASC. Their approach was to measure self-initiated contact and responses to social interaction. In the present study, a similar method was used to measure communicative behaviours. The CRASS scoresheet, described by Edgerton (1994a) to evaluate improvisational music therapy approaches, was used as a basis for data gathering. Divided into two sections: musical CRASS data deals with communicative responses influenced by the tutor, and actions initiated by the participant that demonstrate an element of independence; non-musical CRASS data similarly details responses and actions including eye contact, verbal, vocal and gestural communication. Table 7-4 illustrates the author’s definitions of CRASS behaviours within the present study. The classification makes a distinction between communication initiated by the tutor and communication initiated by the client, as a means of separately identifying their frequency for analysis. Mean communicative responses and communicative acts of the participants, both musical and non-musical, were totalled over the 12 sessions, and are referred to in Figure 7-5 and Figure 7-6 respectively.

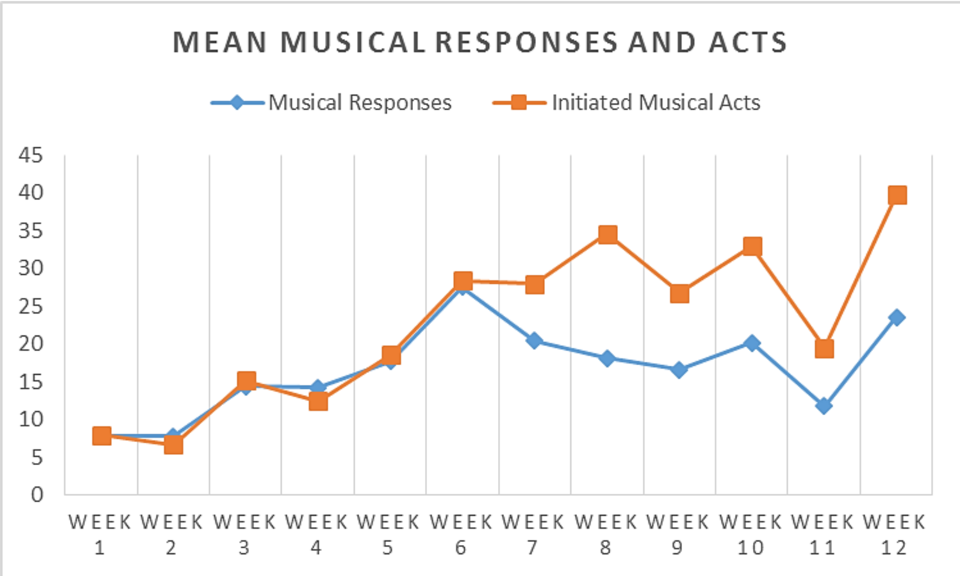


Figure 7-5: Mean musical responses and acts

Although there are minor differences in mean musical responses and acts in weeks seven and eight (Figure 7-5), no identifiable differences in trends between the two were identified over the course of the 12 sessions. It was considered that the musical and non-musical data would therefore be combined as a whole for the remainder of the data analysis. This method of combining the responses and acts for analysis was similar to the Edgerton (1994a) study.

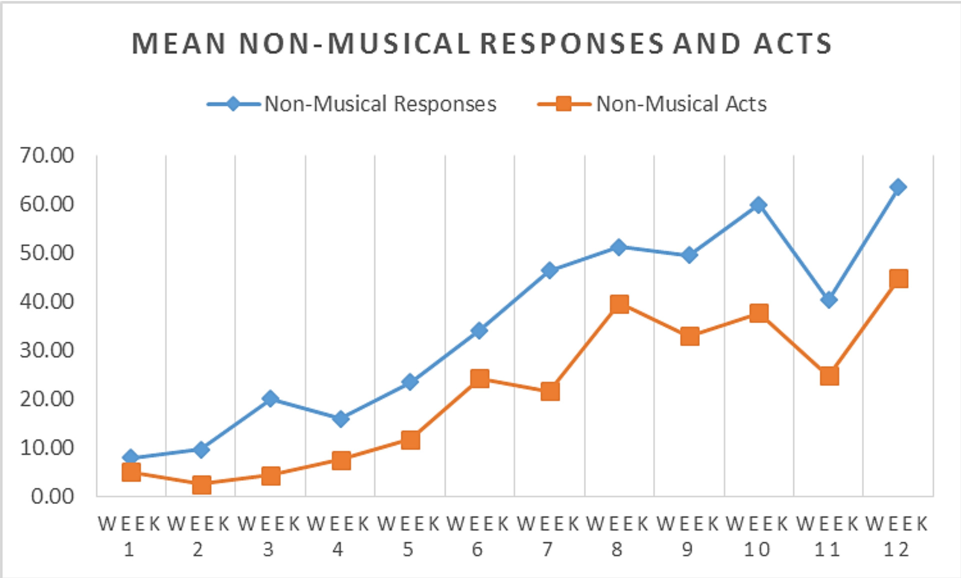


Figure 7-6: Mean non-musical responses and acts

Non-musical CRASS data could be considered the more indicative communicative factor beyond the music sessions and is referred to in more detail in Table 7-7. The frequency of musical and non-musical communicative responses was totalled for each session (see 7.5.1) and was used to validate hypotheses (1) and (2). A post-study questionnaire provided qualitative data concerning observable changes in the participants' behaviours outside of the sessions. A comments section allowed participants to contribute additional feedback. The survey questions were grouped into three categories: communicative behaviours; social/emotional behaviours; and musical behaviours. This data was used to validate hypothesis (3).

	Definition	
Behaviour	**Musical**	**Non-Musical**
Verbal – responses and acts	Words or phrases created by the client during musical play	Words or phrases created by the client outwith musical play
Vocal – responses and acts	Vocalisations created phrases created by the client during musical play	Vocalisations created phrases created by the client outwith musical play
Gestural – responses and acts	Movement of part of the body phrases created by the client signalling an idea or meaning	Movement of part of the body phrases created by the client signalling an idea or meaning
Eye Contact	Non-verbal communication via eyes of client and tutor	Non-verbal communication via eyes of client and tutor
Initiated by the tutor		
Matches a beat	Client imitates tutor's rhythm using their body or an instrument for minimum of 1 measure	n/a
Simultaneously imitates a melodic motif	Client imitates tutor's melodic phrase by use of voice or instrument	n/a
Simultaneously imitates the rhythm of a melodic motif	Client imitates tutor's melodic rhythm by using body, voice or instrument	n/a
Participates in a rhythmic give and take	Client and tutor play a percussive exchange for a minimum of 2 phrases	n/a
Initiated by the Client		
Creates a rhythmic pattern	Client initiates percussive pattern using body, instrument or voice	n/a
Develops a melodic give and take	Client initiates and leads melodic exchange with tutor	n/a
Spontaneously creates a new melodic phrase	Client improvises melody with voice or instrument	n/a
Other	Any undefined percussive or melodic musical behaviour	Any undefined communicative non-musical behaviour

Table 7-4: Definition of CRASS Behaviours

A total of 88.5 hours of video were analysed (two cameras recorded six weekly 30-minute sessions plus one 60-minute group session over 12 weeks – minus absences). In addition to the video material, interviews and questionnaires were used as a means to gather qualitative data. Parents and carers of the participants, as well as the music tutor, were asked to provide information on participants' behaviours before and after the sessions, as well as any observable changes in behaviour at home. A questionnaire was used following Phase 1 of the study (Appendix G – Behaviour Change Survey), whilst a short interview with the music tutor, following Week 2, helped to determine appropriate intervention decisions for all participants (Appendix M - David McCluskey

Interview - 06/02/2017). The objective was to gather data concerning the participants' behaviours outside of the sessions that could contribute to understanding results concerning communicative behaviours (section 7.5.2).

7.5 Results - Phase 1 and 2

The recorded video material was analysed to evaluate the efficacy of *CymaSens*e on the communicative behaviours of each participant over the two phases. Not all of the participants were able to attend all sessions due to absences. Entries in Table 7-7 indicate which sessions each participant attended.

7.5.1 Quantitative Analysis

<u>Phase 1</u>

The Wilcoxon Matched-Pairs Signed-Ranks Test (Johnson & Gibbons, 1973) is used when dealing with non-normally distributed non-parametric data. Both median and mean can be used to calculate Wilcoxon Signed Ranks Tests. Similarly to the Edgerton (1998) study, the session means formed the basis for a series of comparative tests between sessions.The present study is based on Edgerton's (1998) method, which calculated group mean CRASS scores for each weekly session from 10 participants on non-parametric data. Individual participants' data is presented in the appendices (Appendix R: *CymaSense* Study Individual Participant and Group Graphs) as line graphs, and in tabular format in tables 7-7 and 7-8. The means for musical, non-musical, and combined communicative acts and responses (CRASS) for all participants over the first eight sessions, is shown in Figure 7-7. To evaluate the six individuals and one group of two (G1), it was decided to analyse the data in two distinct ways: (i) by including the group in the analysis and (ii) by excluding the group (see Table 7-5). All participants' last session scores were greater than their first session scores indicating a positive level of change over the eight sessions. The combined musical and non-musical scores ranged from 55 to 213 points on a scale of 0 to 250, with a mean of 75.7 with G1, and a mean of 69.8 without G1 included. Musical scores ranged from 23 to 77 including G1 data, 23 to 62 without, with a mean score of 35 including G1 and 32.6 without G1.

Non-musical scores ranged from 38 to 174 points, with a mean of 40.6 with G1 data included and 37.2 without. An overall increase was noted, however, reduction in scores in sessions 2 and 4 are notable and could be explained by absences skewing the data. This will be discussed in Section 7.6.

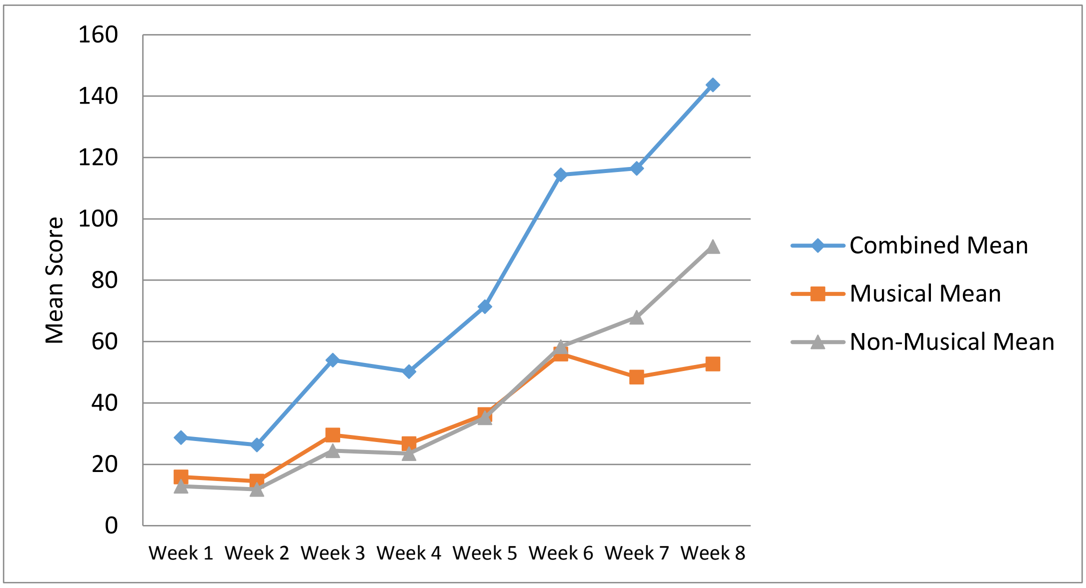


Figure 7-7: One-to-one and group mean scores over weeks 1-8

Similarly, to the Edgerton (1998) study, the Wilcoxon Matched-Pairs Signed Ranks Test was used to determine whether the differences observed between weekly sessions were significant. The mean scores were compared between the following weeks: (a) the first and last sessions of the trial; (b) the first and last sessions of the intervention stage; (c) the third and last sessions of the intervention stage – this was to test the effect of resistance to change autistic people display (Dimitriadis and Smeijsters, 2011). It is assumed that by the third intervention week, resistance to change is minimal; (d) sessions two and three, designed to be the last non-intervention and first intervention session – however, absences led to missing data; (e) the last non-intervention and first intervention session for all participants – this would vary on a session number basis as five of the participants' initial intervention stage was affected by absence. For all of the above, tests were conducted for the combined musical and non-musical data, musical data only, and non-musical data only (See Table 7-5).

A significant difference was observed between first and last session scores for all conditions a(i) and a(ii). The difference between the first and last sessions with intervention were significant for all conditions except b(ii) for musical scores only, Z = -1.6; p = 0.055 (one-tailed), which showed no significant change. To validate the introduction of the intervention session for all participants, barring absences, sessions test c(i) and c(ii), demonstrate a significant change for all musical, non-musical and combined conditions.

Test	Combined Musical and Non-Musical p-value	Musical Only p-value	Non-Musical Only p-value
a(i)	.009	.014	.009
a(ii)	.014	.023	.014
b(i)	.022	.034	.022
b(ii)	.034	**.055**	.034
c(i)	.014	.022	.009
c(ii)	.022	.038	.014
d(i)	.034	.034	.034
d(ii)	**.055**	**.055**	**.055**
e(i)	.014	.014	.014
e(ii)	.023	.023	.023

Table 7-5: Wilcoxon Matched-Pairs Signed Ranks Tests overview (one-tailed) for weeks 1 to 8. Non-significant results are highlighted in red.

Sessions two and three d(i) showed only significant differences for one-to-one sessions only at the .034 level (one-tailed, Z = -1.8). However, the follow-up test, e(i) and e(ii) comparing all last non-intervention sessions with first interventions sessions, indicate significant levels for all conditions.

Four parents, four care workers and one music tutor completed the Behaviour Change Survey. Of the 20 surveys distributed, 16 were returned (80% return rate). The survey consisted of a series of 7-point Likert scale questions, where a value of 1 represented the negative end of the scale. For example, the participant responded to you verbally *much less* since the first session. A value of 4 represented the central position, for example, the participant responded to you verbally *the same* since the first session. A value of 7 represented the positive end of the scale, for example, the participant responded to you verbally *much more* since the first session. An additional comments section was available. Table 7-6 shows an overview of the means for each. The means from all three behavioural categories fell between 5 and 6, indicating a change from slightly more to somewhat more. The musical category had a mean of 5.7 whilst both the communications and social/emotional categories had a mean of 5.6.

Communicative Behaviours	5.6
Social/Emotional Behaviours	5.6
Musical Behaviours	5.7
Overall	5.6

Table 7-6: Mean Scores for Behaviour Change Survey

Phase 2

Figure 7-8 shows the means for musical, non-musical and combined communicative acts and responses (CRASS) for all participants over all 12 sessions.

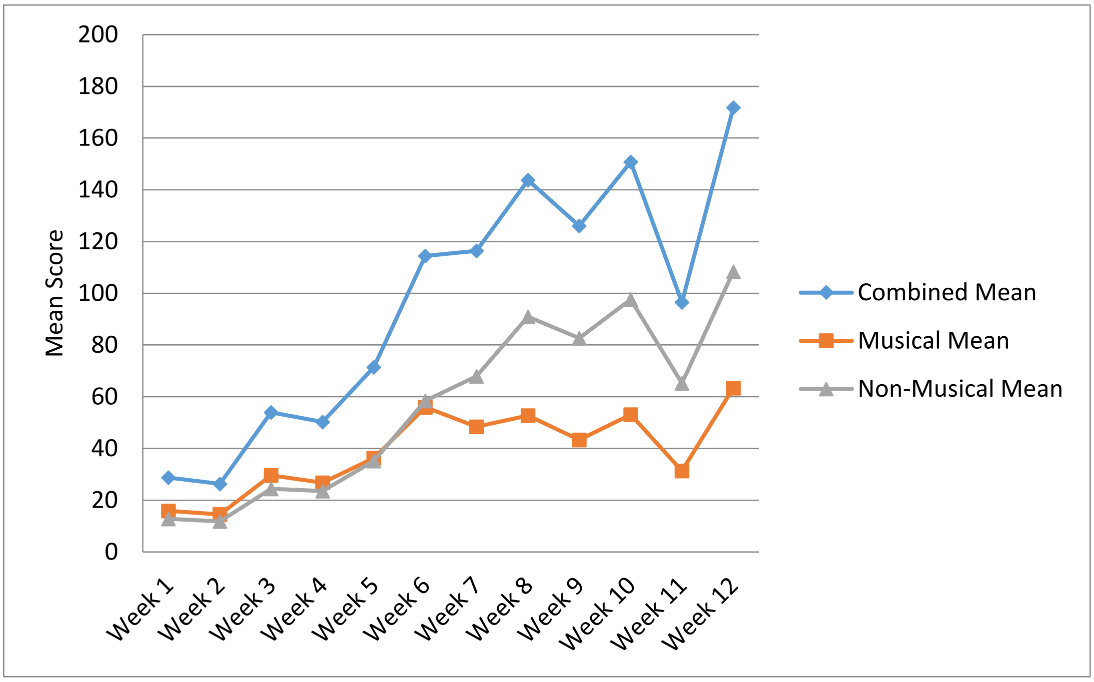


Figure 7-8: One-to-one and group mean scores over weeks 1 to 12

A reduction in scores between weeks 8 and 9 could be explained by the seven-week gap between sessions, while a reduction in scores in week 11 represents the intervention withdrawal phase. Table 7-7 shows non-musical CRASS data over the 12-weeks, while Table 7-8 shows musical CRASS data over the 12 sessions. Participant absences are indicated by the lack of entries in Table 7-7 and Table 7-8, and may have had a limited effect on mean scores. Additionally, although week 12 scores are notably higher than week 11, absences may have affected the overall score. This will be discussed in Section 7.6.

	P1	P2	P3	P4	P5	P6	G1
Week 1	19	14	13	10	4	14	16
Week 2	13	-	16	8	6	11	17
Week 3	37	9	-	22	-	20	34
Week 4	-	19	-	23	17	-	35
Week 5	41	39	24	41	20	45	36
Week 6	52	-	-	95	12	46	87
Week 7	66	44	51	117	26	71	101
Week 8	51	85	34	182	68	84	133
7-Week Break between Phase 1 and Phase 2							
Week 9	50	83	42	179	59	-	-
Week 10	60	82	45	192	-	82	125
Week 11	35	40	-	145	28	51	92
Week 12	-	77	-	190	63	83	129

Table 7-7: Non-musical CRASS data for weeks 1 to 12 (shaded areas indicate absences)

For Phase 2 (weeks 9 to 12): the combined musical and non-musical scores ranged from 27 to 80 points, with a mean of 136.3 with G1, and a mean of 128.8 without G1 included. Musical scores ranged from 19 to 45, with a mean score of 47.8 including G1 and 44.3 without G1. Non-musical scores ranged from 3 to 47 points, with a mean of 88.5 with G1 data included and 84.5 without G1.

	P1	P2	P3	P4	P5	P6	G1
Week 1	22	20	7	13	11	17	21
Week 2	16	-	4	17	14	23	13
Week 3	42	15	-	27	-	32	32
Week 4	-	25	-	19	34	-	29
Week 5	40	36	11	37	49	35	46
Week 6	46	-	-	58	63	37	76
Week 7	43	50	24	34	58	55	75
Week 8	42	47	1	54	73	62	90
7-Week Break between Phase 1 and Phase 2							
Week 9	47	50	1	49	70	-	-
Week 10	49	46	25	55	-	58	86
Week 11	18	23	-	37	26	38	46
Week 12	-	47	-	56	71	61	82

Table 7-8: Musical CRASS data for weeks 1 to 12 (shaded areas indicate absences)

Evaluation of the CRASS data in Phase 2 was undertaken in the same way as Phase 1. The Wilcoxon Matched-Pairs Signed Ranks Test was used to determine whether the differences observed between weekly sessions were significant. The mean scores were compared between the following weeks: (f) the last session of the Phase 1 (week 8) and the first session of Phase 2 (week 9) – data was missing here due to participant absences (see Table 7-7), so the test covered the last intervention of phase 1 and first intervention of phase 2 for all present participants regardless of session number; (g) the reintroduction of the non-intervention baseline stage (week 11) and the previous intervention session (week 10). Due to absences again, this was calculated by removing P3's score, as this was their last attended session, and using P5's last intervention score (week 9) to compare intervention with baseline score; (h) the last session of the intervention stage (week 12) and the previous non-intervention baseline session (week 11) – again, absences meant that the last non-intervention baseline and final intervention of phase 2 did not include P1 or P3's scores (see Table 7-7). For all of the above, tests were conducted for the combined musical and non-musical data, musical data only, and non-musical data only (See Table 7-9). Similarly, to Phase 1, we decided to analyse the data in two ways: (i) by including the group in the analysis and (ii) by excluding it.

Test	Combined Musical and Non-Musical p-value	Musical Only p-value	Non-Musical Only p-value
7-Week Break between Phase 1 and Phase 2			
f(i)	**0.07**	**0.23**	**0.07**
f(ii)	**0.12**	**0.34**	**0.12**
g(i)	0.01	0.01	0.01
g(ii)	0.02	0.02	0.02
h(i)	0.02	0.02	0.02
h(ii)	0.03	0.03	0.03

Table 7-9: Wilcoxon Matched-Pairs Signed Ranks Tests Overview (one-tailed) for weeks 9 to 12. Non-significant results are highlighted in red.

No significant difference was observed between the final session of Phase 1 and the initial session of Phase 2, f(i) and f(ii), for all conditions. The difference between the last session with intervention and the reintroduction of the baseline non-intervention session, g(i) and g(ii), were significant for all conditions. Reintroduction of the intervention following the baseline non-intervention stage indicated a significant difference for all conditions h(i) and h(ii).

7.5.2 Qualitative Analysis - Single Subject Results

Parents and carers of the participants, and the music tutor, provided additional comments through the post-study questionnaire (Appendix G – Behaviour Change Survey). This feedback and the short interview with the music tutor form the basis of the following qualitative analysis.

<u>Participant 1</u>

P1 has ASC, in their late teens, a non-verbal communicator who used facial expressions, body language, gesturing and pictorial methods in order to communicate. P1 vocalised, although they did make verbal sounds and could say some words such as "Night, night", "Where", "Da Da". The participant tended to hum frequently with occasional louder outbursts in vocalisations and appeared to respond more positively to short, simple sentences. P1 usually required between three and five minutes to process information and between five and ten minutes transitioning to and from different activities. Initial observations of the non-intervention sessions noted that they preferred playing percussion.

> “If we brought in that extra element then [they] realise that [their] percussion instruments can be triggering visuals.” [Tutor]

For the first intervention sessions, a microphone was used as the *CymaSense* audio input device to visualise room sounds and project them onto the screen. The interaction with *CymaSense* indicated an improvement in their sense of agency through encouragement to vocalise and see the results. However, due to their preponderance toward leaning slightly forward and using their energy in a percussive manner, the interactive table was chosen by the tutor as a more suitable intervention for sessions 4 to 8 (McGowan, 2017c). During subsequent interventions, the music tutor noted that P1 became slightly more communicative through eye contact and gestural interactions, which was also confirmed from video footage (McGowan, 2017d).

"[P1] developed greater understanding of the Cymatics environment and sharing these activities... [they] did so with curiosity, energy and enthusiasm…could be extremely valuable and meaningful to explore music and creative expression receiving such rich auditory and visual feedback to [their] verbal and non-verbal actions." [Tutor]

One of P1's parents expressed interest in the techniques used within the sessions - "We are interested…to learn how you carried out these sessions and if we could replicate them at home".

Participant 2

P2 has ASC, had been diagnosed with a profound learning disability and was in their late 20s. They were hypersensitive to loud noises or boisterous environments, and would seek out quieter areas. The participant communicated using non-verbal means by using different vocalisations to express happiness, distress or anger. They also used facial expressions, body language, gestural communication and objects of reference to communicate.

Initial observations of the non-intervention sessions revealed that P2 responded to the music tutor sitting close with turn-taking rhythmic activities on the keyboard or electric guitar. "[They] like quite subtle sounds, tones. So that could be interesting finding something that's sensitive enough to have the visual responses to [their] sounds." [Tutor]

P2's first two intervention sessions had a microphone set up to visualise any sound on a screen. However, this approach did not seem effective as they had a tendency to look toward the instrument and were not capable of playing and watching the screen simultaneously. It took two sessions to check that this was not the novelty of a new intervention for P2, which may have taken two sessions to become more accustomed to. Subsequent intervention sessions used the interactive table, which indicated a more effective increase in cause-and-effect and subsequent sense of agency, as well as an increase in interactive communication (Figure 7-7)(McGowan, 2017e).

"[They] gradually came to understand and interact with the Cymatics [software] environment as well as with me. Developing a verbal and non-verbal dialogue between us…I can see gradual sustained focus, attention levels and a greater sense of sharing and communication with me in these creative, expressive activities. All towards greater independence and initiating activity, away from [their] typical repetitive behaviours…very significant developments…often a motivating, and joyous experience..." [Tutor]

Participant 3

P3 has ASC, was non-verbal and in their mid-20s. The participant's care workers commented that they often displayed a sense of detachment, withdrawal and non-participation, and been obsessed by spending lengthy periods in the bathroom. This led to the absences within the study and issues concerning participation within the sessions in which they were present. The music tutor commented: "I feel that [they] weren't ready to explore new unfamiliar activity, for example, Cymatics, when fundamentally the trust between us had to be embedded first…In the latter sessions there were some small but significant moments, where [they] were 'opening up' and feeling more at ease with gradual confidence." Consequently, the intervention did not indicate any significant improvements within their communication levels.

Participant 4

Participant 4 (P4) has ASC, was in their late 20s and had been diagnosed as having non-verbal skills. The participant did not have functional language skills but used vocal expressions, body language, gesturing and pictorial methods in order to communicate. They were known to have an interest in computers, but little was known concerning their interests as they were the only participant not to have worked with the tutor before.

During the sessions, P4 developed a relationship of trust and understanding with the music tutor. They identified a number of plucked and percussive instruments that appealed to them and, similarly to P2, the initial two intervention sessions used a microphone that would visualise any sound on a screen. These sessions indicated a small change in communication levels but also established a set of rules for further exploration. “This was all about creating an environment relating to [P4]’s requirements and levels of communication, social rules, personal space, where [they] could establish a sense of trust and agency in the sessions”. [Tutor]

Subsequent sessions changed the intervention to the interactive table, where greater improvements in communication were notable (Figure 7-7). This allowed them to experiment with a range of percussive instruments that could be placed on top of the table simultaneously visualising the sound. They also developed a greater sense of agency through increased use of the *CymaSense* interface by choosing their own colour schemes at will. The tutor noted: “There were so many positive developments here over the 8 weeks towards greater confidence choice making, independence and gradual co-improvisation. [I] would certainly like to explore Cymatics possibilities further with [P4].”

One of the parents also commented: “For 20 to 30 minutes after each session, [P4] is extremely animated and puts more words together than they do in any other circumstances (for example, five words in a row ‘music room good go back’). [They] try to tell friends and family about the sessions and use the tutor and researcher’s names (in [their] own special pronunciation). These sessions have definitely produced a positive effect in [their] overall communication.”

<u>Participant 5</u>

P5 has ASC, was non-verbal and was in their mid-20s. The participant did not have functional language skills but expresses themselves though vocalisations, using a microphone within previous music sessions. It was evident through their use of the microphone that it would be suitable to introduce the intervention as a projection on screen that could provide meaningful audio-visual feedback. The tutor commented: “The consistency of the setting supported a sense of anticipation and excitement to grow in [them], as [they] looked for the visual responses to [their] actions independently and also within our vocal and musical interplay.”

P5 developed a musical relationship with the tutor that showed significant improvements in interactive communication toward the end of the sessions with the introduction of the two-user version of *CymaSense* (Figure 7-7). Their care worker noted “I have noticed in [P5]’s diary entries, an increase in singing at home.” The tutor commented: “The use of the two-way Cymatics microphone set up really promoted this … I could observe some significant exchanges between us with some very meaningful pauses, and emotional peaks, which [P5] expressed with laughter”. He continued, “[There was] greater close direct eye-to-eye contact than previously before the study … also to motivate [them] to initiate expressive ideas and encourage choice making within our musical interaction.” (McGowan, 2017b)

Participant 6

P6 has ASC and was in their early 20s. The participant’s language skills were functional and their communication was spontaneous. Having previously worked with the tutor, they were known for creatively expressing themselves through musical improvisation. Their tutor commented: “[P6]’s quite set in that they create improvised songs. So [they] like to sing and [they] like to play an instrument…and [they’re] playing on their own. And then we can have parts we do where [they’ll] ask me to play drums or accompany [them].”

A combination of using the microphone to visualise sounds and use of the interactive table allowed P6 to fully express themselves and enhance their creativity (McGowan, 2017a). At the end of the first intervention session P6 commented on *CymaSense* to the tutor: “I love it! It gives you more focus on the song itself…the more it affects you the…better as a singer.”

The tutor went on to highlight, P6 “… seemed inspired working within the Cymatics creative environment, enjoying control of the visual responses. [They] enjoyed the dynamic movement and intense colour responses to their energetic musical improvisations. A very immersive and personalised environment …”

Group 1

Finally, the group of two (G1) comprised two mid-20 year olds with ASC. One with non-verbal skills and one with functional language skills. They were childhood friends and had subsequently participated in a number of therapeutic sessions together. Due to the diversity of both of their needs (one prefers playing percussion and strumming guitar, the other prefers singing and playing percussion), a combination of using the microphone to visualise sound on screen was used, in addition to the interactive table.

They were both quite fluent with the use of computers and became more comfortable and confident in choosing their own colour schemes via the *CymaSense* interface. As the sessions developed, one of the group became more enthused creatively and communicatively. As their care workers noted: “Since Cymatics, [they] have been more into their music and happier that [they] have something else music related…” - “[their] clarity in singing has improved greatly … instead of humming”. They continued, “[They] have disclosed that this is their favourite activity, both verbally and using symbols … I can also see [their] skills at drama has improved, maybe due to more at Cymatics.”

The other group member seemed to develop their level of immersion with the intervention over the course of the sessions but not outwith the sessions. Their care worker noted, “It appears to increase [their] social/musical interests during sessions. But [they] haven’t shown any long-term changes that I have observed.” The group members combined level of communicative interactions indicate significant improvements over the sessions (Figure 7-7).

7.6 Discussion – Phase 1 and 2

The results of the study indicate that the combination of improvisational music sessions and use of the *CymaSense* tool can improve communicative behaviours for some people with ASC. These results support other music therapy related studies (Lim, 2007), studies with TUIs (Villafuerte *et al.*, 2012), and with natural user interfaces (NUI)(Ringland *et al.*, 2014), with respect to enhancing communication for people with ASC. It cannot be said that the same effect will occur on other groups of participants with ASC. At present we do not know the extent to which the Cymatic shapes are responsible for the increases in communicative behaviours, as alternative geometric shapes have not yet been tested. This study differs through employing a combination of music therapy techniques, NUIs and TUIs. It provides the participants with an additional sense of agency and independence through the ability to experience tactile, auditory and visual feedback, within an improvisational music setting. The study suggests they can create a greater sense of predictability and control through use of the interface to control visual elements.

A surprising dip in P1's score for the final session in Phase 2 can be noticed (see Table 7-8). It was noted that he was suffering from a heavy cold that day and his subsequent energy levels could have affected his poorer than expected performance. Similarly, P5 had dental treatment prior to sessions 4 and 5, making him physically tired and less energetic than normal. Participants' absences have already been stated with regard to their emotional health; additionally, the physical health of some participants is likely to have affected their scores and consequently the results of this study.

One recognised trait of people with ASC is the fear of novelty or change within a situation (Trevarthen, 2002). In this study there was no negative novelty effect observed. The results show there was no decrease in CRASS scores when the tool was introduced, and that scores typically increased with use. It is notable that there were no significant changes in overall CRASS scores between the last week of phase 1 and the first week of phase two of the study, which was an interval of seven weeks. The participants had not attended any other music sessions in that time. This could indicate that their music session routine was not interrupted, regardless of the seven-week break.

The present study has not been compared to one without use of the intervention to establish whether there are similar trends in rising levels of communicative behaviours. The results of the present study may have been influenced by familiarity with the tutor and surroundings, thus increasing participants' levels of comfort and sense of agency. It has been identified in autistic studies, that routine and predictability has an effect on reducing stress and increasing communicative behaviours. Recognition of a level of routine has to be conceded here. However, without a parallel study with no intervention this cannot be verified. Nonetheless, qualitative feedback from the music tutor (section 7.5.2) provides evidence of working with the same participants in previous music sessions, and the effect of *CymaSense* on their communicative behaviours within the present study. For example, greater improvisation, development of a performative aspect of musical exploration, greater enthusiasm for shared play regarding the interactive table, and for give and take between the tutor and some partcipants.

One limitation to interpretation of the data relates to the single subject AB design used in Phase 1 of the study. The experimental design used may not be as strong as one where the intervention is withdrawn and then reintroduced (Reichow *et al.*, 2011). A withdrawal phase was considered but was advised against by a music therapy expert, as it may have run the risk of distressing participants if a successful intervention was withdrawn. The ABA design is often criticised for possible ethical issues. In some cases, it may be harmful for the participant to return to the baseline period at an early stage (Shaughnessy and Zechmeister, 1985). Additionally, the practicalities of carrying out this type of study were an important factor that affected its design. It was challenging to secure the participation of a therapist and participants for a long duration, which limited the duration of the different stages of the study. The baseline (A) phase was thus decided to be a two-week period, a compromise that enabled the intervention to be run over a longer stretch of time, which was judged preferable for Phase 1. This decision was also based on the music tutor's prior working experience with the majority of the participants, thus potentially minimising the need for a longer adjustment period. However, following discussion with the music tutor and the participants' parents and carers, consideration for a repeat or continuation of the study resulted in the follow-up Phase 2 for further validation. The results indicate an additional BAB reversal design has provided comparative data to further highlight the positive effect of the intervention on overall communicative behavioural scores.

The statistical methods employed follow the same methods as used in a previous study by Edgerton (1994a). Specifically, the Wilcoxon Matched-Pairs Signed-Ranks Test is recognised by some researchers as being more robust when using the median, rather than the mean, to calculate the significance of the results (Johnson & Gibbons, 1973). Consequently, had median data been used, the results would have differed from the mean data. Future studies will aim to use this method, if appropriate, for greater validity of the findings.

The video data was coded solely by the author due to lack of funding and available personnel. Additionally, the music tutor watched the video recordings on a weekly basis and provided informal verbal feedback to the researcher. However, if the observational data had been evaluated by additional independent observers, and appropriate inter-rater reliability checks completed, the resultant data may have differed somewhat to the data presented.

Due to the prototype nature of *CymaSense*, the author was required on occasion to provide technical support during a few of the sessions. This may have disrupted the flow of the session somewhat, due to time taken to identify an issue and restart the application, as well as introducing another person into the environment. Wider deployment of *CymaSense* would require an update to the software and interface, requiring further testing for levels of robustness, to limit any interruptions to participants' and tutors' roles.

It could be argued that when used as an interactive table, *CymaSense* not only visualises interaction with the table surface itself, but also creates a novel percussive instrument. This creates new opportunities for social interaction through a shared space and turn taking, while independent use could also encourage cause-and-effect and a subsequent sense of agency.

The size and location of the projected image may have affected the participant's ability to appreciate the cause-and-effect nature of the system. This was recognised by the researcher and the tutor through weekly reviews of the sessions. Subsequent decisions were made as noted in the results section (7.5.2).

The application design, as a novel concept for audio visualisation, has been influenced by the author's own bias towards development of a previously explored concept (McGowan, 2014). Literature reviewed in chapters 2 and 3, and requirements gathering from practitioners in chapter 4, aided in the prototype mappings designed for versions one and two of *CymaSense*. Feedback from high functioning autistic and NT users on the chosen design was useful, but as participants did not represent all of the target audience, was limited. Again, it should be stated that an alternative participatory design method with autistic users would likely have developed a different application. Subsequently, the user interface may have been more effective had it been developed at an earlier stage. However, it could also be argued that the Cymatic shapes would not have been introduced as an innovative visualisation aesthetic.

Colour may have affected how participants experienced the sessions. The tutor initially used the default colours (black background and spectrum colours for the Cymatic shapes) for a number of sessions to allow familiarity with the tool. Alternative colours were chosen at random by the tutor in future sessions while some participants chose their own colour schemes. None of the participants was diagnosed with visual or auditory impairments. However, further studies would be required to determine the effectiveness of the colours chosen and the effect of environmental factors like temperature or noise - for example, the hum of the projector. Similarly, little is known concerning how the animation of the shapes themselves affected each subject. Again, however, participants with functional language provided positive feedback concerning the dynamic movement and colour responses. Further limitations of this study will be discussed in chapter 8.

7.7 Phase 3 Interviews

Four interviews were conducted and recorded, following the *CymaSense* music sessions, three with parents of the participants, and one with the music tutor involved in the study. The broad goal of the interviews was to gather background information on the participants' behaviours before and after the TouchBase sessions in which the *CymaSense* application was used. The interviews were also designed to outline how participants' use of the application may be affected by their own auditory and visual preferences. The interview questions would highlight how participants' current use of technology reflects on the *CymaSense* application and its use. The findings of the study could provide insights into the success of *CymaSense* and inform how the application could be further developed for the benefit of improving communication and social interaction for people on the autism spectrum.

7.7.1 Method

Parents of the participants, as well as the music tutor involved within the study, were asked to take part in a series of semi-structured interviews. The two autistic participants from the music sessions with verbal skills were not invited to take part in the interviews, as it was considered by the music tutor that they would not be comfortable responding to a series of questions nor able to sustain a conversation. The purpose of the interviews was to analyse individual participant's preferences, and identify key attributes of the *CymaSense* application for future development. These opinions would feed into the discussion regarding the advantages and disadvantages of the current version of the *CymaSense* application.

7.7.2 Participants

Parents from all eight of the study participants were invited to participate in the interview, as well as the music tutor. Three parents and the music tutor agreed to take part, providing a response rate of 44%. Two mothers, and a mother-and-father couple, were recruited internally from TouchBase following completion of the 12-week study (Sense Scotland, 2017b). The music tutor who ran the sessions was also interviewed. All of the participants' parents were contacted directly by the music tutor several weeks prior to Phase 3 of the study for approval. The music tutor was contacted directly by the researcher. After reading a participant information sheet, all parents and the music tutor provided informed consent for their responses to be included in the study (Appendix P - Information Sheet for Potential Participants – Phase 3 Interview).

7.7.3 Materials

The interviews took place in a private interview room within the TouchBase centre. A digital audio recorder was used to record the interviews. The *CymaSense* application was installed for demonstration purposes to allow parents an opportunity to interact with it themselves.

The set-up consisted of a small MIDI keyboard for user input; a laptop to run the software; a sound module to generate a variety of electronic sounds; an audio interface to process the sounds; a small speaker for audio output; and a projector for visual projection of the shapes onto the interview room wall (Figure 7-9). Interviewees were also provided with the interview questions on paper for referral purposes.

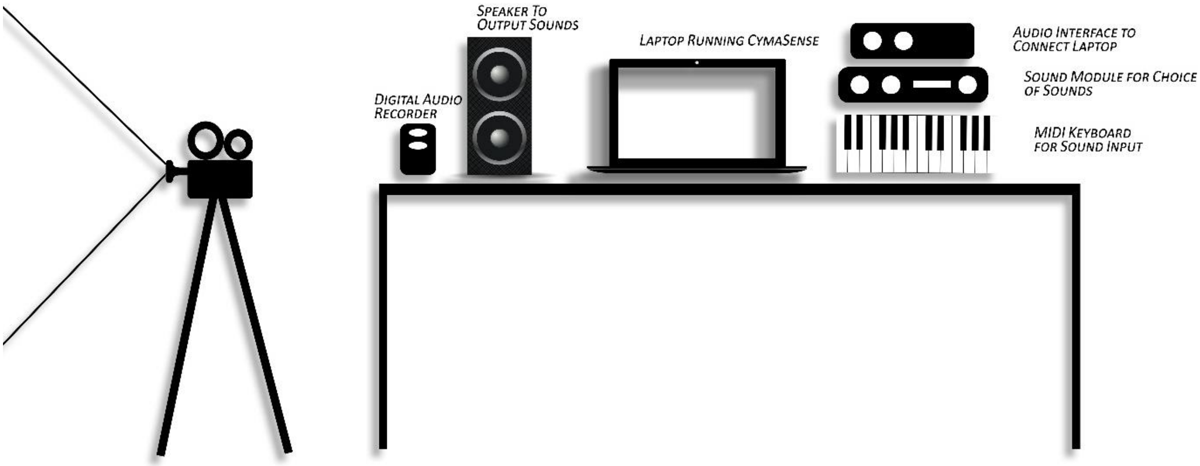


Figure 7-9: Interview room equipment set-up

7.7.4 Design

A semi-structured face-to-face interview technique was chosen allowing participants the opportunity to elaborate, as additional questions may emerge from the dialogue between interviewer and interviewee. As the symptoms of ASC span multiple domains (e.g., communication and language, social, behavioural), direct answers and anecdotal information could provide insight into the choices made by the study participants. Semi-structured interviews are an effective method used in previous research, as a means to gather qualitative background information including the routines and preferences of each study participant (Ulgado *et al*., 2013; Reichow *et al*., 2011). Typically, parents, caregivers and teachers have provided information regarding individuals' behaviour, and it was hoped that this would provide a greater insight into participants' interactions with the *CymaSense* application.

The interview questions were derived from previous research into multimodal applications and music therapy studies for children with autism. Cibrian *et al.* (2017)

use semi-structured interview techniques to aid in the understanding of behavioural and sensory changes, related to the use of multimodal interventions within individuals with ASC. Ringland *et al.* (2014) use similar interview methods to ask the parents of participants to provide feedback on their children's use of a multi-sensory intervention, including what they liked and disliked about the *SensoryPaint* application.

The interview questions, 26 in all, were divided into four sections. The first section included seven questions, which referred to observable behaviour immediately prior to and following the therapy study sessions. Ten questions in section two related to the participants' personal preferences concerning sensory influences. Section three questions related to participants' musical preferences. The remaining five questions in section four related to participants' use of technologies and their interaction with the *CymaSense* application in particular. Table 7-10 provides an overview.

Section	**Description**
Pre/Post Therapy	Questions regarding observable behaviours and emotional stability before and after sessions
Personal Preferences / Sensory Influences	Questions concerning how issues of hypersensitivity and hyposensitivity may affect participants
Musical Preferences	Questions concerning their listening and playing musical preferences at home and within sessions
Technology and *CymaSense*	Feedback and opinions on the pros and cons of the *CymaSense* application

Table 7-10: Overview of Phase 3 interview questions

7.7.5 Procedure

The four subjects were interviewed individually within a small conference room at the TouchBase centre. They were asked 26 questions from the four sections (see Appendix N – Phase 3 Interview Questions for *CymaSense* Study Participant Parents/Guardians for the full list). In addition, the interviewees offered opinions and comments on previously undiscussed elements related to the study. Some of the questions relating to participants' musical preferences at home were not relevant to the music tutor, and thus were not asked. However, the tutor was able to provide opinion on participants' musical preferences within the music sessions. The interviews were expected to last up to an hour and varied in length between 25 and 47 minutes, dependent on how much information each participant contributed. Interviews were audio recorded, transcribed, and then coded using NVivo (QSR International Pty Ltd, 2017). Participants were informed within the participant information sheet (Appendix P - Information Sheet for Potential Participants – Phase 3 Interview) that their responses would remain anonymous, they did not have to answer all of the questions, and that they could stop at any time. Permission was obtained to make use of the results within a thesis or associated publications (Appendix Q - Informed Consent Form for Parents or Guardians – Phase 3 Interviews).

Interviews began with questions concerning the behaviour of the participants immediately before and after the sessions, and went on to query individual participant preferences concerning sensory influences. Questions were then posed on sensory and musical influences, followed by questions on participants' use of technology, and *CymaSense,* and if it continues to play a part within their lives.

Coding was conducted using the transcriptions from the interviews based on a qualitative Grounded Theory approach (Wagner *et al.*, 1968). Codes were allocated to quotations using an open approach where interpretation of quotations suggested appropriate codes, as opposed to pre-defining codes and assigning quotations to them. Following the first pass, which determined a set of 30 codes, a further three passes merged the codes into a condensed set of five, which were checked against the transcripts again for assuredness. The first pass identified general themes from the transcripts that were divided into four sections - sensory influences, routine, control and technology. The second pass noted similarities and combined several of the codes together under the new headings of emotional stability, pattern recognition, self-expression and technology. The third pass further condensed the codes into two main sections, emotional stability and self-expression. Finally, the fourth pass represented the last stage and condensation of the available codes. An inter-rater reliability check was not necessary due to the small sample size. See Table 7-11 below for an overview of the coding stages.

<table>
<tr><th>Fourth Pass</th><th>Third Pass</th><th>Second Pass</th><th>First Pass</th></tr>
<tr><td rowspan="5">Participant Behaviour
Audio-visual learning
Communication
Independence
Interface</td><td rowspan="2">Emotional stability
- Behaviour
- Familiarity
- Sensory influences</td><td rowspan="2">Emotional stability
- Behaviour
- Familiarity
- Isolation
- Mood
- Focus
- Sensory influences</td><td>Sensory influences
- Emotional stability
- Behaviour
- Isolation
- Mood
- Focus
- Hypersensitivity
- Hyposensitivity</td></tr>
<tr><td>Routine
- Anticipation
- Comfort
- Familiarity
- Self-expression</td></tr>
<tr><td rowspan="3">Self-expression
- Audio-visual learning
- Communication
- Independence
- Play
- Technology</td><td>Pattern recognition
- Aesthetics
- Audio-visual learning
- Melody and Rhythm</td><td>Pattern recognition
- Aesthetics
- Audio-visual learning
- Melody
- Rhythm
- Routine</td></tr>
<tr><td>Self-expression
- Communication
- Control
- Independence
- Play</td><td>Control
- Communication
- Independence
- Personal preferences
- Play</td></tr>
<tr><td>Technology
- Computing
- Usability</td><td>Technology
- Computing
- Home use
- Personal use
- Potential use
- Shared use</td></tr>
</table>

Table 7-11: Overview of the four stages of Phase 3 interview transcript codes.

Colour coding denotes transcript code reduction.

7.8 Results

The results are divided into five sections using the fourth pass transcript codes as headings for each section, which include participant behaviour, audio-visual learning, communication, independence and interface. Interviewees commented most on participants’ behaviours prior to and post study. They indicated that, in general, participants’ anxious behaviours gave way to relaxed and stimulated experiences as the study progressed. Interviewees identified their children’s visually driven learning capabilities, and how they may have assisted in facilitating a stimulating and novel audio-visual experience within the music sessions. The music tutor suggested that participants' use of *CymaSense* influenced independent interaction with the application, followed by a sense of control, which naturally facilitated their participation. He recognised the application's usability and accessibility, through lack of training and customisability. Parents identified subsequent increased levels of communication of participants. The five derived code descriptions are described below followed by detailed findings from the transcripts (see Table 7-12). The interviewees are referred to within the results as PA1, PA2, PA3 and MT, for the purposes of anonymization.

Code	**Descriptions**
Participant Behaviour	Participant behaviour is affected by sensory influences, and by familiarity with people and routine. Behaviour prior to, during, and following the study sessions is discussed.
Audio-Visual Learning	Observations on how participants' audio-visual aesthetic choices affect the efficacy of multi-sensory interaction.
Communication	Observations on development of participants' communication, from a musical and non-musical perspective, over the course of the study.
Independence	Opinions on the importance of participant control and independence in the music sessions through use of the *CymaSense* application.
Interface	The playability and accessibility of *CymaSense* are discussed, and how they affected creativity.

Table 7-12: Code Descriptions

Phrases, sentences and short paragraphs were highlighted and assigned to the chosen codes, depending on how exacting or anecdotal interviewees' responses were to the questions. The number of instances of interpreted quotations for each interviewee was noted and the list was ranked according to frequency. A summary of instances from the transcripts are described in Table 7-13 below.

Code	**Respondents**	**Instances**	**%**	**Rank**
Participant Behaviour	4	108	35%	1
Interface	3	81	27%	2
Independence	4	51	17%	3
Audio-Visual Learning	4	44	14%	4
Communication	4	20	7%	5

Table 7-13: Codes resulting from transcribed terms

Participant Behaviour is the highest ranking code with 108 instances, using words and phrases related to factors that affect the routines and general development of participants, from 'unsettled' and 'withdrawn', to 'excitement', and 'joyful'. The ranking indicated a priority in parents and the music tutor over conduct as the main factor that affect the routines and general development of participants.

It should be noted that the second ranked code (referring to accessibility and playability), Interface, although ranking second with 81 instances, was only responded to by three of the interviewees. One was particularly unfamiliar with technology and thus was not comfortable responding to any of the technology-based questions with confidence. Phrases included 'non-verbal playground', 'shared space' and 'aesthetic experience'. The ranking suggests the importance of the playability and accessibility of the application in contributing to its effectiveness.

Independence is ranked third with 51 instances, reflecting the role in having a sense of control for participants as viewed by interviewees. References to terms like 'power', 'control' and 'meaningful' were used.

Fourth ranked is Audio-Visual Learning, with 44 instances. This referred to participants' aesthetic choices and included the phrases 'familiar logos', 'bright colours' and 'never forget an image'. The ranking implied that participants' audio-visual aesthetic choices were less influential in the use of *CymaSense*.

With 20 instances, Communication represents responses including 'verbally more communicative', 'high fives and eye contact', and 'sense of partnership'. The Communication code indicates that observed musical and non-musical communications of participants over the course of the study were of a lesser priority to interviewees.

<u>Participant Behaviour</u>

Participant behaviour is affected by sensory influences, and by familiarity with people and routine. Behaviour prior to, during, and following the study sessions is discussed.

The majority of participants had worked previously with the music tutor, with the exception of one new TouchBase service user. Nonetheless, sufficient time had passed to require a period of reacquaintance. Interviewees' commented that a lack of familiarity with the music tutor and the environment affected the routines and levels of comfort for participants. These factors, combined with varying levels of hypersensitivity and hyposensitivity, resulted in differing levels of emotional stability and behaviour. They reported that participants tended to be apprehensive before the music sessions began, resulting in a range of anxious behaviours including a lack of eye-contact and nervousness - '[they'd] refrain from eye contact with myself' (MT); '[they were] generally unsettled…sort of nervous about coming to a new situation' (PA1).

The music tutor reported that the early sessions, prior to the introduction of the intervention, facilitated an emotional outlet for participants through play, but without much interaction – 'the sessions were almost like a real outlet, for this kind of suppressed emotion … loud drumming, sometimes a bit manic … without it being too reciprocal'. For others there was little apparent enthusiasm - '… quite withdrawn, there didn't seem to be that much energy or motivation to come into a music session' (MT).

The tutor went on to mention that participants can take time becoming comfortable with unfamiliar people and environments, with obsessive behaviours typically preventing creativity and interaction - 'Lots of repetitive, ritualistic behaviours, hyper …. high anxiety'; 'Often when [P2] comes into a session [they've] got an object [they're] fixating on. So the challenge is how do I create some kind of interactive activity?' (MT). The tutor identified a way to build trust with the participants prior to introducing the intervention – 'I would sort of match or try to mirror what [P2] was doing and then gradually use that as a vehicle to create something more musical, or more creative' (MT).

He commented on building a relationship with a participant to create a platform for interaction – 'It can take quite a long time with [P2] to be able to trust people, to be quite relaxed, to interact and to share' (MT). However, he went on to note that having previously worked with the majority of the participants, the familiarisation process was relatively brief – 'Straight away [P6] was quite familiar and at ease'; 'We'd built up a real familiarity there in that space … a really consistent environment which I think is important to [P7] (MT).

Interviewees indicated that sensory influences could affect participants in a number of ways. Aural hypersensitivity was specified as a common issue – 'If it's quite a squeaky high voice, [P2] doesn't like that, [they'll] put [their] fingers in [their] ears' (PA3). In other cases, however, volume of sound may not be a problem – 'Although [P1] likes [their] music loud, [they don't] like to hear people's noise. Like people laughing or crying' (PA2); '[P4] went to a Celtic football match with [their] carer and didn't want to leave. You'd think that would disturb [them], but [they] managed all the way through' (PA1).

Visual hypersensitivity was also identified – '[P2] likes to be in the dark' (PA2); 'When we're out [P4] screws up [their] eyes, [they have] problems' (PA1). Interviewees also mentioned that sensitivity to touch was an issue – '[P2] doesn't like to be touched … by people, by strangers' (PA2); 'the tiniest bit of rain on [their] skin [P4]'ll freak out' (PA1).

Hyposensitivity could also cause issues with dexterity – 'I feel [they've] not got enough sensitivity in [their] fingers … [they] don't realise when things fall' (PA1). It could be inferred, however, that the predictability of the situation affects the hypersensitivity of the stimulus – 'other sounds that will come suddenly at a certain pitch, and [they'll] scream … I think [their] headphones are a protection measure' (PA1). From a hyposensitivity perspective, it was also pointed out that regardless of 'bad fine motor coordination' (PA1) the same participant 'can handle a computer mouse and get on your iPhone with huge fingers without making a mistake' (PA1).

Interviewees noted that participants' behaviour did change once familiarity within the room and sessions took place – 'When [they] knew what was going on and [they] knew the machines were up and running, it sort of coincided with [them] being more confident in [their] environment and more relaxed' (PA1). Subsequently, the tutor identified a change in emotional state for some participants once the intervention had been introduced to the study. Immediately prior to these sessions, '[P7 was] anticipating the new Cymatics environment and activities … gazing at the projector and screen, smiling'; '[P1] had eye contact on Cymatics table (see Figure 7-3) on entering the room, even when it was covered … triggering smile and laughing responses' (MT).

During the intervention sessions interviewees reported observable changes including greater enthusiasm for the sessions –' [P7 was] curious, aware of some sense of change, engaged, communicative' (MT); '… when [the tutor] comes out and [the tutor's] got the key, [P4] is away like a shot' (PA1). Immediately following these, the music tutor indicated that participants overall were emotionally affected – '[P7 had] a sense of having a meaningful engaged experience' (MT); '[P8 had] a sense of fulfilment … an aesthetic, creative and emotional outlet' (MT). Another interviewee pointed out one participant's enthusiasm after a session - '[P4] was so excited, speaking and repeating, and trying to get the idea over all the way back in the car to the house' (PA1).

Interviewees commented that during the withdrawal phase on week 11, participants missed working with the *CymaSense* application – '[P8] was missing the Cymatics set-up and talking about it to others'; '[P7] was looking for visual response when using the vocal mic'; '[P1] was looking for the Cymatics table' (see Figure 7-3) (MT).

Interviewees indicated changes in participant behaviour in the weeks following completion of the sessions - 'at the time yes, [P1's] behaviour did change' (PA3); '[P1] had reduced stereotypical and solely repetitive behaviours'; '[P4] is gradually revealing much more personality, humour, inventiveness, self-organisation and structure' (MT). It could be implied that by the end of the study, attitudes and behaviour had become more enthusiastic and less anxious – '[P1] [shows] instant recognition and joyful response when we meet and I cue for going to music' (MT).

Overall, interviewees indicated that participants' initial anxious behaviours led to a genuine enthusiasm and joy. Introductory sessions tended to be one-way emotional outlets for some, where they were unable to interact with the tutor. Participants' familiarity with the room layout and musical instruments fostered increasing levels of comfort and confidence. Observational and behavioural matching techniques employed by the tutor, allowed trust to be developed within a short period. He then gradually introduced more improvisational and musically creative ideas. Interviewees noted how the unpredictability of a situation could adversely affect participants outside, due to their respective sensory influences. The growing familiarity of the music sessions aided in minimising any unwanted stimuli and increased levels of comfort. Following a number of weeks working with the tutor the intervention, positive behavioural changes were observed.

Audio-Visual Learning

Observations on how participants' audio-visual aesthetic choices affect the efficacy of multi-sensory interaction.

Interviewees reported on personal auditory and visual learning processes of the participants that may have influenced their use of the *CymaSense* application. Parents mentioned that their children are visually driven – '[P1] is a visual learner, [they take] in a lot of the finer detail' (PA3); '[P4] can walk up to something like a find Wally poster, just do this [finger pointing gesture] and point it out' (PA1). They commented on their children's ability for pattern recognition – '[P2] remembers everything, like [they have] got a computer in [their] head, [they sit] in the back [of the car] but [they know] exactly where you are on the road' (PA2). Interviewees went on to indicate participants' preferences for visually-driven problems - '[P2] also has one of those jigsaw puzzles … [they do] that quickly … sometimes [they do not] even look at it, [they] already [know]' (PA2); '[P1] is very good at puzzles, quite intricate ones as well' (PA3).

Interviewees inferred that iconic visual imagery aids participants' memory in associating non-text based logos or signs with particular objects – '[they] never forget an image' (PA1); – '[they're] also attracted by signs and car logos'; 'We've always got to get Tommy Hilfiger brand name underpants … [they] really [go] for familiar logos' (PA1). Similarly, interviewees reported that exaggerated imagery is an effective way to form emotional associations for people with ASC – 'Disney's emotions were so exaggerated … it's much easier to catch onto'; 'A strong image, [they] would be attracted by' (PA1).

Interviewees reasoned that participants with ASC translate audio information into visual components that may be used as a basis for learning – 'Even though [they] like the sound of music, [they seem] to translate everything into visual terms … when [they're] speaking [they] say it as written, if you say to [them] "say knife" [they'll] say "k"' (PA1).

They suggested that meaningful connections to music are facilitated via a visual element, highlighting the importance of multimodal learning – 'It's got to be connected to music. [They] won't watch a Disney film, but [they'll] watch the short singalong ones that he associates with a particular song' (PA1); 'Bringing in that [visual] element [P1] realised, "oh", there's another modality ... [they know] the cause and effect there' (MT).

Interviewees also identified colour as being an important factor for participants in self-regulating their temperament – 'Bright colours, multi-colours, anything with colour [P1] loves it … coloured socks, doesn't like plain ones.'; '[They seem] to be able to match colour, [they know] what goes with what' (PA3). The tutor implied that participants used colour to match their mood during sessions – '[P4] loves manipulating, controlling, reflecting [their] mood with colour palette choice … sharp contrasting primary colours'; '[P6] [likes] big and bold contrasting colours and movement' (MT). He suggested that the animated movement of the Cymatic shapes was a motivating factor for participants – '[P1] reacted very positively; it adds novelty and an extra sensory dimension to the music'; '[P8] was enjoying controlling the animations and extra theatrical sensory dimensions' (MT).

Overall, interviewees suggested that participants could associate music making with its *CymaSense* visual counterpart more effectively than without visual feedback. They identified participants' abilities in pattern recognition, and implied that audio-visual association aided their memory of the *CymaSense* music sessions. This association could be further strengthened through animation of iconic shapes and individual colour choice.

<u>Communication</u>

Observations on development of participants' communication, from a musical and non-musical perspective, over the course of the study.

Interviewees commented on how levels of stress and stability can affect the desire for participants to initiate communication, rather than responding to others. They suggested that once a level of independence had been established, initiating communication seemed to come more naturally.

Interviewees inferred that the stresses of being expected to communicate verbally had an effect on participants – 'if you catch [them] off the cuff, [they manage] to say things quite easily and then other times you're like [P1] say that, and for [them] to think about it and that causes [them] nervousness' (PA3).

However, interviewees recognised that once a sense of control had been established throughout the sessions, participants had a greater ability to express themselves verbally – 'The day that [P4] actually started doing more, taking a bit more control and a wee bit more power, that was the day [they were] walking back there giving me this "music room good go back … go back soon …" that was a wee milestone for me, and I'm sure that's a direct result of the sessions, it definitely is' (PA1). One interviewee highlighted that the sessions had been beneficial from a communicative perspective - 'it's done [them] a lot of good and communication in general is massively changed since we've been here' (PA1). Interviewees pointed out that some participants were communicating with greater vocal or verbal intensity following the study – '[P4] is now responding with greater verbal communication in sessions' (MT); 'we did see a change in [P1], trying to be verbally more communicative' (PA3). Not all participants ability to communicate verbally were altered – '[P2 has] no speech whatsoever' (PA2). However, feedback also indicated participants' non-verbal appreciation of the application – '[P1] Yes, by non-verbal gestures and signs'; '[P4 was] happy to give high five's and eye contact' (MT).

One interviewee indicated that independence gained from increases in communication reduced the need for assistance – '[they're] making [themselves] understood now, so I feel I'm not constantly needed as an interpreter ... I'm feeling a wee sense of freedom in that I'm able to take a wee step back' (PA1).

From a musical perspective, interviewees commented how interactive communication for participants had developed – '[P7] has a greater capacity for shared experience and co-improvisation, towards song and performance composition'; '[P5] [was] using voice and rhythm to manipulate the environment' (MT). The tutor identified that participants were open to novel and shared experiences – '[P4] [showed] greater sense of partnership, communication, negotiation'; '[P2] was more open to try new things, new unfamiliar objects and activity' (MT). He highlighted the ways in which the application nurtured a sense of performance - '[P8] was suggesting new ideas and ways of using Cymatics in a performative way'; 'In fact we did quite a lot of stuff in the last 3 or 4 weeks, where it would almost be like a performance'; '[P8] was using voice and piano to develop a sense of performance and theatre.' (MT).

Overall, interviewees suggested that the increased levels of participant communication related to comfort levels and stability. Participants' anxiety and personal expectations in initial sessions were reflected through lower levels of eye contact and verbal communication. Interviewees suggested verbal and gestural communication levels increased in later sessions as participants' confidence grew. This encouraged a level of musical exploration and play, which opened participants up to new experiences that subsequently led to a desire to communicate with others.

<u>Independence</u>

Opinions on the importance of participant control and independence in the music sessions through use of the CymaSense application.

Interviewees commented on how important levels of control were for participants, through making their own choices, and how that influenced their sense of independence – 'I noticed a difference as a couple of weeks went on and [P4] was actually able to take a bit of the power [themselves] with what was happening with the machines and volume and so on'; 'this is all moving towards independence, definitely' (PA1); '[They initiate], generally, the structure and the direction of the music. [They love] to have that kind of control'; 'I think [P7] really felt it was all about being in control' (MT).

Subsequently, the tutor signified how independence led to a meaningful experience - '[P7] is making these incredible patterns, which [they] alone [are] manipulating and in control of. It's almost letting [them see a side of [themselves], [their] own expressions, animated up there'; 'when [P1] realised that [they were] really manipulating that environment [they'd gotten] this other sensory level, sensory feedback…it was really meaningful to [them]' (MT).

The tutor implied that initial use of the application seemed to distance participants from himself – 'the effect initially was "wow", the level of independence [P1] had controlling the Cymatics environment … [they] became deeply engaged in the object, and for a while less engaged in what I was doing'; 'There were a few weeks where it was about [P7] and the Cymatics, and less about my interaction' (MT). However, he suggested this was a period of self-expression from which participants became more independent – 'I thought it was really interesting, because there was that level of independence when [P1] was manipulating the colours by [their] beats' (MT). He noted his subsequent ability to allow participants space to control the session from time to time; 'I could actually withdraw my input and just watch what was going on' (MT).

The tutor recognised the effect that greater control had on creativity - '[P7] was becoming a bit more controlled, realising that the Cymatics was able to match [their] whole range of emotions and vocal expression' (MT). He reported that participants then invited him to join in once a level of control had been established – 'over the weeks, [P7]'d certainly invited me in to become much more reciprocal … that really built up that dialogical element to the sessions' (MT).

The tutor implied that some participants developed their level of self-awareness within a social context over the course of the study – '[P8] developed self-identity as a performer'; '[P5] was enjoying the sense of a defined role within the group as a leader' (MT).

As the music sessions developed, interviewees indicated that levels of independence increased, beginning from an apparently isolated period of exploration, through to gaining greater levels of confidence, which finally led to an interactive experience. This process lessened the need for caregiver assistance.

<u>Interface</u>

The playability and accessibility of CymaSense are discussed, and how they affected creativity. Please refer to Table 7-14 for a summary overview of participants' feedback on technological interaction.

Interviewees commented on the ways participants' attitudes differed towards technology outwith and within the sessions. Some participants seemed to be drawn to technology – 'what you can certainly say with [them] is that computers are just [their] thing' (PA1); '[They] do use a computer, a smartboard [they] used at school … [they've] got [their] own little tablet' (PA3). On the other hand, interviewees implied that participants can tire of technology – '[They have] a Wii app, but I think [they find] it a bit boring' (PA1); '[They're] not a technology-driven [person]' (PA2).

Regardless of the participants' preferences, interviewees inferred that interaction with *CymaSense* was positive – '[P8] [finds it] very positive, enjoying the sense of control and independence' (MT); 'from the non-intervention stage to the intervention stage, when the technology came in, [they were] definitely a lot more interested.' (PA1).

Interviewees suggested that *CymaSense* was intuitive and accessible enough not to require training for use – 'you know straight away, that person realises they can control the sensory environment independently, and the fact there's no instructions needed'; 'sensory integration in a safe, novel and structured way' (MT). In addition, they noted that the interface was user friendly – '[P4] loves, manipulating, control, and reflecting his mood with colour palette choice and shape'; 'you could see that [P4] became very familiar with the Cymatics and the laptop' (MT). The tutor identified how participants adapted the application to suit their own tastes – 'they could take ownership of, rather than it being a tool that was all instructive and prescriptive'; '[P8] makes decisions and initiates a change of colours, [they] would say "what if it was gold and black?"' (MT).

The tutor mentioned some unpredictable improvisation from participants, relating to *CymaSense's* playability – 'lots of surprises there about people being really creative with it'; '[P4] would then bring in other instruments, acoustic instruments, as though [they were] being curious and thinking "so if drum on that surface I'm going to get these patterns, okay I've got that right, sometimes if I vocalise …"' (MT). He commented that it had created novel experiences for participants, describing it as a ‘non-verbal playground’ (MT), adding that it added ‘extra theatrical sensory dimensions to the music sessions’ (MT). He suggested it could amplify feelings of creativity in participants through ‘augmentation of emotion and creative expression’ (MT).

The tutor implied that by using the application via the interactive table (Figure 7-3), the shared space created a comfortable environment for participants - ‘that’s so important that there was shared space, that was certainly within his comfort zone, that I was a space apart … so much less eye-to-eye contact needed’ (MT). He inferred that this multimodal shared space facilitated a greater improvisational dynamic – ‘… a visual field in the middle that we’re interacting with … even the different dynamics, and formations of the Cymatics were really influenced by the proximity’; ‘[it] developed motivation for more spontaneous co-improvised expressions’ (MT). He signified the importance of a shared activity within a session and how it could aid in the development of communication – ‘you didn’t want it to be an activity that it’s just about using a gadget, you want it to be shared. You want a bit of inter-subjectivity in there, so it’s something we could talk about, not verbally, but we can play with, almost compare and have that dialogical dynamic happening, and I think that definitely occurred’ (MT).

The music tutor suggested that the aesthetic of the Cymatic shapes may have expanded the expressive potential of the sessions - a ‘great tool to widen aesthetic experience, impact on the scope of the sessions’; ‘…adds novelty and extra sensory dimension to the music sessions’ (MT). He implied the application worked well to raise participants’ awareness through the multimodal approach – ‘Great tool for sensory integration and connectivity of the environment’; ‘Greater ability for cross-modal expression and activity, [P1] is initiating a wider repertoire of musicality and expressions through movements, rhythm and vocalisation’ (MT).

Interviewees commented on the effectiveness of the audio to visual mapping. They implied that participants recognised and explored the connection between audio volume and visual scale: ‘you see it can be a tiny little shape that they’re making, or it can be massive, so tailored to that individual' (MT); 'Once it clicks with [them], "I hit this hard it's bigger faster"'(PA3). The tutor mentioned that the sensitivity of the application aided in creativity - 'The sensitivity of the triggers led [them] to explore more subtle, meditative expressions' (MT). He implied that the 3D nature of the shapes augmented the audio-visual dynamic – 'I think [P7] enjoyed the 3D visual aspect of Cymatics, which mirrored [their] wide range of vocal expressions when using the microphone, [their] voice animating the room'; 'The 3D aspect was important and meaningful' (MT).

The tutor also recognised successful pitch to colour associations – '[It] links in well with [P6]'s synaesthesia, relating sounds, pitch to colour and sensory integration' (MT). He specified one participant's recognition of how pitch related to Cymatic shape – '[P4]'s really using pitch, and making that connection between how pitch and Cymatics work. So the higher pitches, "what happens if I'm going up the scale?" "Oh right, what happens visually there?"'(MT).

The tutor implied that the Cymatic shapes created an interesting aesthetic that augmented the musical interaction – 'I think it really is a good thing because it's just like a different realm, you know … the shapes and the contours lend themselves to something like melody and pitch and percussion and music certainly' (MT). He suggested that the organic nature of Cymatics was motivational for participants compared to other forms of music visualisation – 'a lot of the guys look at their frequency graph or whatever, and that's quite mathematical … some people are quite attracted to that kind of visual feedback. But there's something really attractive and motivational, the organic element, the nature of the visuals are attractive to a lot of people' (MT).

Interviewees recognised potential for the application and suggested other user groups as beneficiaries – 'Scottish Autism, Sensatronic-Lab, mainstream schools' (MT); 'I would have definitely recommended this to them. I would have said to them, go and try this' (PA1); 'Children in [P1]'s class ... you could take it forward from there' (PA3). The tutor signified that even though the application worked well with the participants with ASC, 'all with different sensory needs and different levels of needs, and different levels of ability' (MT), he would be keen to use it with others – 'there's a whole range of other people that I work with that I would love to introduce that. I mean even people who have visual impairments' (MT). The tutor commented that longer-term use would be favourable for participants who take time to adapt to new situations – '[It] might not be for everybody, but significantly I would say it would be great to use longer term' (MT).

Interviewees suggested personalisation of animated shapes and gestural recognition to further tailor the application for potential users – 'Personalised animations, symbol palette, movement sensor applications' (MT). The tutor suggested that participant input could provide potential for more meaningful interaction – 'can it trigger patterns or animations that have been developed by participants? Or images? I think that would be interesting looking at the wider potential of it to really personalise that' (MT). Another interviewee proposed use of *CymaSense* as a speech development tool – 'when [P1]'s not speaking, [their] muscles aren't being used, to see these vowels all the time, it's almost an exercise, I think that would be good' (PA3). The tutor also pointed to suggestions made by one of the study participants - '[P8] mentions wider animation possibilities and performative potential' (MT).

Table 7-14 provides a summary overview of participants' feedback on technological interaction. It highlights positive and negative attributes of participants' attitudes towards currently used technology, and *CymaSense*. Overall, despite varying attitudes towards computing technology outwith the music sessions, interviewees suggested that *CymaSense* was accessible for both participants and for the tutor facilitating the sessions. They indicated that the audio-to-visual mappings were effective, and that the interface was intuitive enough to allow repeated use and encourage a sense of control within participants. Interviewees also indicated potential uses for additional therapeutic groups, and have made suggestions concerning more personalised uses of the application.

	Attribute	Positives	Negatives	Comments
Currently Used Technology	Home Computers	Some participants drawn to them, useful means of learning	Can encourage isolation, not socially interactive	Not used by all participants, but useful tools used in moderation
	Nintendo Wii	Encourage body awareness	Repetitive games can bore some participants	
	iPad, iPhones	Good variety of apps, portable	Not all apps well developed for beneficial use, flat screen not good for hyposensivity	
	Smartboard	Large screen for feedback, good learning environment	Limited to school use, expensive	
CymaSense	General Use / Wall-Projected	Intuitive, positive interaction, non-verbal playground, augmented creativity/expression, encouraged performance, integration of therapeutic environment, initiating wider possibilities through visualisation of vocals, rhythm and movement, shared experience not a gadget	Does not encourage whole body awareness	Gestural based musical interaction could encourage body awareness. Could be projected onto any object for future use
	Interface	Easy to use, frequent colour changes to match mood,	Did not use other features such as recording and playback	Other features could be introduced over longer term use
	Interactive Table	Shared space created physical comfort zone, less eye-contact required for interaction, shared visual field improved musical interaction, acoustic percussion placed on table triggers visual output too	Audio output created from electronic applications only	Any object could be turned into a musical instrument via same contact microphone technique to extend tangible user interface possibilities
	Aesthetic	Cymatic shapes widen audio-visual aesthetic experience, extra sensory visual dimension, organic nature reflects musical improvisation well, better than spectral analysis	We do not know how successful other shapes would be as they have not been tested	Future study comparing a variety of visual output is recommended
	Mapping	Works as a learning tool through association of pitch to shape, pitch to colour and volume to size - 3D dynamic nature aids in musical exploration	Mapping of tone to surface quality of shapes were not mentioned	Tonal mapping may have added to the general visual exploration, however, more exaggerated tone to surface quality recommended
	Potential	Suggested use: other therapeutic groups; performance; speech therapy tool. Longer term use may be more beneficial, personalisation of shapes requested	Recognisable objects may detract from musical exploration through association for ASC users	Future version allowing easy projection of user-based shapes suggested

Table 7-14: A summary overview of participants' feedback on technological interaction

7.9 Discussion – Phase 3

The results of the interviews support other studies that describe the use of multi-sensory environments, tangible user interfaces and natural user interfaces. Work by Cibrian *et al.* (2017) embodies the Therapeutic Instrumental Music and Performance technique (TIMP) in their *BendableSound* application (see Figure 7-10) for children with ASC.

Figure 7-10: A child with ASC interacting with *BendableSound* (Todos Somos Uno, 2017)

The TIMP technique is where therapists play musical instruments to help clients practice physical exercises; however, the clients themselves do not play any instruments. *BendableSound* was shown to be a successful way to encourage body awareness and independence in children with ASC through the use of an interactive audio-visual fabric surface. The *CymaSense* study differs in its aims to create a multi-sensory environment more typical of a regular improvisational music therapy session, allowing participants options to play any instruments they desired.

Ringland *et al.* (2014) also demonstrate multi-sensory work for children with ASC with their *SensoryPaint* application (section 2.2.2), focusing on body awareness and sensory stimuli. The authors employ a natural user interface (NUI) approach negating a need for technological tools or training, similar to the approach used by *CymaSense*. Villaroman *et al.* (2011) identify NUIs as a more intuitive way for children with ASC to interact with a computing device compared to a typical graphical user interface. They employ a Microsoft Kinect sensor to facilitate interaction with various applications through gestural interaction. Research has shown that use of multimodal and NUIs aid in balancing children's attention between their own bodies and sensory stimuli, augment existing therapies, and promote socialisation (Ringland *et al*., 2014). It has been recognised by Crippa *et al.* (2013) that people on the autism spectrum have poor hand-eye coordination (section 2.2.2). Extended use of *CymaSense,* through the use of a tangible user interface, could improve their hand-eye coordination as well as communicative behaviours outside of the music sessions.

Anecdotal feedback from the interviews indicate that participant behaviour, prior to, during and following the study sessions, is affected by a number of factors. The expectations of parents and tutors can be an additional cause of anxiety for people on the autism spectrum, further creating behavioural problems. Pares *et al.* (2005) recognised this within their own MEDIATE study. Subsequently, when people with ASC are less self-conscious and express themselves more freely, confidence builds within that individual. The MEDIATE study differed in a number of ways to the present study that employed *CymaSense*. Children interacted with a digitised large screen environment (see Figure 2-11) using a natural user interface approach that encouraged full body interaction. There were a maximum of three sessions for participants between 5 and 35 minutes long, depending on their levels of comfort. However, the goals of the study were similar to the TouchBase study in aiming to help gain a sense of control and improve levels of communication. Although the TouchBase study took longer to complete, the implications for increases in interactive communication are potentially greater than the MEDIATE study, based on reported increases in communicative behaviours. Developments in participants' ability to communicate with others can subsequently take the pressure off caregivers as translators and facilitators. There is evidence in other studies for children with ASC that support the idea of lessening caregiver assistance through increased use of a multimodal intervention (Schaaf *et al*., 2014). Schaaf employed a measure of caregiver assistance in self-care within their occupational therapy based study, and demonstrated a significant improvement. Results from this study suggest that the *CymaSense* application is responsible for changes in communicative behaviours over a 12-week period.

Prior to the start of the study, the music tutor expressed his reservations that the application might be too distracting for some participants. Stimulus overselectivity in autism is a recognised problem where people with ASC respond to only a limited number of cues in their environment (Hunt *et al.*, 2004). The tutor's concern related to a potential lack of engagement from a musical perspective. Initially, this seemed to be the case as some participants became so engaged with the application that they ignored the tutor for a period of time. However, it could be gathered from the interviews that engagement with the application encourages independence, further developing social interaction, and then communication, for some of the participants. Music therapist Dallimer commented that research would be needed on the suitability of an audio- visual instrument for particular client groups (Hunt *et al*., 2004). She specified that in some cases the visuals might distract the client from the music, whereas in other situations the visuals may be a 'way in' to a client who was previously struggling to become engaged in the music. Evaluation of the interviews suggests that regular use of the application amongst participants develops a sense of control and independence. This in turn leads to musical exploration, which further establishes a sense of identity. This process then recapitulates with the participant becoming more aware of the potential for involvement of the music tutor. The desire of the participant to share in the audio-visual music making process translates into eye contact, gestural interactions for turn-taking or even verbalised invitations for the tutor to join in and improvise. A subsequent increase in social interaction occurs.

Neuropsychologist Damasio (1999) describes core consciousness experience as non-verbal and non-cognitive, arguing that communicating through the use of sound is more effective for music therapists working with the autistic, than language based interventions. It could be argued that *CymaSense* augments that non-verbal communication through its visual modality. Participants subsequently feel more at ease without the necessity for language. Moreover, having a shared space between therapist and client shifts focus from any expectation of the participant to a joint visual canvas where both therapist and client have equal say over its visual output. The addition of the visual modality fosters a co-creative environment that raises awareness of the potential for therapeutic music sessions through its ability to visualise any sound.

Interviewees in Phase 3 suggested that the increased levels of participant communication related to comfort levels and stability within the sessions. It could be that the increasing levels of communicative behaviours, noted in Phases 1 and 2, were attributed to participants' levels of familiarity with the music tutor and levels of comfort within their surroundings. To verify this, a separate study without *CymaSense* would be necessary to compare the effect of the application. However, it should be noted that the music tutor, who had worked previously with all but one of the participants, inferred that the motivational factors of *CymaSense* were driven by the visual modality. This suggests a comparison between previously held purely musical interaction sessions, and the effect of *CymaSense* on the present study (see section 7.8).

It was reported that participants missed interaction with the *CymaSense* application during the withdrawal phase. However, it could equally be argued that its availability had become part of their new routine and its subsequent removal created a need for its use. It is well noted in literature that people on the autism spectrum rely on routine as a means to feel comfortable in their environment (Fletcher-Watson *et al.*, 2016). Wigram (2000) recognises that during improvisational music therapy, certain patterns can also reveal routines within participants' music making. He suggests that a balance between predictability in improvised routines and controlled flexibility in how melody and rhythm are used, can create effective interaction (Wigram and Elefant, 2009). He goes on to highlight that it is participants' intentionality that needs to be best understood from the musical exchanges, rather than any recognised musical routines that may be apparent. In the context of the use of *CymaSense*, once a platform for creativity has been established, the absence of the visual modality could be analogous to disturbing the predictability of that aspect of their musical routine.

From a play perspective, it is described by Tarbox and Persicke (2014) as being easy for therapists to fall into their own routines for teaching purposes. This can be detrimental for the participants' flexibility and behavioural development. However, aside from the initial welcome and end-of-session routines, the music tutor seemed to encourage participants to express themselves in a diverse and creative way throughout the majority of the music sessions.

General feedback seems to indicate that the audio-to-visual mappings, which drive the selection and animation of the Cymatic shapes, were appropriate. Comments from the interviews indicate that recognition of iconic shapes, such as car logos, was a strong feature amongst some participants and may aid in in musical learning through association of pitch and shape (See Table 5-4). Although the shapes were of a generally abstract nature, feedback indicates an organic and identifiable quality to them, which helped facilitate interaction. It could be argued that if the shapes were more symbolic and identifiable, the effectiveness of the non-verbal interaction could be compromised, by relating more to language or to specific objects. Previous research has shown that some autistic participants can easily identify shapes within complex patterns compared to neurotypicals (Parés *et al*., 2005). It is conceivable that visually driven participants thrived on the complexity and variety of the 3D shapes and the ways in which their musical input could affect the visual output in variety of permutations. Additionally, the 3D nature of the shapes implies an added sense of dynamic to the interactions. However, not having tested the application with 2D shapes, further research is required. This would involve the creation of, and comparison, of a set of similar 2D and 3D shapes that were triggered by participants' choice of audio input. This potential study could be facilitated through the CymaSense application.

Consideration could be given to the fact that the use of colour was an important means of facilitating choice and subsequent independence for the study participants. The repeated interaction of the user interface for some participants allowed self-regulation of their mood through colour choice, and increased a sense of control. In addition, minimal instruction was given to the music tutor prior to carrying out the intervention, implying an accessible design. It appears that the working practices of the tutor were not adversely affected by using *CymaSense*, as he nor any participants were deterred from playing any of their favoured instruments.

The music tutor did not encourage participants to use all available functions of the current version of *CymaSense*, for example, recording and playback, other than colour selection capabilities and use of shape rotation. The tutor may have been reluctant to provide too many options for participants, or to use an untested function that may have interrupted the session. However, the reasons for this were not identified and another study would be required to evaluate the need for all currently available functionality.

Potential use of *CymaSense* has been highlighted in a number of ways, including greater personalisation through creation of customised shapes and as a speech therapy tool. Feedback from the interviews indicates that there is a strong association between iconic shapes and objects for participants. It is conceivable that visualisation of personalised shapes would reinforce associations from the participants' perspective and subsequently narrow the field of exploration from a musical perspective. Visualisation of recognisable shapes could remove any element of surprise and detract from the improvisational aspect of a music session by reinforcing established relationships. However, additional studies are required to test the efficacy of personalised shapes compared to Cymatic shapes.

7.10 Conclusions

In this study, we set out to test the following hypotheses: (1) There is a significant difference between the number of musical and non-musical communicative responses demonstrated by the autistic participants in the first and last sessions of the 12 week study; (2) There is a significant difference between the number of musical and non-musical communicative responses demonstrated by the autistic participants in their last non-intervention and first intervention sessions; (3) There will be changes in the communicative, social and musical behaviours of the autistic participants observable by parents, care workers or tutor at the conclusion of the 12-week period. We designed and ran a series of therapeutic music sessions with eight participants over 12 weeks using the *CymaSense* prototype. Use of *CymaSense* was customised for each participant during the sessions either as: an interactive table; a two-user version with two microphones to visualise the sound of client and participant projected on to the wall; or via a single microphone to visualise any acoustic sound in the music room projected onto the wall. We have shown that use of *CymaSense* indicates an increase in communicative behaviours for the majority of the autistic participants.

Although it is difficult or even impossible to gather a homogenous group of people with ASC, the design, implementation and results of the sample population in our study support the initial hypotheses. These state that the use of an interactive audio-visual tool appears to improve communication for people on the autism spectrum. A further series of interviews identified attributes of the study participants that may have affected their interaction with *CymaSense*, as well as key elements of the application that worked well and those that could be improved upon.

This evaluation of *CymaSense* opens up new possibilities for other sensory impaired groups. The *CymaSense* system architecture can support visualisation of any sound through 2D or 3D graphics, making customization for alternative groups simple. Future studies concerning the use of *CymaSense* by children and by alternative disability groups, including the hearing impaired, may promote social interaction by encouraging group play and turn taking.

TUI interventions (Villafuerte *et al.*, 2012) or NUI interventions (Ringland *et al.*, 2014), used in other studies, promote communication and social interaction within autistic children. In this study, which involved eight autistic adults, four of which were non-verbal and two only exhibited limited language skills; we have demonstrated that significant improvements in communication can be observed by augmenting music sessions with real-time visual feedback. The single case qualitative analysis has provided specific insight into the usefulness of the intervention and of the system developed.

8 Conclusions and Future Work

The final chapter begins by restating the research aim and questions, and then looks at how each part of the thesis has addressed them. Strengths and limitations are discussed, and contributions are identified. The chapter concludes with future work.

8.1 Answering the research questions

The aim of this research was to develop and trial a multimodal application that would allow therapeutic music practitioners a novel way to improve communicative behaviours for people on the autism spectrum. In order to achieve this aim, the following main research question and three sub-questions had to be addressed. The main question asked whether augmentation of music sessions with real-time 3D graphics could improve therapeutic outcomes for people with autism. Sub-question one addressed how effective the audio-visual mapping of the prototype developed was for autistic and neurotypical end-users. Sub-question two queried what benefits a shared real-time interactive audio-visual application brought to autistic clients within therapeutic music sessions. The final sub-question investigated the perceived benefits of the application beyond its use within music sessions.

The main research question addressed whether an interactive 3D visual modality within music sessions could be effective as a therapeutic tool for people on the autism spectrum. Chapter 2 reviewed the challenges people with autism face and how their cognitive abilities can be affected. It also looked at current interventions and identified music therapy as a creative and emotionally engaging form of therapy. The visual representation of sound was reviewed in Chapter 3 with Cymatics being identified as an aesthetic for the visual modality of an application, *CymaSense*. In a preliminary study in Chapter 4, interviews with therapeutic music practitioners gathered opinions on current practice and the needs of autistic clients within music therapy, and identified potential ways to improve their methods. Practitioners also highlighted some of the technologies that are currently used, and the scope for future applications. Three sub-questions addressed the main question more specifically.

Sub-question one sought to establish whether designed audio-visual correspondences of a prototype application would be intuitive to both autistic and neurotypical users. Chapter 3 looked at cross-modal correspondences and how audio-visual information has been represented through media and computing, dependent on its requirements and design. Chapter 5 covered the design and implementation of *CymaSense* versions one and two, based on literature reviewed in Chapters 2 and 3, and from requirements analysis in Chapter 4. A survey in Chapter 6 completed by neurotypical participants and those with high functioning autism, determined whether the designed audio-visual attributes were effective and appropriate for further evaluation with end-users.

The second and third sub-questions were concerned with the identification of beneficial attributes for autistic clients, and how they may have been developed in the use of a shared audio-visual interactive application. Current autism-based interventions were identified in literature in Chapter 2, including practices in clinical and community-based music therapy. A number of assistive technologies were reviewed in Chapter 2, some of which have previously been utilised for effect within therapeutic environments. Interviews with the music tutor prior to and post-study reflected on the ways in which *CymaSense* benefitted their practice and their clients. Effective measures had to be established and combined with appropriate methods of testing. A published method used in improvisational music therapy, identified in Chapter 2, was used as a basis for a 12-week study with eight autistic participants. A single case design approach was employed using the *CymaSense* application as intervention, which was tailored in a number of ways for each participant. The study, detailed in Chapter 7, included observational analysis of a number of musical and non-musical communicative measures within a therapeutic environment. Phase 1 included an initial eight-week series of sessions, using a simple AB intervention approach. Following the decision to validate initial findings, a subsequent four-week follow-up Phase 2 was agreed by all stakeholders in the form of a BAB reverse intervention withdrawal method. An interval of seven weeks divided the sessions. Following Phase 2, parents, carers and tutors were asked to complete a questionnaire providing opinions on observable changes in participants' behaviours as a result of the study. This was followed by Phase 3, a series of semi-structured interviews, which took place with parents of participants and the music tutor. The aim was to gather qualitative data concerning the background preferences of clients, and their subsequent use of *CymaSense*. Quantitative data analysed from video observation over 12 weeks, and feedback from the questionnaire and interviews, indicated that both musical and non-musical communicative behaviours of the majority of the participants had increased in response to use of the intervention.

8.2 Strengths and limitations

8.2.1 Methods

Methods associated with capturing experiences of people on the autism spectrum are typically difficult to standardise, due to the nature of the condition. Geist and Hitchcock (2014) argued that if practitioners wished to seek out the very best internal validity for music therapy, then randomized controlled trials (RCTs) should be pursued, assuming that the sample size is large enough. However, in dealing with autistic participants, no typical group exists where all participants can be treated in the same way. In addition, the sample size within this study was small, and unsuitable for RCTs. The thesis adopted a mixed method approach for both quantitative and qualitative assessment of the mappings of *CymaSense*, and for its use within practice. A composite variable approach was used through prior identification of the target behaviours of participants, which were themselves adapted from a method used by Edgerton (1994a) in identifying behavioural changes in improvisational music therapy. This method had not been used within the evaluation of a multimodal application.

Further investigation of methods to gather the opinions of users on the lower end of the spectrum would have been appropriate in developing *CymaSense*. For example, initial passive observation of music sessions as employed by (Cibrian *et al*., 2017) could have identified any common issues faced by session participants in their use of technology and their favoured interaction methods. This would have influenced initial design decisions as part of the requirements gathering process. Low fidelity prototypes, paper-based or prototyped screens, could have been co-created following discussion with parents and the music tutor concerning what shapes and colours were attractive to participants. Participatory design approaches (PD) have been used in research in the co-creation of smart objects and augmented reality aplications (Frauenberger *et al.*, 2019)(Escobedo *et al.*, 2014). However, Politis (ASDTech, 2019) commented that recent studies have shown participatory design can sometimes produce an outcome that is less effective than its non-PD developed version. This may be due to the autistic participants' lack of understanding in more complex technologies, thus not enabling a meaningful contribution. Politis suggested, therefore, that sometimes it is not possible to involve a special population in Participatory Design and seldom, when Designing by focus groups can be stifling to a new idea. Nonetheless, direct feedback from non-verbal users may have been facilitated through the use of augmentative and alternative communication (AAC) methods (National Academy of Sciences, 2017). This approach could have complemented chapter 4 requirements gathering data, which would have been implemented as informed design decisions within chapter 5. Interviews conducted in chapter 7 were limited to parents of participants and the music tutor. Additional feedback from participants was deemed unsuitable by the tutor. However, limited feedback from each participant could have been facilitated through simple question and answer from the tutor, or via AAC methods, which may have provided greater insight into the effectiveness of the application. This approach was implemented by Ringland *et al.* (2014) in evaluation of *SensoryPaint*.

Regarding ethical considerations, HFA participants within the mapping survey granted explicit consent for their participation. However, consent for autistic participants within the chapter 7 study, including permission for video observation, was provided solely by their parents or guardians. Video observation was discussed with participants with verbal skills, however, no explicit permission was requested from them. Previous autism-related research has demonstrated the abilty to obtain permsission from both participants and their parents (DePape et al., 2012)(Ludlow et al., 2014a). Future studies would aim to make every effort to inform and obtain permsission from verbal and non-verbal participants, given their available skills, and communication abilities.

Many intervention-based studies within autism typically run over a limited time span dependent on the availability of participants and resources, including regular access to a suitable environment. For example, Cibrian *et al.* (2017) tested their *BendableSound* installation on a daily basis over six days, Hobbs and Worthington-Eyre's (2008) Virtual Musical Instrument was trialled over an eight-week period on a weekly basis. Similarly, the Edgerton (1994a) improvisational music therapy study was tested over ten weeks. Pavlicevic *et al.* (2013) noted that access to long-term music therapy (over two years or more), and possibly to any therapeutic activity, helped young autistic adults and their families cope with the demands of everyday life, stresses, and life transitions. Extended effects of the use of *CymaSense* over a longer period are not known at this time. The longer term benefits or limitations of *CymaSense* may identify how much of an effect regular music sessions are having on participants compared with the use of the intervention, and how life outside of sessions has been affected.

8.2.2 System Design

CymaSense is currently a combination of two software environments, one to analyse and process sound, the other to create 3D visualisations based on the audio input. The design decision to use particle-based animations has created a CPU intensive system where a powerful computer is required for use. A redesign of the system for easier installation and use on mobile devices is recommended. Advocates of persuasive technology design for young people with ASC, propose that use should extend beyond the school and into the home (Mintz *et al.*, 2012). This would allow shared use of the application in any environment for family and friends. A limitation of this development would likely result in lower quality graphics. However, the current application can be used to visualise any 2D or 3D shape as a result of its system architecture, allowing customisation of shape visualisation for end-users.

The use of 3D visualisation has been implemented in gamified virtual reality scenarios as avatars, aimed at targeting emotional expression for the purposes for teaching children with autism (Boucenna *et al*., 2014). Similarly, Cheng and Chen (2010) implemented a 3D-facial recognition intervention system for Individuals with intellectual and developmental disabilities. Pouris and Fels (2012) created a visualisation system for hearing-impaired users that used simple 3D shapes as a basis for the representation of pitch, volume, tempo and rhythm of MIDI information (see Figure 3-9). A number of interactive 3D applications, discussed in section 3.5.1, have been employed to represent music in a number of subjective ways. The use of animated 3D models that visualise the volume, pitch, and tonal qualities of music, based on Cymatic shapes, is novel within therapeutic sessions. Results have suggested that the spherical nature of the rotated shapes, which allow viewing from a number of angles, potentially reduces repetitiveness and increases unpredictability. However, the design may also make recognition of tonal changes more difficult. In this respect, the use of 2D shapes may be more effective.

It was documented within chapter 5, that the author had previous interest in representing sound as propagating three-dimensional bubbles through an animation project. Cymatics are a relatively unexplored means of visualising music within interactive applications, although its aesthetic appeal and direct relationship with sound has made it ideal as a basis for the *CymaSense* visualisation. However, the design decisions have restricted experimentation of alternative audio-visual mappings. For example, we do not know how effective simpler geometry, the use of pitch to height mapping, or tone to colour may have affected the levels of communicative behaviours of participants. In order to manage any potential researcher bias, literature reviewed in chapter 3 allowed exploration of alternative visualisation methods dependent on their use and intended audience. Practitioner interviews provided information regarding currently used technology and the potential for an innovative approach, which included alternative visualisation methods. Feedback from the supervision team has seen two versions of the *CymaSense* design created. The designed mappings of version two were tested within an audio-visual survey as presented in chapter 6. Moreover, the present research was not attempting to test a range of audio-visual associations for autistic users, but rather to develop and trial a multimodal method that may be useful within therapeutic sessions. The methods used within the thesis were based on previous studies in gathering qualitative and quantitative data through interviews, audio-visual surveys, questionnaires, and case studies used within evaluation of therapeutic interventions. Appropriate ethical procedures were observed and evidence of the data collected and analysed has been made available for analysis. Results have indicated a strong affirmation of the designed audio-visual correspondences, which suggest the Cymatic aesthetic is one sucessful approach. However, an alternative study that focuses on more in-depth variation of audio to visual mappings may provide a clearer understanding the needs of autistic users. This is further discussed in section 8.4.

The design of *CymaSense* was based on literature reviewed and feedback from therapeutic music practitioners concerning the needs of their autistic clients. High functioning autistic participants provided input with regard to the audio-visual mapping survey. However, there was no direct input from autistic end-users in its initial design as discussed in 8.2.1. Some of the TouchBase study participants demonstrated interest in interacting with the interface, choosing colour schemes to regulate their mood, which may have increased their sense of agency as a result. However, not all aspects of *CymaSense* were utilised, in particular, the record and playback functions. These could have been overly complex and unnecessary for the needs of therapist and client. A longer-term study with appropriate practitioner and end-user collaborative design input may indicate functionality that is more appropriate.

Single and two-user modes within *CymaSense* allow individual and shared use of the application. The 12-week study has demonstrated use of the single-user mode as a way for participants to experiment on their own terms, and as a way for both client and therapist to share the audio-visual canvas. The music tutor indicated that this increased exploration for some participants. The two-user mode provides a clear distinction between two musical inputs through its side-by-side visualisation. It has also been suggested by the study music tutor that the two-user mode encourages collaboration, improvisation, and has exhibited a level of performative behaviour in some of the participants.

Similar to other multi-modal music therapy interventions identified in Chapter 2, results from the use of *CymaSense* suggest that it fosters creative expression for individuals with ASC. A level of flexibility in its design could be inferred in the way it adapted to a range of client needs, through visualisation of acoustic or electronic instruments, and not being restricted in its use as an installation with limited musical input. A degree of accessibility has also been proposed, through a lack of disruption of the therapist’s practice within the 12-week study, in addition to the application not requiring training for immediate use. Moreover, when used with the interactive table, *CymaSense* could arguably be described as an accessible audio-visual instrument. Further studies that demonstrate extended use of the table could improve hand-eye coordination, recognised as an issue for some people with ASC (Crippa *et al.,* 2013), as well as communicative behaviours outside of the music sessions.

Shared spaces in autism interventions have shown in an increase in communication and social interaction, in both physical (Villafuerte *et al*., 2012; Hobbs and Worthington-Eyre, 2008) and virtual environments (Parsons, 2015). *CymaSense* has demonstrated its ability to increase the number of communicative behaviours over a 12-week period. Having a shared visual projection can allow both therapist and client to focus on a third party entity, reducing the need for potentially awkward eye-to-eye communication, until such times as the client feels comfortable enough to do so. Similarly, a shared playable surface which also doubles as the visualising space, conceivably allows development of creative expression and may increase communicative behaviours as a result.

8.3 Contributions

The main contribution of this thesis relates to the use of a real-time interactive multimodal application, designed for use by people on the autism spectrum within therapeutic music sessions.

A method for the visualisation of sounds has been defined, based on feedback from therapeutic music practitioners and literature reviewed. Design principles have been derived from autism-based studies, a review of cross-modal correspondences, use of assistive technological interventions, and interactive audio-visual applications. An application, *CymaSense*, was designed and built to visualise the sound of any acoustic or electronic instrument within music sessions. The application is the first attempt to create an interactive therapeutic tool that simulates the refractive wave patterns seen in Cymatics, as 3D spherical geometry in real-time. *CymaSense* was evaluated in an audio-visual mapping survey. The designed audio-visual mappings have contributed to the understanding of effective multimodal associations. Empirical evidence has confirmed previous findings including volume to scale, pitch to lightness, and timbre to shape. The application has demonstrated effective pitch to shape mapping, which differs from other applications where the pitch is primarily associated with vertical height.

CymaSense was assessed in an extended therapeutic music-based study which adopted an evaluative method based on a single case design, previously used to evaluate the effects of improvisational music therapy (Edgerton, 1994a). The study has shown that use of a multimodal application, within a therapeutic context, can increase musical and non-musical communicative behaviours for people on the autism spectrum over a 12-week period. This method could be applied to a wider range of contexts, evaluating the effects of alternative multimodal interventions for autistic participants.

Feedback from the TouchBase study in Chapter 7, suggests that shared use of a multimodal application may help address the issue of mind blindness for autistic people within music sessions. Leslie and Frith (1987) identified that people with ASC lack the ability to take another person's perspective. Clients with ASC in music sessions may find difficulty in perceiving the therapist's motivations or feel comfortable within an environment defined by a hierarchical therapist-client relationship. A shared visualisation of musical input could aid in redefining the perceived teacher-pupil relationship, and creating a collaborative platform for creative input. Creativity then becomes more experimental and playful from an audio-visual perspective, as therapist and client, or group, have the potential to make the same shapes regardless of their musical skills. The study results indicate that *CymaSense* creates a positive reaction for end-users, encouraging play and a sense of agency. The research contributes to further understanding of the way in which multimodal applications can increase communicative behaviours within autistic clients.

8.4 Future work

Although results from the mapping survey and evaluation of *CymaSense* within the 12-week study were positive, additional work has been identified. Future research may include a study that compares several weeks of improvisational music sessions without intervention, followed by the use of *CymaSense* over the same number of weeks. The study could be broken up into two 6-week sessions, and would require participation over a 12-week period with the same end-users. Results may aid in clarification of the effectiveness of *CymaSense* as an intervention, compared to the effect of improvisational music sessions on their own.

Testing of a wider range of 2D and 3D shapes will aid in identification of effective mappings, dependent on user choice. A study that visualised simpler geometric forms (for example, 2D circles, squares and triangles, and 3D spheres, cubes and tetrahedrons) would allow analysis of alternative cross-modal mappings. This could be accomplished via an interactive audio-visual survey and would include testing pitch to vertical height or scale (Walker *et al.*, 2010; Küssner and Leech-Wilkinson, 2014), volume to light intensity or colour (Marks, 1974), and tone to colour or brightness (Smith and Williams, 1997; Pietrowicz and Karahalios, 2013). These mappings would be implemented and tested for efficacy against currently designed cross-modal mappings. Following this, a comparison of the simpler geometry used in the previous study would be made against more complex shapes, including Cymatic shapes, to indicate the most effective audio-visualisation. An additional way of evaluating this, as suggested by the study music tutor, would be through the visualisation of user-defined choices compared against the current Cymatic shapes in a primary study. A comparative investigation of this nature would aid in establishing the validity of Cymatic shapes against end-user choices.

Due to the current demands of *CymaSense* on the CPU, a redesign of the system is required for usage that is more efficient. This includes consolidation of the current audio processing software, and game engine used for visualisation, into one software development environment. This could be implemented solely within Unity (2018) using Pure Data (IEM, 2017) as a native plug-in to process audio input. Development of an efficient algorithm to visualise sound in real time, as Cymatic shapes or otherwise, would reduce processor reliance on using 3D meshes as the basis for particle animations. This would allow a greater level of portability and use of the application on a variety of hardware, including mobile devices.

A *CymaSense* app for tablet or smartphone, for example, could be used as a means for people with anxiety issues to centre themselves in stressful situations. For example, when travelling, the user could wear headphones to block out unwanted noise and use the app to visualise favoured music. Alternatively, the application could be used to visualise sounds within the users' surroundings as a means to transform seemingly harsh vocal and environmental sounds into a more aesthetically pleasing experience.

An app could be gamified for shared or individual play, where solo use encourages vocalisation to unlock further levels of alternative visualisations, or where family members can encourage competition through audio-visual 'ping-pong'. This may aid in increasing levels of communicative behaviours with family and friends. An educational version of the app could be used to teach musical theory or simple composition to users. Alternative pitches could be played that demonstrated the visual equivalent of a specific note. Users are then encouraged to vocalise, hum, or play the appropriate note on an instrument to recreate the same shape.

From a commercial perspective, *CymaSense* has been employed as a means to visualise music at festivals, and as a successful installation, including a five-day run at Edinburgh International Science Festival in 2018. The application can be used to accompany live musicians within a performance-based scenario, by providing a visual indication of each musician's input, or by generating shapes that represent the sound as a whole.

A number of stakeholders and study interviewees have suggested possible uses for *CymaSense* aside from autistic end-users. Other sensory impaired groups could benefit from using the application and would be worthy of evaluation. Research for the deaf and hearing impaired have developed and utilised audio-visual applications in a similar manner for autistic clients within music therapy (Grierson, 2011), and for speech therapy (Pietrowicz and Karahalios, 2013). Using the application would be a way to recognise changes in pitch through shape, or as a means to visualise rhythm. Multi-sensory rooms can act as complimentary therapies for the treatment of a variety of learning disabilities, including psychiatric disorders and dementia (Kwok *et al.*, 2003; Novak *et al.*, 2012). They aim to create an atmosphere of warmth, trust, and relaxation, and provide scope for exploration, discovery, and learning. Installation of the interactive table in a multi-sensory room may act as a therapeutic interactive tool for patients and families. Raglio *et al*. (2008) have shown that music therapy can be effective in reducing behavioural and psychologic symptoms for those with dementia. The author has also been approached by a Department of Defence hospital in Chicago concerning the present research, to help with the association of Pathology from Blast Injuries to the Soldiers returning home from Iraq and Afghanistan. The results from Chapter 7 suggest that application of therapeutic music sessions in conjunction with *CymaSense* could be beneficial for other groups with cognitive issues.

CymaSense's use with the interactive table could be extended to become a coordinate tracked system, where a camera can track user movement, visualising sound at the point where the user contacts the surface of the table. This way *CymaSense* could be played more like a musical instrument with alternative user modes assigning different regions of space to a particular type of instrument, sound or pitch, further encouraging play and allowing a greater range of interactivity.

The use of *CymaSense* within a virtual or augmented reality environment could provide a number of opportunities for development. Interest has been shown in utilising *CymaSense* within research by Boyd *et al.* (2016), who suggested using the application as a means to visually highlight volume levels of speech within the next iteration of their *SayWAT* assistive technology. The smart-glass based application was designed to educate autistic clients in managing physical proximity and vocal levels in a social context. The authors feel a more attractive and engaging approach may be more beneficial for end-users than 2D graphics.

An augmented reality version of the *CymaSense* could be used in conjunction with facial recognition of emotions, where sound inflections of spoken vocal phrases would be visualised alongside emoticons of emotional states. A gamified version could then test the user showing only emoticons, requesting that the user recreate the appropriate sound. Alternatively, the visualised sound would only be played and the user would be asked to select the appropriate emoticon for a reward-based system.

Virtual reality has been used as an immersive development platform for musical creativity through games, or as a musical teaching and learning tool. A study by Magrini *et al.* (2015) presented a gestural-based application that detects movement and synthesizes sound in real-time based on those movements. *CymaSense* could also be developed as the basis of a gestural environment such as this, where interaction with virtual instruments or objects trigger sound and 3D visuals in conjunction with user movement.

A simple addition to the current version of *CymaSense* includes the addition of an automatic screen recording facility that could be saved as a video file. This functionality would allow sharing of a session with friends or family members who were not present, and it would allow participants to watch themselves. As noted in section 4.2.5, recording and reviewing sessions within a group could be as rewarding a process as performing in front of an audience, and be a useful way to record progress. This may encourage end-users to focus on play and performative aspects of therapeutic sessions, which may further develop communicative behaviours.

References

AAXA Technologies Inc. (2017). AAXA Technologies - Pico Projector Specialists - Advanced Nano-LCoS Systems. Retrieved February 23, 2017, from http://www.aaxatech.com/

Abdelkrim, A., Gezahegn, Y., Ebinger, C., Calais, E., Wright, T., Miller, M., … Mayberry, G. (2009). The impact of latency on application performance. *Anvanced Workshop on Evaluating, Monitoring, and Communicating Volcanic and Seismic Hazards in Africa*, 10.

Abirached, B., Zhang, Y., Aggarwal, J. K., Tamersoy, B., Fernandes, T., & Carlos, J. (2011). Improving communication skills of children with ASDs through interaction with virtual characters. *2011 IEEE 1st International Conference on Serious Games and Applications for Health (SeGAH)*, 1–4. https://doi.org/10.1109/SeGAH.2011.6165464

Ableton. (2017). Learn more about our music making software Live | Ableton. Retrieved December 17, 2015, from https://www.ableton.com/en/live/

Accordino, R., Comer, R., & Heller, W. B. (2007). Searching for music's potential: A critical examination of research on music therapy with individuals with autism. *Research in Autism Spectrum Disorders*, *1*(1), 101–115. https://doi.org/10.1016/j.rasd.2006.08.002

Adeli, M., Rouat, J., & Molotchnikoff, S. (2014). On the Importance of Correspondence Between Shapes and Timbre. *ICAD*. Retrieved from https://smartech.gatech.edu/handle/1853/52093

Adobe. (2010). Adobe Soundbooth CS4/CS5 * View audio waveforms and spectrums. Retrieved November 16, 2015, from http://help.adobe.com/en_US/Soundbooth/2.0/WS6C986A8C-C258-481c-BCDA-CFD812925BF7a.html

Adobe. (2018). Buy Adobe Premiere Pro CC | Video editing and production software. Retrieved February 20, 2018, from https://www.adobe.com/uk/products/premiere.html

Adobe Spark. (2018). Transmission of Sounds. Retrieved January 16, 2018, from https://spark.adobe.com/page/2P5yPzQCfWtuM/

Aigen, K. S. (2012). *Community Music Therapy*. https://doi.org/10.1093/oxfordhb/9780199928019.013.0010

Aldridge, D. (1994). Single-case research designs for the creative arts therapist. *The Arts in Psychotherapy*, *21*(5), 333–342.

Aldridge, D. (2003). *Case Study Designs in Music Therapy*. Jessica Kingsley Publishers.

Alessandrini, A., Cappelletti, A., & Zancanaro, M. (2014). Audio-augmented paper for therapy and educational intervention for children with autistic spectrum disorder. *International Journal of Human-Computer Studies*, *72*(4), 422–430. https://doi.org/10.1016/j.ijhcs.2013.12.001

Allen, R., Hill, E., & Heaton, P. (2009). “Hath charms to soothe . . .”: an exploratory study of how high-functioning adults with ASD experience music. *Autism : The International Journal of Research and Practice*, *13*(1), 21–41. https://doi.org/10.1177/1362361307098511

Alves, B. (2005). Digital Harmony of Sound and Light. *Computer Music Journal*, *29*(4), 45–54. https://doi.org/10.1162/014892605775179982

Alves, B. (2012). Consonance and Dissonance in Visual Music. *Organised Sound*, *17*(02), 114–119. https://doi.org/10.1017/S1355771812000039

Alzheimer’s Society. (2018). Alzheimer’s Society’s view on dementia research | Alzheimer’s Society. Retrieved August 5, 2018, from https://www.alzheimers.org.uk/about-us/policy-and-influencing/what-we-think/dementia-research

American Psychiatric Association. (2013). Diagnostic and Statistical Manual of Mental Disorders (5th ed.). In *American Psychiatric Publishing. Washington, DC.* (5th ed.).

Arlington, VA.: American Psychiatric Publishing.

Analema Group. (2017). ANALEMA GROUP on WordPress.com. Retrieved April 30, 2015, from https://analemagroup.wordpress.com/

Anderson, K. A., Shattuck, P. T., Cooper, B. P., Roux, A. M., & Wagner, M. (2014). Prevalence and correlates of postsecondary residential status among young adults with an autism spectrum disorder. *Autism*, *18*(5), 562–570. https://doi.org/10.1177/1362361313481860

Animated Science. (2015). Soundwaves on an oscilloscope - YouTube. Retrieved November 26, 2017, from https://www.youtube.com/watch?v=d7m4JZ9kiYs

Apple. (2019). iPad 9.7-inch - Apple (MY). Retrieved August 11, 2018, from https://www.apple.com/uk/ipad/

Apple Inc. (2017a). Impaktor - The drum synthesizer on the App Store. Retrieved April 10, 2017, from https://itunes.apple.com/gb/app/impaktor-the-drum-synthesizer/id557824278?mt=8

Apple Inc. (2017b). Logic Pro X - Music production. Cranked up to X. - Apple (UK). Retrieved December 17, 2015, from http://www.apple.com/uk/logic-pro/

Apple Inc. (2017c). Quartz Composer. Retrieved August 1, 2016, from https://developer.apple.com/library/mac/documentation/GraphicsImaging/Conceptual/QuartzComposerUserGuide/qc_intro/qc_intro.html

Apple Inc. (2018). Apple (United Kingdom) - GarageBand for Mac. Retrieved August 14, 2015, from http://www.apple.com/uk/mac/garageband/

Apple Inc. (2018). MacBook Pro - Apple (UK). Retrieved February 23, 2017, from http://www.apple.com/uk/macbook-pro/?afid=p238%7CsbOuPsHFv-dc_mtid_187079nc38483_pcrid_177734582548_&cid=aos-uk-kwgo-mac-slid--product-

ARICD. (2013). Association for Research in Infant and Child Development. Retrieved from http://www.aricd.ac.uk/about-the-griffiths-scales/

Armstrong, D., Gosling, A., Weinman, J., & Marteau, T. (1997). THE PLACE OF INTER-RATER RELIABILITY IN QUALITATIVE RESEARCH : AN EMPIRICAL STUDY. *Sociology*, *31*(3), 597–606.

Articles, R. O., Distant, T., Council, H., Horvath, P., & Presenters, T. (2010). Jeff Volk Cymatics Article.

ASDTech. (2019). Interview with Dr Yurgos Politis, researcher in assistive technology and special education | ASDTech. Retrieved July 15, 2019, from http://www.asdtech.ed.ac.uk/index.php/2019/07/12/interview-with-dr-yurgos-politis-researcher-in-assistive-technology-and-special-education/

Athanasopoulos, G., Tan, S.-L., & Moran, N. (2016). Influence of literacy on representation of time in musical stimuli: An exploratory cross-cultural study in the UK, Japan, and Papua New Guinea. *Psychology of Music*, *44*(5), 1126–1144. https://doi.org/10.1177/0305735615613427

Atlassian Confluence 5.4. (2017). CryEngine. Retrieved August 1, 2016, from http://docs.cryengine.com/pages/viewpage.action?pageId=17826178

Audiotool. (2015). The tonematrix, a pentatonic step sequenzer by Audiotool. Retrieved September 22, 2015, from http://tonematrix.audiotool.com/

Autism East Midlands. (2018). Sutherland House School | Autism East Midlands. Retrieved August 6, 2018, from https://www.autismeastmidlands.org.uk/our-school/

Autism Initiatives UK. (2017). Number 6. Retrieved June 2, 2015, from http://www.number6.org.uk/index.html

Autism Link. (2014). Autism Information Archives - Autism Link. Retrieved January 18, 2017, from http://autismlink.com/category/autism-information/

Autism Speaks Inc. (2017). *DSM-5 News and Updates Autism Speaks*. Retrieved from https://www.autismspeaks.org/what-autism/dsm-5

AutismParentingMagazine.com. (2018). Best Autism Apps For iPad, iPhone and Android - Ultimate Guide. Retrieved July 24, 2018, from https://www.autismparentingmagazine.com/best-autism-apps/

Autismtopics.org. (2016). Autism Triad of Impairments. Retrieved August 24, 2017, from http://www.autismtopics.org/t3 autism triad.html

Autistic UK. (2019). What is Neurodiversity? Retrieved June 27, 2019, from https://autisticuk.org/neurodiversity/

Autistica.org. (2018). Our research - Autism | Autistica. Retrieved June 28, 2018, from https://www.autistica.org.uk/our-research/our-research

Autodesk Inc. (2018). Maya | Computer Animation & Modelling Software. Retrieved from http://www.autodesk.co.uk/products/maya/overview

Autodesk Inc. (2018). Create blend shape deformers | Maya | Autodesk Knowledge Network. Retrieved July 25, 2018, from https://knowledge.autodesk.com/support/maya/learn-explore/caas/CloudHelp/cloudhelp/2018/ENU/Maya-CharacterAnimation/files/GUID-7413C450-603C-4EAD-AF70-465D4EAE5973-htm.html

Avid. (2017). Pro Tools | Avid. Retrieved November 26, 2017, from http://www.avid.com/pro-tools

Babbie, E. (2012). The Practice of Social Research. In *Wadsworth Cengage Learning*. https://doi.org/9780495598411

Bai, Z., Blackwell, A. F., & Coulouris, G. (2015). *Using Augmented Reality to Elicit Pretend Play for Children with Autism*. *21*(5), 598–610. https://doi.org/10.1109/TVCG.2014.2385092

Bare Conductive. (2018). Touch Board. Retrieved October 13, 2015, from http://www.bareconductive.com/shop/touch-board/

Barlow, D. H., & Hersen, M. (1973). Single-Case Experimental Designs: Uses in Applied Clinical Research. *Archives of General Psychiatry*, *29*(3), 319–325. https://doi.org/10.1001/archpsyc.1973.04200030017003

Baron-Cohen, S., Wyke, M. A., & Binnie, C. (1987). Hearing words and seeing colours: An experimental investigation of a case of synaesthesia. *Perception*, *16*(6), 761–767. https://doi.org/10.1068/p160761

Baron-Cohen, Simon, Johnson, D., Asher, J., Wheelwright, S., Fisher, S. E., Gregersen, P. K., & Allison, C. (2013). Is synaesthesia more common in autism? *Molecular Autism*, *4*(1), 40. https://doi.org/10.1186/2040-2392-4-40

Baron-Cohen, Simon, Leslie, A. M., & Frith, U. (1985). Does the autistic child have a “theory of mind”? *Cognition*, *21*, 37–46. https://doi.org/10.1016/0010-0277(85)90022-8

Baron-Cohen, Simon, Scott, F. J., Allison, C., Williams, J., Bolton, P., Matthews, F. E., & Brayne, C. (2009). Prevalence of autism-spectrum conditions: UK school-based population study. *British Journal of Psychiatry*, *194*(6), 500–509. https://doi.org/10.1192/bjp.bp.108.059345

Batty, J., & Horn, K. (2013). *Audiovisual Granular Synthesis – Micro Relationships Between Sound and Image*.

Békésy, G. von. (1957). The Ear. *Scientific American*, *197*(2), 66–79.

Benenzon, R. (1999). *Rolando Benenzon’s talk in the pleanry session “Five International Models of Music Therapy Practice”, held at the IX World Congress of Music Therapy 1999, Washington*.

Benenzon, R. O. (2007). The Benenzon Model. *Nordic Journal of Music Therapy*, Vol. 16, pp. 148–159. https://doi.org/10.1080/08098130709478185

Bennett, I. (2006). Control of noise at Work Regulations 2005. *Acoustics Bulletin*, *31*(3), 35–37.

Benton, L., Johnson, H., Ashwin, E., Brosnan, M., & Grawemeyer, B. (2012). Developing IDEAS: Supporting Children with Autism within a Participatory Design Team. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*, 2599–2608. https://doi.org/10.1145/2207676.2208650

Berghammer, R., & Fronk, A. (2004). Applying relational algebra in 3D graphical software design. *7th Int. Semin. Relational Methods Comput. Sci.*, 62–74. Retrieved from http://link.springer.com/chapter/10.1007/978-3-540-24771-5%7B_%7D6

Bergstrom, T., Karahalios, K., & Hart, J. C. (2007). Isochords. *Proceedings of Graphics Interface 2007 on - GI '07*, 297. https://doi.org/10.1145/1268517.1268565

Bewitched.com. (2005). Martin Wattenberg: Shape of Song. Retrieved November 26, 2017, from http://www.bewitched.com/song.html

Beyerdynamic. (2018). beyerdynamic DT 250: Closed dynamic headphones. Retrieved June 29, 2018, from https://europe.beyerdynamic.com/dt-250.html

Bilingual Speech Therapist. (2016). Autism. Retrieved August 7, 2018, from http://www.bilingualspeechtherapist.com/?tag=autism

Bishop, S. L., Farmer, C., Bal, V., Robinson, E. B., Willsey, A. J., Werling, D. M., … Thurm, A. (2017). Identification of developmental and behavioral markers associated with genetic abnormalities in autism spectrum disorder. *American Journal of Psychiatry*, *174*(6), 576–585. https://doi.org/10.1176/appi.ajp.2017.16101115

Black, B. P., & Penrose-Thompson, P. (2012). Music as a Therapeutic Resource in End-of-Life Care. *Journal of Hospice & Palliative Nursing*, *14*(2), 118–125. https://doi.org/10.1097/NJH.0b013e31824765a2

Blackburn, M. (2009). Composing from spectromorphological vocabulary: proposed application, pedagogy and metadata. *Electroacoustic Music Studies*, online. Retrieved from http://www.ceiarteuntref.edu.ar/blackburn%5Cnhttp://www.ems-network.org/ems09/papers/blackburn.pdf

Blake, R., Turner, L. M., Smoski, M. J., Pozdol, S. L., & Stone, W. L. (2003). Visual recognition of biological motion is impaired in children with autism. *Psychol Sci*, *14*(2), 151–157. https://doi.org/10.1111/1467-9280.01434

Bock, M. A. (2007). *Marjorie A. Bock*. *22*(2), 88–95.

Bond, B., & Stevens, S. S. (1969). Cross-modality matching of brightness to loudness by 5-year-olds. *Perception & Psychophysics*, *6*(6), 337–339. https://doi.org/10.3758/BF03212787

Bondy, A., & Frost, L. (2001). The picture exchange communication system. *Behavior Modification*, Vol. 25, pp. 725–744. https://doi.org/10.1177/0145445501255004

Bossius, T., & Lilliestam, L. (2012). *Musiken och jag : Rapport från forskningsprojektet "Musik i Människors Liv."* Goteborg: Bo Ejeby Förlag.

Boucenna, S., Narzisi, A., Tilmont, E., Muratori, F., Pioggia, G., Cohen, D., & Chetouani, M. (2014). Interactive Technologies for Autistic Children: A Review. *Cognitive Computation*, *6*(4), 722–740. https://doi.org/10.1007/s12559-014-9276-x

Boucher, J., Lewis, V., & Collis, G. M. (2000). Voice Processing Abilities in Children with Autism, Children with Specific Language Impairments, and Young Typically Developing Children. *Journal of Child Psychology and Psychiatry*, *41*(7), 847–857. https://doi.org/10.1111/1469-7610.00672

Boyd, L. E., Rangel, A., Tomimbang, H., Conejo-Toledo, A., Patel, K., Tentori, M., & Hayes, G. R. (2016). SayWAT: Augmenting Face-to-Face Conversations for Adults with Autism. *Chi*, 4872–4883. https://doi.org/10.1145/2858036.2858215

Brain Power. (2018). Help | BRAIN POWER. Retrieved January 24, 2018, from http://www.brain-power.com/help-us/

Brandalise, A. (2015). Music Therapy and Theatre: A Community Music Therapy Socio-

Cultural Proposal for the Inclusion of Persons With Autism Spectrum Disorders. *Voices: A World Forum for Music Therapy*, *1*(1). https://doi.org/10.15845/voices.v1i1.733

Bredek, C., Granpeesheh, D., Thompson, K., & Matalon, R. (2014). Visual and Other Sensory Modifications. In *Evidence-Based Treatment for Children with Autism* (pp. 115–132). https://doi.org/10.1016/B978-0-12-411603-0.00006-9

Brinkman, A., & Mesiti, M. (1991). Graphic modeling of musical structure. *Computers in Music Research*, *3*, 1–42.

Brooke, J. (2011). *SUS - A quick and dirty usability scale*. 1–8.

Brown, S. (1997). Clinical Improvisation Aesthetic in Creative Music Therapy : Dimension Musical and the Interpersonal. *Science*, *23*(5), 397–405.

Butler, R. A. (1973). The relative influence of pitch and timbre on the apparent location of sound in the median sagittal plane. *Perception & Psychophysics*, *14*(2), 15–18. https://doi.org/10.3758/BF03212386

Butt, S., & Phillips, J. G. (2008). Personality and self reported mobile phone use. *Computers in Human Behavior*, *24*(2), 346–360. https://doi.org/10.1016/j.chb.2007.01.019

Caltabiano, A. (2010). *The impact of music therapy on the social behaviours of children with autism in a structured outdoor inclusive setting*. Retrieved from http://ses.library.usyd.edu.au/handle/2123/6442

Cappelen, B., & Andersson, A.-P. (2016). Health Improving Multi-Sensorial and Musical Environments. *Proceedings of the Audio Mostly 2016 on - AM '16*, 178–185. https://doi.org/10.1145/2986416.2986427

Cardon, T. A. (2016). Technology and the Treatment of Children with Autism Spectrum Disorder. In *Autism and Child Psychopathology Series*. https://doi.org/10.1007/978-3-319-20872-5

Cariad Interactive. (2018a). ReacTickles Magic | Interactive Software Designed with Children on the Autistic Spectrum. Retrieved August 16, 2015, from http://cariadinteractive.com/reactickles-magic/

Cariad Interactive. (2018b). Somantics. Retrieved June 15, 2015, from http://cariadinteractive.com/somantics/

Carlson, C., & Wang, G. (2012). Borderlands - An Audiovisual Interface for Granular Synthesis. *Proceedings of the International Conference on New Interfaces for Musical Expression*, (September).

Carnahan, C., Basham, J., & Musti-Rao, S. (2009). A Low-Technology Strategy for Increasing Engagement of Students with Autism and Significant Learning Needs. *Exceptionality*. https://doi.org/10.1080/09362830902805798

Castellano, M. A., Bharucha, J. J., & Krumhansl, C. L. (1984). Tonal hierarchies in the music of north India. *Journal of Experimental Psychology. General*, *113*(3), 394–412. https://doi.org/10.1037/0096-3445.113.3.394

Cevasco, A., & Hong, A. (2011). Utilizing Technology in Clinical Practice : A Comparison of Board~Certified Music Therapists and Music Therapy Students. *Music Therapy Perspectives*, *29*(1).

Charlop-Christy, M. H., Carpenter, M., Le, L., LeBlanc, L. a, & Kellet, K. (2002). Using the picture exchange communication system (PECS) with children with autism: assessment of PECS acquisition, speech, social-communicative behavior, and problem behavior. *Journal of Applied Behavior Analysis*, *35*(3), 213–231. https://doi.org/10.1901/jaba.2002.35-213

Chen, C. H., Lee, I. J., & Lin, L. Y. (2015a). Augmented reality-based self-facial modeling to promote the emotional expression and social skills of adolescents with autism spectrum disorders. *Research in Developmental Disabilities*, *36*, 396–403. https://doi.org/10.1016/j.ridd.2014.10.015

Chen, C. H., Lee, I. J., & Lin, L. Y. (2015b). Augmented reality-based self-facial modeling to promote the emotional expression and social skills of adolescents with autism spectrum disorders. *Research in Developmental Disabilities*, *36*, 396–403. https://doi.org/10.1016/j.ridd.2014.10.015

Chen, C. H., Lee, I. J., & Lin, L. Y. (2016). Augmented reality-based video-modeling storybook of nonverbal facial cues for children with autism spectrum disorder to improve their perceptions and judgments of facial expressions and emotions. *Computers in Human Behavior*, *55*, 477–485. https://doi.org/10.1016/j.chb.2015.09.033

Cheng, Y., & Chen, S. (2010). Improving social understanding of individuals of intellectual and developmental disabilities through a 3D-facail expression intervention program. *Research in Developmental Disabilities*, *31*(6), 1434–1442. https://doi.org/10.1016/j.ridd.2010.06.015

Chew, E. (1999). Towards a mathematical model of tonality. *Computers in Entertainment*, *3*(4), 1–166. https://doi.org/10.1145/1095534.1095539

Chin, H. Y., & Bernard-Opitz, V. (2000). Teaching conversational skills to children with autism: effect on the development of a theory of mind. *Journal of Autism and Developmental Disorders*, *30*(6), 569–583. https://doi.org/11261468

Chinn, H. A., Gannett, D. K., & Morris, R. M. (1940). A New Standard Volume Indicator and Reference Level. *Proceedings of the IRE*, *28*(1), 1–17. https://doi.org/10.1109/JRPROC.1940.228815

Chiu, L.-H. (1988). Measures of self-esteem for school-age children. *Journal of Counseling and Development*, *66*(6), 298–301. https://doi.org/10.1002/j.1556-6676.1988.tb00874.x

Choungourian, A. (1968). Color preferences and cultural variation. *Perceptual and Motor Skills*, *26*(3), Suppl:1203-1206. https://doi.org/10.2466/pms.1968.26.3c.1203

Chow, J., Feng, H., Amor, R., & Wünsche, B. (2013). Music education using augmented reality with a head mounted display. *Proceedings of the Fourteenth Australasian User Interface Conference*. Retrieved from http://dl.acm.org/citation.cfm?id=2525501

Christensen, T. (2008). *The Cambridge history of Western music theory*. Retrieved from http://books.google.com/books?hl=en&lr=&id=ioa9uW2t7AQC&oi=fnd&pg=PA1&dq=the+cambridge+history+of+western+music+theory&ots=wuKXL9UdTM&sig=jpWc6nEA8UE0KDsG7Fo19gaw_l0

Christi Carnahan, Shobana Musti-Rao, & Jody Bailey. (2008). Promoting Active Engagement in Small Group Learning Experiences for Students with Autism and Significant Learning Needs. *Education and Treatment of Children*, *32*(1), 37–61. https://doi.org/10.1353/etc.0.0047

Chrome Experiments. (2015). Chrome Experiments - Loop Waveform Visualizer by Felix Turner. Retrieved September 22, 2015, from https://www.chromeexperiments.com/experiment/loop-waveform-visualizer

Cibrian, F. L., Pena, O., Ortega, D., & Tentori, M. (2017). *BendableSound : An Elastic Multisensory Surface using Touch-based interactions to Assist Children with Severe Autism during Music Therapy*. 1–29.

Cibrian, F. L., Peña, O., Ortega, D., & Tentori, M. (2017). BendableSound: An elastic multisensory surface using touch-based interactions to assist children with severe autism during music therapy. *International Journal of Human-Computer Studies*, *000*, 1–16. https://doi.org/10.1016/j.ijhcs.2017.05.003

Ciuha, P., Klemenc, B., & Solina, F. (2010a). Visualization of concurrent tones in music with colours. *Proceedings of the International Conference on Multimedia - MM '10*, 1677. https://doi.org/10.1145/1873951.1874320

Ciuha, P., Klemenc, B., & Solina, F. (2010b). Visualization of concurrent tones in music with colours. *Proceedings of the International Conference on Multimedia - MM '10*, 1677. https://doi.org/10.1145/1873951.1874320

Clarke, E. F. (1999). Rhythm and timing in music. In *The psychology of music (2nd ed.).; The psychology of music (2nd ed.). Academic Press series in cognition and perception: A series of monographs and treatises* (pp. 473–500).

https://doi.org/10.1016/B978-012213564-4/50014-7

Clift, S., Hancox, G., Morrison, I., Hess, B., Kreutz, G., & Stewart, D. (2010). Choral singing and psychological wellbeing: Quantitative and qualitative findings from English choirs in a cross-national survey. *Journal of Applied Arts and Health*, Vol. 1, pp. 19–34.

Cognable. (2016). Cause and Effect Sensory Light Box. Retrieved December 14, 2015, from http://lightbox.cognable.com/

Collins, D. (2003). Pretesting survey instruments: an overview of cognitive methods. *Care Rehabil*, *12*, 229–238.

Collopy, F. (2007). RhythmicLight.com Timeline. Retrieved May 10, 2015, from http://rhythmiclight.com/archives/timeline.html

Color-Hex.org. (2018). Color - Wiki. Retrieved June 8, 2018, from https://color-hex.org/blog/color-wiki

Color & Music, L. (2016). Magic Music Visuals. Retrieved August 1, 2016, from https://magicmusicvisuals.com/

Computer Graphics Illinois. (2011). Isochords: Visualizing Structure in Music | Computer Graphics Illinois. Retrieved November 26, 2017, from https://graphics.cs.illinois.edu/papers/isochords

ComputerTechBlog. (2017). Detecting Ephemeral Port Exhaustion in Windows 7 / 8 / 2012 | ComputerTechBlog. Retrieved February 12, 2018, from http://www.computertechblog.com/detecting-ephemeral-port-exhaustion-in-windows-7-8-2012/

Conrad, D. (1999). The Dichromaccord: Reinventing the Elusive Color Organ. *Leonardo*, Vol. 32, pp. 393–398. https://doi.org/10.1162/002409499553631

Coopersmith, S. (1959). A method for determining types of self-esteem. *Journal of Abnormal Psychology*, *59*(1), 87–94. https://doi.org/10.1037/h0048001

Creative Field Recording. (2018). The Unconventional Microphone Buyer’s Guide | Creative Field Recording. Retrieved February 14, 2018, from https://www.creativefieldrecording.com/2017/06/07/the-unconventional-microphone-buyers-guide/#contact

Crippa, A., Forti, S., Perego, P., & Molteni, M. (2013). Eye-hand coordination in children with high functioning autism and Asperger’s disorder using a gap-overlap paradigm. *Journal of Autism and Developmental Disorders*, *43*(4), 841–850. https://doi.org/10.1007/s10803-012-1623-8

Critter & Guitari. (2018). Critter & Guitari – Critter & Guitari. Retrieved February 13, 2018, from https://www.critterandguitari.com/

CritterGuitari. (2014). CritterGuitari. Retrieved February 13, 2018, from https://cdn.shopify.com/s/files/1/0159/3944/products/out_1-wide_grande.jpg

Cross, I. (2014). Music and communication in music psychology. *Psychology of Music*, *42*(6), 809–819. https://doi.org/10.1177/0305735614543968

Cross, Ian. (2010). Listening as Covert Performance. *Journal of the Royal Musical Association*, *135*(sup1), 67–77. https://doi.org/10.1080/02690400903414848

Cross, Ian, Farrant, C., & Cripps, C. (2013). Music and Communication : Music Therapy and Music Psychology. *Psychology of Music*, *42*(September), 809–819. https://doi.org/10.1177/0305735614543968

Cycling ’74. (2018a). Cycling ’74. Retrieved August 1, 2016, from https://cycling74.com/

Cycling ’74. (2018b). Max. Retrieved February 14, 2016, from https://cycling74.com/products/max/

Cycling ’74. (2018c). Project: Synesthetic Audio-Visual Platform | Cycling ’74. Retrieved January 29, 2018, from https://cycling74.com/projects/synesthetic-audio-visual-platform

Cymascope.com. (2018a). CymaScope :: Sound Made Visible. Retrieved from http://cymascope.com/cymascope.html

Cymascope.com. (2018b). CymaScope Videos - CymaScope Shop. Retrieved from https://www.cymascope.com/shop/cymascope-videos/

Cymascope.com. (2018c). Physics :: Cymascope Research. Retrieved December 30, 2015, from http://cymascope.com/cyma_research/physics.html

Cymascope.com. (2018d). Research :: Geometry. Retrieved from http://www.cymascope.com/cyma_research/geometry.html

Damasio, A. (1999). The feeling of what happens. *Nature*. https://doi.org/10.1176/appi.ps.51.12.1579

Damien, B. (2018). A dive in music html5/webGL experiment. Retrieved September 22, 2015, from Damien, Benoit website: http://do.adive.in/music/

Davey, P. (1998). True colors: The glorious polychromy of the past suggests a strong historical need for color, despite current reductive fashions. *The Architectural Review*, *204*, 34–36.

Davidson, J., & Henderson, V. L. (2010). “Coming out” on the spectrum: Autism, identity and disclosure. *Social and Cultural Geography*, *11*(2), 155–170. https://doi.org/10.1080/14649360903525240

Davidson, L., Scripp, L., & Welsh, P. (1988). “Happy Birthday”: Evidence for Conflicts of Perceptual Knowledge and Conceptual Understanding. *Journal of Aesthetic Education*. https://doi.org/10.2307/3332965

Dawe, M. (2006). Desperately Seeking Simplicity: How Young Adults with Cognitive Disabilities and Their Families Adopt Assistive Technologies. *Proceedings of the ACM 2006 Conference on Human Factors in Computing Systems*, 1143–1152. https://doi.org/10.1145/1124772.1124943

Delano, M., & Snell, M. E. (2006). The Effects of Social Stories on the Social

Engagement of Children with Autism. *Journal of Positive Behavior Interventions*, *8*(1), 29–42. https://doi.org/10.1177/10983007060080010501

Delapaix, G. (2013). *Tuning, Timbre, Spectrum, Scale,*.

Dennis, M., Lazenby, a L., & Lockyer, L. (2001). Inferential language in high-function children with autism. *Journal of Autism and Developmental Disorders*, *31*(1), 47–54. https://doi.org/10.1023/A:1005661613288

DeNora, T. (2000). *Music in Everyday Life*. Cambridge : Cambridge University Press.

DePape, A.-M. R., Hall, G. B. C., Tillmann, B., & Trainor, L. J. (2012). Auditory Processing in High-Functioning Adolescents with Autism Spectrum Disorder. *PLoS ONE*, Vol. 7, p. e44084. https://doi.org/10.1371/journal.pone.0044084

Derivative. (2017). TouchDesigner. Retrieved August 1, 2016, from http://www.derivative.ca/wiki088/index.php?title=Ableton_Live_and_TouchDesigner

Devereux, P. (2001). *Stone Age soundtracks : the acoustic archaeology of ancient sites*. London: Vega.

Dezfoolian, L., Zarei, M., Ashayeri, H., & Looyeh, M. Y. (2013). A Pilot Study on the Effects of Orff-Based Therapeutic Music in Children With Autism Spectrum Disorder. *Music and Medicine*, *5*(3), 162–168. https://doi.org/10.1177/1943862113491502

DiCicco-Bloom, B., & Crabtree, B. F. (2006). The qualitative research interview. *Medical Education*, *40*(4), 314–321. https://doi.org/10.1111/j.1365-2929.2006.02418.x

Diment, L., & Hobbs, D. (2014). A gesture-based virtual art program for children with severe motor impairments – development and pilot study. *Journal of Assistive, Rehabilitative & Therapeutic Technologies*, *2*(0). https://doi.org/10.3402/jartt.v2.23206

Dimitriadis, T., & Smeijsters, H. (2011). Autistic spectrum disorder and music therapy:

theory underpinning practice. *Nordic Journal of Music Therapy*, *20*(2), 108–122. https://doi.org/10.1080/08098131.2010.487647

Dinahmoelabs.com. (2015). Dinahmoe Labs. Retrieved September 22, 2015, from http://dinahmoelabs.com/tonecraft

Dominick, K. C., Davis, N. O., Lainhart, J., Tager-Flusberg, H., & Folstein, S. (2007). Atypical behaviors in children with autism and children with a history of language impairment. *Research in Developmental Disabilities*, *28*(2), 145–162. https://doi.org/10.1016/j.ridd.2006.02.003

Drummond, R. J., Mcintire, W. G., & Ryan, C. W. (1977). *SELF-ESTEEM INVENTORY FOR STUDENTS I N GRADES TWO T O TWELVE1*. 943–946.

Dubspot. (2016). Digital Metering Explained: Peak vs. RMS | Dubspot. Retrieved June 15, 2018, from http://blog.dubspot.com/digital-metering-peak-vs-rms/

Eagleman. (2018). Time and the Brain (or, What's happening in the Eagleman Lab). Retrieved January 24, 2018, from http://www.eagleman.com/research/110-time-and-the-brain-or-what-s-happening-in-the-eagleman-lab

Eden Futures. (2016). Eden Futures: The Autistic Spectrum. Retrieved August 24, 2017, from https://www.edenfutures.org/index.php/care-pathways/the-autistic-spectrum/

Edgerton, C. L. (1994a). The Effect of Improvisational Music Therapy on the Communicative Behaviors of Autistic Children. *Journal of Music Therapy*, *31*(1), 31–62. https://doi.org/10.1093/jmt/31.1.31

Edgerton, C. L. (1994b). The Effect of Improvisational Music Therapy on the Communicative Behaviors of Autistic Children. *Journal of Music Therapy*, *31*(1), 31–62. https://doi.org/10.1093/jmt/31.1.31

Education, M., & Press, I. (2016). *Council for Research in Music Education Layered Analysis : A Video-Based Qualitative Research Tool to Support the Development of a New Approach for Children with Special Needs Author (s): Phil Ellis Source :*

Bulletin of the Council for Research in Music. (130).

El Heraldo de Saltillo. (2017). El Heraldo de Saltillo – Bendable sound: innovación interactiva para niños con autismo. Retrieved August 25, 2017, from http://elheraldodesaltillo.mx/2017/01/12/bendable-sound-innovacion-interactiva-para-ninos-con-autismo/

Ellis, P., & Leeuwen, L. Van. (2000). Living Sound : human interaction and children with autism. *Music in Special Education, Music Therapy and Music Medicine*, 1–23.

Epic Games, I. (2017). Unreal Engine. Retrieved August 1, 2016, from https://docs.unrealengine.com/latest/INT/Engine/Audio/Overview/

Erkkilä, J. (2004). From Signs to Symbols, from Symbols to Words. *Voices: A World Forum for Music Therapy*, *4*(2). https://doi.org/10.15845/voices.v4i2.176

Escobedo, L., Nguyen, D. H., Boyd, L., Hirano, S., Rangel, A., Garcia-Rosas, D., … Hayes, G. (2012). MOSOCO: a mobile assistive tool to support children with autism practicing social skills in real-life situations. *Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems*, 2589–2598. https://doi.org/10.1145/2208636.2208649

Escobedo, L., Tentori, M., Quintana, E., Favela, J., & Garcia-Rosas, D. (2014). Using Augmented Reality to Help Children with Autism Stay Focused. *IEEE Pervasive Computing*, *13*(1), 38–46. https://doi.org/10.1109/MPRV.2014.19

Evans, B. (2005). Foundations of a Visual Music. *Computer Music Journal*, *29*(4), 11–24. https://doi.org/10.1162/014892605775179955

Evans, K. K., & Treisman, A. (2011). Natural cross-modal mappings between visual and auditory features. *Journal of Vision*, *10*(1), 6–6. https://doi.org/10.1167/10.1.6

Ewan Sinclair. (2018). Ewan Sinclair | sense scotland arts. Retrieved February 13, 2018, from https://sensescotlandarts.wordpress.com/artist-residencies/ewan-sinclair/

Fabri, M., & Andrews, P. C. S. (2014). *Hurdles and Drivers Affecting Autistic Students ’*

Higher Education Experience : Lessons Learnt From the Multinational Autism & Uni Research Study. https://doi.org/10.21125/inted.2016.1373

Fabri, M., & Andrews, P. C. S. (2016). *Human-Centered Design with Autistic University Students: Interface, Interaction and Information Preferences*. https://doi.org/10.1007/978-3-319-40355-7_15

Fahlenbrach, K. (2008). Emotions in sound: Audiovisual metaphors in the sound design of narrative films. *Projections*, *2*(2), 85–103. https://doi.org/10.3167/proj.2008.020206

Fales, C. (2002). The Paradox of Timbre. *Ethnomusicology*, *46*(1), 56–95.

Farmer, G. D., Baron-Cohen, S., & Skylark, W. J. (2017). People With Autism Spectrum Conditions Make More Consistent Decisions. *Psychological Science*, *28*(8), 1067–1076. https://doi.org/10.1177/0956797617694867

Farr, W., Yuill, N., & Raffle, H. (2010). Social benefits of a tangible user interface for children with Autistic Spectrum Conditions. *Autism*, *14*(3), 237–252. https://doi.org/10.1177/1362361310363280

Ferster, C. B. (1964). Positive reinforcement and behavioral deficits of autistic children. In *Conditioning Techniques in Clinical Practice and Research*. Springer Berlin Heidelberg.

FigurenotesGlobal Ltd. (2018). FigurenotesGlobal Ltd -. Retrieved February 15, 2016, from http://www.figurenotes.com/

Fletcher-Watson, S., Pain, H., Hammond, S., Humphry, A., & McConachie, H. (2016). Designing for young children with autism spectrum disorder: A case study of an iPad app. *International Journal of Child-Computer Interaction*, *7*, 1–14. https://doi.org/10.1016/j.ijcci.2016.03.002

Focusrite. (2018). Scarlett 2i2 | Focusrite. Retrieved February 23, 2017, from https://uk.focusrite.com/usb-audio-interfaces/scarlett-2i2

Fortenberry, C. L., Grist, C. L., & McCord, D. M. (2011). Personality trait differences between typically developing children and those diagnosed with autism spectrum disorder. *Individual Differences Research*, *9*(2), 73–83.

Foundry. (2018). VR/AR/MR, what's the difference? | Virtual reality | Foundry. Retrieved August 9, 2018, from https://www.foundry.com/industries/virtual-reality/vr-mr-ar-confused

Fourney, D. W., & Fels, D. I. (2009). Creating access to music through visualization. *2009 IEEE Toronto International Conference Science and Technology for Humanity (TIC-STH)*, (September), 939–944. https://doi.org/10.1109/TIC-STH.2009.5444364

Fowler, S. (2008). *Multisensory rooms and envoronnements: Controlled sensory experiences for people with profound and multiple disabilities*. Retrieved from https://books.google.com/books?id=f3IGsdYU2GwC&pgis=1

Frauenberger, C., Good, J., Alcorn, A., & Pain, H. (2013). Conversing through and about technologies: Design critique as an opportunity to engage children with autism and broaden research(er) perspectives. *International Journal of Child-Computer Interaction*, *1*(2), 38–49. https://doi.org/10.1016/j.ijcci.2013.02.001

Frauenberger, C., Makhaeva, J., & Spiel, K. (2017). *Blending Methods : Developing Participatory Design Sessions for Autistic Children*.

Frauenberger, C., Spiel, K., & Makhaeva, J. (2019). Thinking OutsideTheBox - Designing Smart Things with Autistic Children. *International Journal of Human-Computer Interaction*, *35*(8), 666–678. https://doi.org/10.1080/10447318.2018.1550177

Frith, U. (1994). Autism and theory of mind in everyday life. *Social Development*, *3*(2), 108–124. https://doi.org/10.1111/j.1467-9507.1994.tb00031.x

Future Publishing Limited. (2017). The 20 best DAW software apps in the world today | MusicRadar. Retrieved November 30, 2015, from http://www.musicradar.com/tuition/tech/the-20-best-daw-software-apps-in-the-world-today-238905

G. Kent, R., J. Carrington, S., Le Couteur, A., Gould, J., Wing, L., Maljaars, J., … R. Leekam, S. (2013). Diagnosing autism spectrum disorder: Who will get a DSM-5 diagnosis? *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *54*(11), 1242–1250. https://doi.org/10.1111/jcpp.12085

GABOR, D. (1947). Acoustical Quanta and the Theory of Hearing. *Nature*, *159*(4044), 591–594. https://doi.org/10.1038/159591a0

Gantt, H. L. (1910). Work, Wages and Profit Vol. In *New York: the Engineering Magazine*.

Ganz, J. B., Davis, J. L., Lund, E. M., Goodwyn, F. D., & Simpson, R. L. (2012). Meta-analysis of PECS with individuals with ASD: Investigation of targeted versus non-targeted outcomes, participant characteristics, and implementation phase. *Research in Developmental Disabilities*, *33*(2), 406–418. https://doi.org/10.1016/j.ridd.2011.09.023

Gao, X. P., Xin, J. H., Sato, T., Hansuebsai, A., Scalzo, M., Kajiwara, K., … Billger, M. (2007). Analysis of cross-cultural color emotion. *Color Research and Application*, *32*(3), 223–229. https://doi.org/10.1002/col.20321

Gattino, G. S., Riesgo, R. dos S., Longo, D., Leite, J. C. L., & Faccini, L. S. (2011). Effects of relational music therapy on communication of children with autism: a randomized controlled study. *Nordic Journal of Music Therapy*, *20*(2), 142–154. https://doi.org/10.1080/08098131.2011.566933

Gatzsche, G., Idmt, F., Mehnert, M., & Technische, U. (2007). A symmetry based approach for musical tonality analysis. *8th International Conference on Music Information Retrieval (ISMIR 2007)*.

Gehlhaar, R., Rodrigues, P. M., Girão, L. M., & Penha, R. (2014). Instruments for Everyone: Designing New Means of Musical Expression for Disabled Creators. In A. L. Brooks, S. Brahnam, & L. C. Jain (Eds.), *Technologies of Inclusive Well-Being: Serious Games, Alternative Realities, and Play Therapy* (pp. 167–196). https://doi.org/10.1007/978-3-642-45432-5_9

Geist, K., & Hitchcock, J. H. (2014). Single case design studies in music therapy: Resurrecting experimental evidence in small group and individual music therapy clinical settings. *Journal of Music Therapy*, Vol. 51, pp. 293–309. https://doi.org/10.1093/jmt/thu032

Geretsegger, M., Holck, U., & Gold, C. (2012). Randomised controlled trial of improvisational music therapy's effectiveness for children with autism spectrum disorders (TIME-A): study protocol. *BMC Pediatrics*, *12*(1), 2. https://doi.org/10.1186/1471-2431-12-2

Gingrich, O., Renaud, A., & Emets, E. (2013). KIMA - A Holographic Telepresence Environment Based on Cymatic Principles. *Leonardo*, *46*(4), 332–343. https://doi.org/10.1162/LEON_a_00604

GitHub. (2018). Sigmund Object. Retrieved August 9, 2016, from https://github.com/v7b1/sigmund_64bit-version/releases

Glass. (2017). Glass. Retrieved December 22, 2017, from https://x.company/glass/

Goddard, P., & Goddard, D. (2012). *I am intelligent: From heartbreak to healing – A mother and daughter's journey through autism.* Guilford: Rowman & Littlefield.

Golan, O., & Baron-Cohen, S. (2006). Systemizing empathy: Teaching adults with Asperger syndrome or high-functioning autism to recognize complex emotions using interactive multimedia. *Development and Psychopathology*, *18*, 591–617. https://doi.org/10.1017/S0954579406060305

Goldsmith, T. R., & Leblanc, L. A. (2004). Use of Technology in Interventions for Children with Autism. *Journal of Early and Intensive Behavior Intervention*, *1*, 166–178.

Google Developers. (2018). Glass Explorer Edition | Google Developers. Retrieved August 10, 2018, from https://developers.google.com/glass/

GoPro. (2016). GoPro - HERO Session Waterproof Camera. Retrieved February 23, 2017, from https://shop.gopro.com/EMEA/cameras/hero-session/CHDHS-104-

master.html

Government, T. S. (2013). *The Scottish Strategy for Autism - Menu of Interventions*.

Grandin, T. (2009). Visual Abilities and Sensory Differences in a Person with Autism. *Biological Psychiatry*, *65*(1), 15–16. https://doi.org/10.1016/j.biopsych.2008.11.005

Grant, E. (2012). Cymatics.jpg (JPEG Image, 1024 × 682 pixels). Retrieved January 9, 2017, from Simple Grid Theme website: https://farm9.staticflickr.com/8064/8197461646_d82d3a67c7_b.jpg

Gray, D. (2013). *The Visualization and Representation of Electroacoustic Music*.

Green, G., & Ricciardi, J. (2015). Findings and conclusions: National standards project, phase 2. In *National Autism Center*.

Grekow, J. (2011). Emotion based music visualization system. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *6804 LNAI*, 523–532. https://doi.org/10.1007/978-3-642-21916-0_56

Grey, J. M. (1978). Perceptual effects of spectral modifications on musical timbres. *The Journal of the Acoustical Society of America*, *63*(5), 1493. https://doi.org/10.1121/1.381843

Grierson, M. S. (2011). Making music with images: Interactive audiovisual performance systems for the deaf. *International Journal on Disability and Human Development*, *10*(1), 37–41. https://doi.org/10.1515/IJDHD.2011.009

Griffin, E. (2013). VU Meter - Pyramid Pyro - 5 Minutes - YouTube. Retrieved February 20, 2018, from https://www.youtube.com/watch?v=W-xpX7KH44Y

Griffiths, R. (1970). *The abilities of young children*.

Grynszpan, O., Weiss, P. L., Perez-Diaz, F., & Gal, E. (2014). Innovative technology-based interventions for autism spectrum disorders: A meta-analysis. *Autism*, Vol.

18, pp. 346–361. https://doi.org/10.1177/1362361313476767

Guardian News and Media Limited. (2017). The lunchtime revolution at a school for children with autism | Life and style | The Guardian. Retrieved January 18, 2017, from https://www.theguardian.com/lifeandstyle/2015/jul/19/lunchtime-revolution-school-children-autism?CMP=share_btn_gp

Guyatt, G., Sackett, D., Taylor, D. W., Ghong, J., Roberts, R., & Pugsley, S. (1986). Determining Optimal Therapy — Randomized Trials in Individual Patients. *New England Journal of Medicine*, *314*(14), 889–892. https://doi.org/10.1056/NEJM198604033141406

Hailpern, J., Halle, J., Karahalios, K., Dethorne, L., & Coletto, M.-K. (2008). A3: a coding guideline for HCI+ autism research using video annotation. *Proceedings of the 10th International ACM SIGACCESS Conference on Computers and Accessibility*, 11–18. Retrieved from http://portal.acm.org/citation.cfm?id=1414471.1414476

Hart, S. (2006). NASA-task load index (NASA-TLX); 20 years later. *Human Factors and Ergonomics Society Annual Meting*, 904–908. https://doi.org/10.1037/e577632012-009

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. *Advances in Psychology*, *52*(C), 139–183. https://doi.org/10.1016/S0166-4115(08)62386-9

Hartley, S. L., Sikora, D. M., & McCoy, R. (2008). Prevalence and risk factors of maladaptive behaviour in young children with Autistic Disorder. *Journal of Intellectual Disability Research : JIDR*, *52*(10), 819–829. https://doi.org/10.1111/j.1365-2788.2008.01065.x

Helle-Valle, A., Binder, P. E., Anderssen, N., & Stige, B. (2017). Is restlessness best understood as a process? Reflecting on four boys' restlessness during music therapy in kindergarten. *International Journal of Qualitative Studies on Health and Well-Being*, *12*(1), 1298266. https://doi.org/10.1080/17482631.2017.1298266

Hemphill, M. (1996). A note on adults' color–emotion associations. *Journal of Genetic*

Psychology. https://doi.org/10.1080/00221325.1996.9914865

Hernandez, L. M., Rudie, J. D., Green, S. A., Bookheimer, S., & Dapretto, M. (2015). Neural signatures of autism spectrum disorders: Insights into brain network dynamics. *Neuropsychopharmacology*, *40*(1), 171–189. https://doi.org/10.1038/npp.2014.172

Herskowitz, V. (2003). *Computer-Based Therapy for Autistic Children*.

Hill, A. (2013). *Interpreting Electroacoustic Audio-visual Music*. De Montford University.

Hilliard, R. B. (1993). Single-case methodology in psychotherapy process and outcome research. *Journal of Consulting and Clinical Psychology*, *61*(3), 373–380. https://doi.org/10.1037/0022-006X.61.3.373

Hillier, A., Greher, G., Poto, N., & Dougherty, M. (2012). Positive outcomes following participation in a music intervention for adolescents and young adults on the autism spectrum. *Psychology of Music*, *40*(2), 201–215. https://doi.org/10.1177/0305735610386837

Hillier, A., Kopec, J., Poto, N., Tivarus, M., & Beversdorf, D. Q. (2015). Increased physiological responsiveness to preferred music among young adults with autism spectrum disorders. *Psychology of Music*, 0305735615576264-. https://doi.org/10.1177/0305735615576264

Himberg, T. (2006). Co-operative tapping and collective time-keeping - differences of timing accuracy in duet performance with human or computer partner. *9th International Conference on Music Perception & Cognition*, 377.

Hipke, K., Holt, M., Price, D., Brumet, A., & Anderson, K. (2010). *AudioVision : Sound Detection for the Deaf and Hard-of- hearing*.

Hobbs, D., & Worthington-Eyre, B. (2008). The efficacy of combining augmented reality and music therapy with traditional teaching - Preliminary results. *I-CREATe 2008 - International Convention on Rehabilitation Engineering and Assistive Technology 2008*, 241–244. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-82455174925&partnerID=40&md5=d82c97653937b3821edc1e5bc97e0516

Hodgson, J. (2010). *Understanding records : a field guide to recording practice*. Bloomsbury Publishing Plc.

Holland, S. (1994). Learning about harmony with Harmony Space: an overview. *In M. Smith, A. Smaill, and G. Wiggins, Editors, Music Education: An Artificial Intelligence Approach, Workshops in Computing*, pp. 25–40. Retrieved from http://www.lestrum.org/Site/References/E26D871F-9A66-4670-AEA4-D0D3D91F6173_files/CCRMA.pdf

Hollander, F. M., Hollander, F. M., Juhrs, P. D., & Juhrs, P. D. (1974). Orff-Schulwerk: An effective treatment tool with autistic children. *Journal of Music Therapy*, *11*(1), 1–12. https://doi.org/10.1093/jmt/11.1.1

Holmes, T. (2012). Electronic and Experimental Music:Technology, Music, and Culture. In *Computer Music Journal* (4th ed.). Retrieved from http://www.jstor.org/stable/3680269?origin=crossref

Honing, H. (2001). From Time to Time: The Representation of Timing and Tempo. *Computer Music Journal*. https://doi.org/10.1162/014892601753189538

Hosseini, M., Fayyaz, I., Arab, S., Naghashian, H., Poudineh, Z., & Ghasemtabar, S. (2015). Music therapy: An effective approach in improving social skills of children with autism. *Advanced Biomedical Research*, *4*(1), 157. https://doi.org/10.4103/2277-9175.161584

Hourcade, J. P., Williams, S. R., Miller, E. A., Huebner, K. E., & Liang, L. J. (2013). Evaluation of tablet apps to encourage social interaction in children with autism spectrum disorders. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '13*, 3197–3206. https://doi.org/10.1145/2470654.2466438

Howlin, P. (1998). Practitioner review: psychological and educational treatments for autism. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *39*(3), 307–322. https://doi.org/doi:10.1111/1469-7610.00327

Howlin, Patricia, Baron-Cohen, S., & Hadwin, J. (1998). *Teaching Children With Autism to Mind-Read : A Practical Guide for Teachers and Parents*. J. Wiley & Sons.

Hubbard, T. L. (1996). Synesthesia-like mappings of lightness, pitch, and melodic interval. *The American Journal of Psychology*, *109*(2), 219–238. https://doi.org/10.2307/1423274

Hunt, A., Kirk, R., & Neighbour, M. (2004). Multimedia Interfaces for Music Therapy. *Ieee Multimedia*, *11*(3), 50–58.

Hutchins, T. L., & Prelock, P. a. (2006). Using Social Stories and Comic Strip Conversations To Promote Socially Valid Outcomes for Children with Autism. *Seminars in Speech and Language*, *27*(01), 047–059. https://doi.org/10.1055/s-2006-932438

Huws, J. C., & Jones, R. S. P. (2008). Diagnosis, disclosure, and having autism: An interpretative phenomenological analysis of the perceptions of young people with autism. *Journal of Intellectual and Developmental Disability*, *33*(2), 99–107. https://doi.org/10.1080/13668250802010394

i.pininmg.com. (2018). Tortoise Shell. Retrieved January 4, 2018, from https://i.pinimg.com/originals/50/af/4e/50af4e367a5c35e092ace8382bc48a2e.jpg

IDG Consumer & SMB. (2012). Parents Herald Rise in Apps to Help Treat Autism but Proof of Therapeutic Benefits Is Lacking | PCWorld. Retrieved May 10, 2015, from http://www.pcworld.com/article/249775/parents_herald_rise_in_apps_to_help_treat_autism_but_proof_of_therapeutic_benefits_is_lacking.html

IEM. (2017). Pure Data — Pd Community Site. Retrieved September 18, 2017, from http://puredata.info/

IK Multimedia US. (2017). IK Multimedia | iRig 2 - Guitar interface adapter for iPad, iPhone iPod touch, Android and Mac. Retrieved April 10, 2017, from http://www.ikmultimedia.com/products/irig2/

Ikuta, N., Iwanaga, R., Tokunaga, A., Nakane, H., Tanaka, K., & Tanaka, G. (2016). Effectiveness of Earmuffs and Noise-cancelling Headphones for Coping with Hyper-reactivity to Auditory Stimuli in Children with Autism Spectrum Disorder: A Preliminary Study. *Hong Kong Journal of Occupational Therapy*, *28*, 24–32. https://doi.org/10.1016/j.hkjot.2016.09.001

in5d.com. (2018). Pine Cone. Retrieved January 5, 2018, from http://in5d.com/wp-content/uploads/2015/04/fdjdjsrtt.jpg

Influentialpoints.com. (2015). Binomial and related tests: Use and Misuse - binomial test, independence, sign test, McNemar's test, Cox and Stuart test for trend. Retrieved July 5, 2018, from http://influentialpoints.com/Training/Binomial_and_related_tests_use_and_misuse.htm

Infmetry. (2018). Handheld Trackball Wireless Mouse - INFMETRY. Retrieved July 28, 2018, from https://www.infmetry.com/products/handheld-trackball-wireless-mouse

iOS MARS. (2017). Borderlands Granular update will be released March 30th | iOS MARS. Retrieved December 3, 2015, from http://main.iosmars.com/2015/03/29/borderlands-granular-update-will-be-released-march-30th/

IRCAM. (2015). Extended shapes on the Tonnetz for (instantaneous) composition and modal analysis in modern music. - Ressources. Retrieved November 25, 2015, from http://medias.ircam.fr/xa70d77

IRCAM. (2018). SoundBox.IanaToMIDI2.png. Retrieved February 7, 2018, from http://forumnet.ircam.fr/wp-content/uploads/2012/11/SoundBox.IanaToMIDI2.png

IRCAM Forumnet. (2017). WWW Ircam: Musical Representations. Retrieved October 8, 2015, from http://www.ircam.fr/repmus.html?&L=1&cHash=58765e3ce41f95d9501a072863 89f208

Isaacson, E. (2005). What You See Is What You Get: on Visualizing Music. *Ismir - International Society of Information Retrieval*, 389–395. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.222.8642&rep=rep1&type=pdf

Janata, P., & Grafton, S. T. (2003). Swinging in the brain: shared neural substrates for behaviors related to sequencing and music. *Nature Neuroscience*, *6*(7), 682–687. https://doi.org/10.1038/nn1081

Jarrold, C., & Scott-Samuel, N. (2005). Motion perception in autism spectrum disorder: we'll move forward once the data become more coherent. *Current Psychology of Cognition*, *23*, 122–131.

Jenny, H. (1968). CYMATICS. *The Sciences*, *8*(7), 12–18. https://doi.org/10.1002/j.2326-1951.1968.tb00384.x

Jones, C. D., & Schwartz, I. S. (2009). When asking questions is not enough: An observational study of social communication differences in high functioning children with autism. *Journal of Autism and Developmental Disorders*, *39*(3), 432–443. https://doi.org/10.1007/s10803-008-0642-y

Jones, & Feeley. (2009). Parent Implemented Joint Attention Intervention for Preschoolers with Autism. *Journal of Speech and Language Pathology - Applied Behavior Analysis*, *4*(1), 74–90.

Jordà, S., Geiger, G., Alonso, M., & Kaltenbrunner, M. (2007). The reacTable : Exploring the Synergy between Live Music Performance and Tabletop Tangible Interfaces. *Proceedings of Conference on Tangible and Embedded Interaction TEI '07*, 139–146. https://doi.org/10.1145/1226969.1226998

JoyLabz. (2018). Makey Makey | Buy Direct (Official Site). Retrieved December 13, 2015, from http://www.makeymakey.com/

Kalas, A. (2012). Joint attention responses of children with autism spectrum disorder to simple versus complex music. *Journal of Music Therapy*, *49*(4), 430–452. https://doi.org/10.1093/jmt/49.4.430

Kallinen, K., & Ravaja, N. (2007). Comparing speakers versus headphones in listening to news from a computer - individual differences and psychophysiological responses. *Computers in Human Behavior*, *23*(1), 303–317. https://doi.org/10.1016/j.chb.2004.10.014

Kandalaft, M. R., Didehbani, N., Krawczyk, D. C., Allen, T. T., & Chapman, S. B. (2013). Virtual Reality Social Cognition Training for Young Adults with High-Functioning Autism. *Journal of Autism and Developmental Disorders*, *43*(1), 34–44. https://doi.org/10.1007/s10803-012-1544-6

Kanner, L. (1943). *Autisitc Disturbances of Affective Contact* (p. 34). p. 34. Retrieved from http://neurodiversity.com/library_kanner_1943.pdf

Kaplan, R. S., & Steele, A. L. (2005). An analysis of music therapy program goals and outcomes for clients with diagnoses on the autism spectrum. *Journal of Music Therapy*, *42*(1), 2–19. https://doi.org/15839730

Kaya, N., & Epps, H. H. (2004). Relationship between Color and Emotion: A Study of College Students. *College Student J*, *38*(3), 396–405. Retrieved from https://nzdis.org/projects/attachments/299/colorassociation-students.pdf

Keefer, C., & Guldemond, J. (2013). *Oskar Fischinger (1900-1967): Experiments in Cinematic Abstraction*.

Kelley, R. T. (2003). *Charting Enharmonicism on the Just Intonation Tonnetz : A Practical Approach to Neo-Riemannian Analysis by Robert T. Kelley Spring, 2002 - 2003*. 2002–2003.

Kern, P., & Aldridge, D. (2006a). Using embedded music therapy interventions to support outdoor play of young children with autism in an inclusive community-based child care program. *Journal of Music Therapy*, *43*(4), 270–294. https://doi.org/10.1093/jmt/43.4.270

Kern, P., & Aldridge, D. (2006b). Using embedded music therapy interventions to support outdoor play of young children with autism in an inclusive community-based child care program. *Journal of Music Therapy*, *43*(4), 270–294. https://doi.org/10.1093/jmt/43.4.270

Kern, P., Wolery, M., & Aldridge, D. (2007). Use of Songs to Promote Independence in Morning Greeting Routines For Young Children With Autism. *Journal of Autism and Developmental Disorders*, *37*(7), 1264–1271. https://doi.org/10.1007/s10803-006-0272-1

Keshav, N. U., Salisbury, J. P., Vahabzadeh, A., & Sahin, N. T. (2017). Social Communication Coaching Smartglasses: Well Tolerated in a Diverse Sample of Children and Adults With Autism. *JMIR MHealth and UHealth*, *5*(9), e140. https://doi.org/10.2196/mhealth.8534

Keyfitz, N., & McNeill, W. H. (1996). Keeping Together in Time: Dance and Drill in Human History. *Contemporary Sociology*, Vol. 25, p. 408.

Kientz, J. A., Goodwin, M. S., Hayes, G. R., & Abowd, G. D. (2013). Interactive Technologies for Autism. *CHI'07 Extended Abstracts on Human Factors in Computing Systems*, *2*(2), 2109–2112. https://doi.org/10.2200/S00533ED1V01Y201309ARH004

Kim, J., Wigram, T., & Gold, C. (2009). Emotional, motivational and interpersonal responsiveness of children with autism in improvisational music therapy. *Autism*, *13*(4), 389–409. https://doi.org/10.1177/1362361309105660

Kim, Jinah, Wigram, T., & Gold, C. (2008). The Effects of Improvisational Music Therapy on Joint Attention Behaviors in Autistic Children: A Randomized Controlled Study. *Journal of Autism and Developmental Disorders*, *38*(9), 1758–1766. https://doi.org/10.1007/s10803-008-0566-6

King, A. J., & Palmer, A. R. (1985). *Integration of visual and auditory information in bimodal neurones in the guinea-pig superior colliculus*.

Koegel, R. L., & Koegel, L. K. (1995). *Teaching children with autism: Strategies for* *initiating positive interactions and improving learning opportunities*. Paul H Brookes Publishing, 1995.

Koelsch, S., Fritz, T., v. Cramon, D. Y., Müller, K., & Friederici, A. D. (2006). Investigating emotion with music: An fMRI study. *Human Brain Mapping*, *27*(3), 239–250. https://doi.org/10.1002/hbm.20180

Kruge, N., & Wang, G. (2011). MadPad : A Crowdsourcing System for Audiovisual Sampling. *Proceedings of the International Conference on New Interfaces for Musical Expression*, (June), 185–190. Retrieved from http://www.nime.org/proceedings/2011/nime2011_185.pdf

Krumhansl, C. L. (1992). Cognitive Foundations of Musical Pitch. *The Journal of the Acoustical Society of America*, Vol. 92, p. 1193. https://doi.org/10.5084/pmmb.v11i1.798

Krumhansl, Carol L. (2005). The geometry of musical structure. *Computers in Entertainment*, Vol. 3, p. 3. https://doi.org/10.1145/1095534.1095542

Kuchera-Morin, J., Wright, M., Wakefield, G., Roberts, C., Adderton, D., Sajadi, B., … Majumder, A. (2014). Immersive full-surround multi-user system design. *Computers and Graphics (Pergamon)*, *40*(1), 10–21. https://doi.org/10.1016/j.cag.2013.12.004

Küssner, M. B. (2014). *Shape, Drawing and Gesture: Cross-Modal Mappings of Sound and Music*. King's College London.

Küssner, M. B., & Leech-Wilkinson, D. (2014). Investigating the influence of musical training on cross-modal correspondences and sensorimotor skills in a real-time drawing paradigm. *Psychology of Music*, *42*(3), 448–469. https://doi.org/10.1177/0305735613482022

Kvam, K. E. (2015). *Barriers to Music Therapy in the Care of Those With Alzheimer ' s / Dementia*. Georgia Southern University.

Kwok, H. W. M., To, Y. F., & Sung, H. F. (2003). The application of a multisensory

Snoezelen room for people with learning disabilities - Hong Kong experience. *Hong Kong Medical Journal*, *9*(2), 122–126.

LaGasse, A. B. (2014). Effects of a Music Therapy Group Intervention on Enhancing Social Skills in Children with Autism. *Journal of Music Therapy*, *00*(00), 1–26. https://doi.org/10.1093/jmt/thu012

Lai, G., Pantazatos, S. P., Schneider, H., & Hirsch, J. (2012). Neural systems for speech and song in autism. *Brain*, *135*(3), 961–975. https://doi.org/10.1093/brain/awr335

Laushey, K. M., & Heflin, L. J. (2000). Enhancing social skills of kindergarten children with autism through the training of multiple peers as tutors. *Journal of Autism and Developmental Disorders*, *30*(3), 183–193. https://doi.org/10.1023/A:1005558101038

Lazar, A., Cornejo, R., Edasis, C., & Piper, A. M. (2016). Designing for the Third Hand : Empowering Older Adults with Cognitive Impairments through Creating and Sharing. *Proceedings of the Designing Interactive Systems Conference (DIS '16)*, 1047–1058. https://doi.org/10.1145/2901790.2901854

Leap Motion Inc. (2018). Leap Motion | 3D Motion and Gesture Control for Virtual Reality. Retrieved September 22, 2015, from https://www.leapmotion.com/product/vr

Leman, M., Lesaffre, M., Nijs, L., & Deweppe, A. (2010). User-oriented studies in embodied music cognition research. *Musicae Scientiae Special Issue*, *Special is*(2010), 203–223. https://doi.org/10.1177/10298649100140S212

Lerdahl, F. (2005). *Tonal Pitch Space*. https://doi.org/10.1093/acprof:oso/9780195178296.001.0001

Leslie, A. M., & Frith, U. (1987). Metarepresentation and autism: How not to lose one's marbles. *Cognition*, *27*(3), 291–294. https://doi.org/10.1016/S0010-0277(87)80014-8

Lett, W. R. (1993). Therapist creativity: The arts of supervision. *The Arts in Psychotherapy*, *20*(5), 371–386. https://doi.org/10.1016/0197-4556(93)90044-3

Levin, G. (2000). Painterly Interfaces for Audiovisual Performance. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Painterly+Interfaces+for+Audiovisual+Performance#0

Libre Music Production. (2018). ADSR envelope | Libre Music Production. Retrieved July 2, 2018, from https://libremusicproduction.com/answer/adsr-envelope

Lim, H a. (2007). The Effect of" Developmental Speech-Language Training through Music" on Speech Production in Children with Autism Spectrum Disorders. *Journal of Music Therapy*, *XLVII*(1), 2–26. Retrieved from papers://9813c380-4a5a-426e-ab3b-10e227534cf8/Paper/p5

Lim, H a, & Draper, E. (2011). The Effects of Music Therapy Incorporated with Applied Behavior Analysis Verbal Behavior Approach for Children with Autism Spectrum Disorders. *Journal of Music Therapy*, *48*(4), 532–550. https://doi.org/10.1093/jmt/48.4.532

Lim, Hayoung. (2010). Effect of “developmental speech and language training through music” on speech production in children with autism spectrum disorders. *Journal of Music Therapy*, *47*(1), 2–26. https://doi.org/10.1093/jmt/47.1.2

Lin, M. F., Hsu, M. C., Chang, H. J., Hsu, Y. Y., Chou, M. H., & Crawford, P. (2010). Pivotal moments and changes in the Bonny Method of Guided Imagery and Music for patients with depression. *Journal of Clinical Nursing*, *19*(7–8), 1139–1148. https://doi.org/10.1111/j.1365-2702.2009.03140.x

Linux Journal. (2015). An Introduction To OSC | Linux Journal. Retrieved February 14, 2016, from Linux Journal website: http://www.linuxjournal.com/content/introduction-osc

Lipkin, P., Law, J., Marvin, A., Rubenstein, E., & Toroney, J. (2016). Auditory hypersensitivity issues in children with autism spectrum disorders (ASD): Characteristics and burden. *Annals of Neurology*, *80*, S392.

https://doi.org/10.1002/pon.4272

Liu, R., Salisbury, J. P., Vahabzadeh, A., & Sahin, N. T. (2017). Feasibility of an Autism-Focused Augmented Reality Smartglasses System for Social Communication and Behavioral Coaching. *Frontiers in Pediatrics*, *5*(June), 1–8. https://doi.org/10.3389/fped.2017.00145

Lookingatsound. (2011). Visualising Music - lookingatsound - Personal network. Retrieved November 18, 2015, from http://cargocollective.com/lookingatsound/following/lookingatsound/Visualising-Music

Loopseque. (2012). Loopseque | Loopseque. New Music Ecosystem. Retrieved August 28, 2015, from http://loopseque.com/loopseque-for-ipad/

Lord, C., & McGee, J. (2001). *Educating children with autism: Committee on educational interventions for children with autism*. Washington, DC: National Academy Press.

Ludlow, A. K., Heaton, P., Hill, E., & Franklin, A. (2014a). Colour Obsessions and Phobias in Autism Spectrum Disorders: the Case of J.G. *Neurocase, 20*(3), 296–306. https://doi.org/10.1080/13554794.2013.770880

Ludlow, A. K., Heaton, P., Hill, E., & Franklin, A. (2014b). Colour Obsessions and Phobias in Autism Spectrum Disorders: the Case of J.G. *Neurocase, 20*(3), 296–306. https://doi.org/10.1080/13554794.2013.770880

Luisa Demattè, M., Sanabria, D., & Spence, C. (2007). Olfactory-tactile compatibility effects demonstrated using a variation of the Implicit Association Test. *Acta Psychologica*, *124*(3), 332–343. https://doi.org/10.1016/j.actpsy.2006.04.001

Mackay, T., Ward, J., Cole, C., Mccutcheon, M., & Aitken, K. (2013). *GOOD AUTISM PRACTICE The Scottish Perspective*. (October).

Madsen, C. (1999). *A Behavioral Approach To Music Therapy* (IX World Congress of Music, Ed.). Washington.

Magrini, M., Carboni, A., Salvetti, O., & Curzio, O. (2015). An Auditory Feedback based system for treating Autism Spectrum Disorder. *Proceedings of the 3rd 2015 Workshop on ICTs for Improving Patients Rehabilitation Research Techniques - REHAB '15*, (November), 30–33. https://doi.org/10.1145/2838944.2838952

Makhaeva, J., Frauenberger, C., & Spiel, K. (2016). Creating creative spaces for co-designing with autistic children. *Proceedings of the 14th Participatory Design Conference on Full Papers - PDC '16*, 51–60. https://doi.org/10.1145/2940299.2940306

Maratos, a S., Gold, C., Wang, X., & Crawford, M. J. (2008). Music therapy for depression. *Cochrane Database of Systematic Reviews (Online)*, (1), CD004517. https://doi.org/10.1002/14651858.CD004517.pub2

Mardirossian, A., & Chew, E. (2007). Visualizing Music: Tonal Progressions and Distributions. *8th International Conference on Music Information Retrieval Vienna Austria*, 189–194. https://doi.org/10.1.1.125.3959

Marks, L.E. (1974). *On Associations of Light and Sound : The Mediation of Brightness , Pitch , and Loudness*. *87*(1), 173–188.

Marks, L.E. (1982). Bright Sneezes and Dark Coughs, Loud Sunlight and Soft Moonlight. *Journal of Experimental Psychology: Human Perception and Performance*, *8*(2).

Marks, Lawrence E. (1974). On associations of light and sound: the mediation of brightness, pitch, and loudness. *The American Journal of Psychology*, *87*(1–2), 173–188. https://doi.org/10.2307/1422011

Marks, Lawrence E. (1987). On cross-modal similarity:auditory-visual interactions in speeded discrimination. *J.Exper.Psychol.: Human Perception and Performance*, Vol. 13, pp. 384–394.

Marks, Lawrence E ., Hammeal, R. J. ., Bornstein, M. H. ., & Smith, L. B. . (1987). Perceiving Similarity and Comprehending Metaphor. *Monographs of the Society for Research in Child Development*, *52*(1).

Marks, Lawrence E, & Pierce, J. B. (1975). of Sensory Dimensions. *Psychological Bulletin*, *82*(3).

Marwick C. (1996). LEaving concert hall for clinic, therapists now test music's "charms." *JAMA*, *275*(4), 267–268. https://doi.org/10.1001/jama.1996.03530280017006

Max, M. L., & Burke, J. C. (1997). Virtual reality for autism communication and education, with lessons for medical training simulators. *Studies in Health Technology and Informatics*, *39*, 46–53.

McClelland, M., Morrison, F., & Holmes, D. (2000). Children At Risk for Early Academic Problem: The Role of Learning-Related Social Skill. *Early Childhood Research Quarterly*, *15*(3, Autumn 2000), 307–329. https://doi.org/http://doi.org/10.1016/S0885-2006(00)00069-7

McGinnity, K., & Negri, N. (2005). *Walk awhile in my autism*. Cambridge Book Review Press.

McGowan. (2017a). Video Figure 1 - YouTube. Retrieved September 5, 2017, from https://www.youtube.com/watch?v=BTWtVjPfBrg&feature=youtu.be

McGowan. (2017b). Video Figure 2 - YouTube. Retrieved September 5, 2017, from https://www.youtube.com/watch?v=rXOv6NKMjog&feature=youtu.be

McGowan. (2017c). Video Figure 3 - YouTube. Retrieved September 5, 2017, from https://www.youtube.com/watch?v=0c9IJUJhqZg&feature=youtu.be

McGowan. (2017d). Video Figure 3 - YouTube.

McGowan. (2017e). Video Figure 4 - YouTube. Retrieved September 5, 2017, from https://www.youtube.com/watch?v=EbKGC_weRGg&feature=youtu.be

McGowan, J. (2014). Holographic Music (Watch in 1080p!). Retrieved February 17, 2016, from https://www.youtube.com/watch?v=BtXYzj-iDRs

McLachlan, J. (2016). Music therapy and autism : case studies. Retrieved June 17, 2019, from Network Autism website: https://network.autism.org.uk/good-practice/case-studies/music-therapy-and-autism

Mei, C., Mason, L., & Quarles, J. (2014). Usability issues with 3D user interfaces for adolescents with high functioning autism. *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility - ASSETS '14*, 99–106. https://doi.org/10.1145/2661334.2661379

Melara, R. D. (1989). Dimensional Interaction Between Color and Pitch. *Journal of Experimental Psychology: Human Perception and Performance*, *15*(1), 69–79. https://doi.org/10.1037/0096-1523.15.1.69

Metric Halo. (2018). SpectraFoo. Retrieved February 20, 2018, from http://mhsecure.com/metric_halo/products/software/spectrafoo.html#tab=1

Meyer, G, F., & Wuerger, S, M. (2001). Cross-modal integration of auditory and visual motion signals. *Neuroreport*, *12*(11), 2557–2560. https://doi.org/10.1097/00001756-200108080-00053

Meyer, L. (1956). *Emotion and Meaning in Music*. Chicago and London: The University of Chicago Press.

Michaud, F., & Theberge-Turmel, C. (2002). Mobile Robotic Toys and Autism. In K. Dautenhahn, A. Bond, L. Cañamero, & B. Edmonds (Eds.), *Socially Intelligent Agents: Creating relationships with Computers and Robots* (pp. 125–132). https://doi.org/10.1007/b116424

Microsoft Corporation. (2012). Kinect Sensor. Retrieved from https://docs.microsoft.com/en-us/previous-versions/microsoft-robotics/hh438998(v=msdn.10)

Microsoft Corporation a. (2018). Microsoft HoloLens | The leader in mixed reality technology. Retrieved August 10, 2018, from https://www.microsoft.com/en-us/hololens

Miles, J., & Henderson, D. M. (1990). Parametrically Forced Surface-Waves. *Annual*

Review of Fluid Mechanics, *22*, 143–165. Retrieved from papers://b382215d-ac95-4dce-9bab-469b6d836056/Paper/p163

Miles, L. K., Nind, L. K., Henderson, Z., & Macrae, C. N. (2010). Moving memories: Behavioral synchrony and memory for self and others. *Journal of Experimental Social Psychology*, *46*(2), 457–460. https://doi.org/10.1016/j.jesp.2009.12.006

Miles, L. K., Nind, L. K., & Macrae, C. N. (2009). The rhythm of rapport: Interpersonal synchrony and social perception. *Journal of Experimental Social Psychology*, *45*(3), 585–589. https://doi.org/10.1016/j.jesp.2009.02.002

Miller, L. J., Anzalone, M. E., Lane, S. J., Cermak, S. A., & Osten, E. T. (2007). Concept evolution in sensory integration: A proposed nosology for diagnosis. *American Journal of Occupational Therapy*, *61*(2), 135–142. https://doi.org/10.5014/ajot.61.2.135

Mintz, J., Branch, C., March, C., & Lerman, S. (2012). Key factors mediating the use of a mobile technology tool designed to develop social and life skills in children with Autistic Spectrum Disorders. *Computers and Education*, *58*(1), 53–62. https://doi.org/10.1016/j.compedu.2011.07.013

Misra, A., Wang, G., & Cook, P. (2005). SNDTOOLS : Real-TIME AUDIO DSP AND 3D VISUALIZATION. *… of the International Computer Music …*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.380.7524

Miyazaki, R. (2003). Exploring MIDI Datasets. *ACM SIGGRAPH 2003 Sketches & Applications*, 1. ACM Press.

Mobogenie. (2017). Self Esteem Test (Psychology) Download - Self Esteem Test (Psychology) 1.0 (Android) Free Download - Mobogenie.com. Retrieved November 24, 2017, from https://www.mobogenie.com/download-self-esteem-test-psychology-2036747.html

Mondloch, C. J., & Maurer, D. (2004). Do small white balls squeak? Pitch-object correspondences in young children. *Cognitive, Affective, & Behavioral Neuroscience*, *4*(2), 133–136. https://doi.org/10.3758/CABN.4.2.133

Monist, T. (2014). *Hegeler Institute*. *91*(3), 475–505.

Mora-Guiard, J., Crowell, C., Pares, N., & Heaton, P. (2017). Sparking social initiation behaviors in children with Autism through full-body Interaction. *International Journal of Child-Computer Interaction*, *11*, 62–71. https://doi.org/10.1016/j.ijcci.2016.10.006

Moritz, W. (1986). Towards an Aesthetics of Visual Music. *ASIFA Canada*, *14:3*.

Möritz, W. (2004). *Optical Poetry: The Life and Work of Oskar Fischinger*. Retrieved from http://books.google.com/books?id=xuFPa4oL26oC&pgis=1

Morris, E. K., Smith, N. G., & Altus, D. E. (2005). B. F. Skinner's contributions to applied behavior analysis. *The Behavior Analyst*, *28*(2), 99–131. https://doi.org/10.1007/BF03392108

Morris, R., & Picard, R. (2009). *Managing Sound Sensitivity in Autism Spectrum Disorder : New Technologies for Customized Intervention by*. MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

motionelements. (2013). Understanding Linear vs Non-linear Editing. Retrieved February 20, 2018, from https://www.motionelements.com/blog/articles/understanding-linear-vs-non-linear-editing

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders*, *36*(1), 27–43. https://doi.org/10.1007/s10803-005-0040-7

MTC. (2014). The Music Therapy Charity. Retrieved September 8, 2018, from https://www.musictherapy.org.uk

Mundy, P., Delgado, C., & Block, J. (2003). Early social communication scales (ESCS). *Coral Gables, FL: …*, (305). Retrieved from http://www.ucdmc.ucdavis.edu/mindinstitute/ourteam/faculty_staff/escs.pdf

Murray, D. (1997). Autism and information technology:therapy with computers. In *Autism and Learning: a guide to good practice.* (pp. 110–117).

Musanim.com. (2011). Music Animation Machine — "Music Worth Watching." Retrieved November 8, 2015, from http://www.musanim.com/

Myles, B. S., Huggins, A., Rome-Lake, M., Hagiwara, T., Barnhill, G. P., & Griswold, D. E. (2003). Written Language Profile of Children and Youth with Asperger Syndrome: From Research to Practice. *Education and Training in Developmental Disabilities*, *38*(4), 362–369. https://doi.org/10.2307/23879912

Nath, A., & Young, S. (2015). *VESBALL : A ball-shaped instrument for music therapy*. 387–391.

National Academy of Sciences. (2017). *The Promise of Assistive Technology to Enhance Activity and Work Participation*. https://doi.org/10.17226/24740

National Autism Center. (2009). National Standards Project Findings and Conclusions. *Autism*, 68. https://doi.org/10.1097/00006199-197003000-00021

Neale, H., Cobb, S., & Wilson, J. (2002). A front ended approach to the user-centred design of VEs. *Proceedings IEEE Virtual Reality 2002*, *2002*. https://doi.org/10.1109/VR.2002.996522

Nettheim, N. (2015). Article: A Bibliography of Statistical Applications in Musicology, by Nigel Nettheim. Retrieved November 18, 2015, from http://nettheim.com/publications/statistics-in-musicology/statistics-in-musicology.html

Newbutt, N., Sung, C., Kuo, H.-J., Leahy, M. J., Lin, C.-C., & Tong, B. (2016). Brief Report: A Pilot Study of the Use of a Virtual Reality Headset in Autism Populations. *Journal of Autism and Developmental Disorders*, *46*(9), 3166–3176. https://doi.org/10.1007/s10803-016-2830-5

NHS Education for Scotland. (2014). The Health and Care Professions Council Standards. Retrieved June 13, 2019, from https://www.hcpc-uk.org/

Nicolaidis, C., Raymaker, D., McDonald, K., Dern, S., Boisclair, W. C., Ashkenazy, E., & Baggs, A. (2013). Comparison of healthcare experiences in autistic and non-autistic adults: A cross-sectional online survey facilitated by an academic-community partnership. *Journal of General Internal Medicine*, *28*(6), 761–769. https://doi.org/10.1007/s11606-012-2262-7

Nordoff Robbins Research Department. (2014). *The Nordoff Robbins Evidence Bank 2014 - 3rd Edition*.

Norris, C., & Dattilo, J. (1999). Evaluating Effects of a Social Story Intervention on a Young Girl with Autism. *Focus on Autism and Other Developmental Disabilities*, *14*(3), 180–186. https://doi.org/10.1177/108835769901400307

Norwich, B., Webster, R., Blatchford, P., Pellicano, L., Tod, J., Ellis, S., … Dockrell, J. (2014). Research in special needs and inclusive education: the interface with policy and practice. *Journal of Research in Special Educational Needs*, *14*(3), 192–192. https://doi.org/10.1111/1471-3802.12070

Novak, T., Scanlan, J., McCaul, D., MacDonald, N., & Clarke, T. (2012). Pilot study of a sensory room in an acute inpatient psychiatric unit. *Australasian Psychiatry*, *20*(5), 401–406. https://doi.org/10.1177/1039856212459585

Novation. (2018). Launchpad | NovationMusic.com. Retrieved from https://global.novationmusic.com/launch/launchpad#

Oculus VR, L. (2018). Oculus. Retrieved August 10, 2018, from https://www.oculus.com/

Odom, S. L., Thompson, J. L., Hedges, S., Boyd, B. A., Dykstra, J. R., Duda, M. A., … Bord, A. (2015). Technology-Aided Interventions and Instruction for Adolescents with Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, *45*(12), 3805–3819. https://doi.org/10.1007/s10803-014-2320-6

OpenGL. (2018). OpenGL API Documentation. Retrieved October 19, 2015, from https://www.opengl.org/documentation/

Ortega, D. H., Cibrian, F. L., & Tentori, M. (2015). BendableSound: A Fabric-based Interactive Surface to Promote Free Play in Children with Autism. *Proceedings of the 17th International ACM SIGACCESS Conference on Computers and Accessibility*, 315–316. https://doi.org/10.1145/2700648.2811355

Ortiz-Vigon Uriarte, I. de L., Garcia-Zapirain, B., & Garcia-Chimeno, Y. (2015). Game design to measure reflexes and attention based on biofeedback multi-sensor interaction. *Sensors (Switzerland)*, *15*(3), 6520–6548. https://doi.org/10.3390/s150306520

Ox, J. (2001). 2 performances in the 21 st. Century Virtual Color Organ: GridJam and Im Januar am Nil. *Proceedings Seventh International Conference on Virtual Systems and Multimedia*, (2000), 580–589. https://doi.org/10.1109/VSMM.2001.969716

Ox, Jack, & Keefer, C. (2008). CVM-Ox-Keefer-Visual Music. Retrieved December 17, 2015, from http://www.centerforvisualmusic.org/Ox_Keefer_VM.htm

Ox, Jack, & Keefer, C. (2015). CVM Library. Retrieved May 10, 2015, from http://www.centerforvisualmusic.org/Library.html#books

Oxford University Press. (2017a). music - definition of music in English from the Oxford dictionary. Retrieved November 30, 2015, from http://www.oxforddictionaries.com/definition/english/music

Oxford University Press. (2017b). rhythm - definition of rhythm in English from the Oxford dictionary. Retrieved December 17, 2015, from http://www.oxforddictionaries.com/definition/english/rhythm

Oxford University Press. (2017c). sound - definition of sound in English from the Oxford dictionary. Retrieved November 30, 2015, from http://www.oxforddictionaries.com/definition/english/sound

Oxford University Press. (2017d). Tonality in Oxford Music Online. Retrieved November 9, 2015, from http://www.oxfordmusiconline.com.ezproxy.napier.ac.uk/subscriber/article/grove/music/28102?q=tonality&search=quick&pos=1&_start=1

Panksepp, J., & Bernatzky, G. (2002). Emotional sounds and the brain: the neuro-affective foundations of musical appreciation. *Behavioural Processes*, *60*(2), 133–155. https://doi.org/10.1016/S0376-6357(02)00080-3

Parés, N., Carreras, A., Durany, J., Ferrer, J., Freixa, P., Gómez, D., … Sanjurjo, À. (2005). *Promotion of Creative Activity in Children With Severe Autism Through Visuals in an Interactive Multisensory Environment*. https://doi.org/http://doi.acm.org/10.1145/1109540.1109555

Parsons, B. D., Novich, S. D., & Eagleman, D. M. (2013). Motor-sensory recalibration modulates perceived simultaneity of cross-modal events at different distances. *Frontiers in Psychology*, *4*(FEB), 1–12. https://doi.org/10.3389/fpsyg.2013.00046

Parsons, S, & Mitchell, P. (2002). The potential of virtual reality in social skills training for people with autistic spectrum disorders. *Journal of Intellectual Disability Research*, Vol. 46, pp. 430–443. https://doi.org/10.1046/j.1365-2788.2002.00425.x

Parsons, Sarah. (2015). Learning to work together: Designing a multi-user virtual reality game for social collaboration and perspective-taking for children with autism. *International Journal of Child-Computer Interaction*, *6*, 28–38. https://doi.org/10.1016/j.ijcci.2015.12.002

Pasiali, V. (2004). The Use of Prescriptive Therapeutic Songs in a Home-Based Environment to Promote Social Skills Acquisition by Children with Autism: Three Case Studies. *Music Therapy Perspectives*. https://doi.org/10.1093/mtp/22.1.11

Paterson, C. R., & Arco, L. (2007). Using video modeling for generalizing toy play in children with autism. *Behavior Modification*, *31*(5), 660–681. https://doi.org/10.1177/0145445507301651

Patton, K. (2007a). Morphological notation for interactive electroacoustic music. *Organised Sound*, *12*(02), 123. https://doi.org/10.1017/S1355771807001781

Patton, K. (2007b). Morphological notation for interactive electroacoustic music. *Organised Sound*, *12*(02), 123. https://doi.org/10.1017/S1355771807001781

Pavlicevic, M. (2014). Afterword: Knock knock... *Psychology of Music*, *42*(6), 2014–2016. https://doi.org/10.1177/0305735614550059

Pavlicevic, Mercédès, & Ansdell, G. (2009). Between communicative musicality and collaborative musicing: A perspective from community music therapy. In *Communicative musicality: Exploring the basis of human companionship.* (pp. 357–376).

Pavlicevic, Mercédès, O'Neil, N., Powell, H., Jones, O., & Sampathianaki, E. (2013). Making music, making friends: Long-term music therapy with young adults with severe learning disabilities. *Journal of Intellectual Disabilities : JOID*, 5–19. https://doi.org/10.1177/1744629513511354

Paxton, K., & Estay, I. A. (2007). Counselling people on the autism spectrum: A practical manual. *Counselling People on the Autism Spectrum: A Practical Manual.* Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=psyc5&NEWS=N&AN=2007-04903-000

Pellegrino, R. (1983). *The electronic arts of sound and light*. London: Van Nostrand Reinhold Company.

Pelletier, M. (2018). Circle of Fifths. Retrieved November 10, 2015, from http://www.circleoffifths.com/#axzz3r5EnXlDr

Pellicano, L., Dinsmore, A., & Charman, T. (2013). *A Future Made Together* (Vol. 44).

Percussa. (2018a). Percussa AudioCubes: Wireless Patching and Live Performance Interface. Retrieved July 24, 2018, from https://www.percussa.com/what-are-audiocubes/

Percussa. (2018b). Percussa AudioCubes: Wireless Patching and Live Performance Interface. Retrieved January 4, 2018, from https://www.percussa.com/what-are-audiocubes/

Petra Kern, K., Rivera, N. R., Chandler, A., & Humpal, M. (2013). Music therapy services for individuals with autism spectrum disorder: A survey of clinical practices and training needs. *Journal of Music Therapy*, *50*(4), 274–303. https://doi.org/10.1093/jmt/50.4.274

Petry, B., Illandara, T., & Nanayakkara, S. (2016). MuSS-Bits: Sensor-display blocks for deaf people to explore musical sounds. *Proceedings of the 28th Australian Computer-Human Interaction Conference, OzCHI 2016*, 72–80. https://doi.org/10.1145/3010915.3010939

Pietrowicz, M., & Karahalios, K. (2013). Sonic Shapes: Visualizing vocal expression. *Icad*, (January 2013), 157–164.

Plaisted, K., Swettenham, J., & Rees, L. (1999). Children with autism show local precedence in a divided attention task and global precedence in a selective attention task. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *40*(5), 733–742. https://doi.org/10.1111/1469-7610.00489

Pöppel, E., Schill, K., & von Steinbüchel, N. (1990). Sensory integration within temporally neutral systems states: A hypothesis. *Naturwissenschaften*, *77*(2), 89–91. https://doi.org/10.1007/BF01131783

Popper, F. (1968). Origins and Development of Kinetic Art. *New York Graphic Society*, 156–172. https://doi.org/loc?

Porayska-Pomsta, K., Frauenberger, C., Pain, H., Rajendran, G., Smith, T., Menzies, R., … Lemon, O. (2012). Developing technology for autism: An interdisciplinary approach. *Personal and Ubiquitous Computing*, *16*(2), 117–127. https://doi.org/10.1007/s00779-011-0384-2

Pouris, M., & Fels, D. I. (2012). Creating an entertaining and informative music visualization. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *7382 LNCS*(PART 1), 451–458. https://doi.org/10.1007/978-3-642-31522-0_68

Preis, J., Arnon, R., Silbert, D., & Rozegar, A. (2015). Does Music Matter? The Effects of Background Music on Verbal Expression and Engagement in Children with Autism

Spectrum Disorders. *Music Therapy Perspectives*, 1–10. https://doi.org/10.1093/mtp/miu044

Prevezer, W., Fidler, R., Kelsang, R., & Coombes, S. (2012). *Musical Interaction*. NORSACA.

Prudence, P. (2017). Paul Prudence. Retrieved August 18, 2015, from http://www.paulprudence.com/

Purch. (2018). Google Glass Review - Wearable Tech - Tom's Guide. Retrieved August 10, 2018, from https://www.tomsguide.com/us/google-glass,review-2153.html

Putnam, C., & Chong, L. (2008). Software and technologies designed for people with autism: what do users want? *Proceedings of the 10th International ACM SIGACCESS Conference on Computers and Accessibility*, 3–10. https://doi.org/10.1145/1414471.1414475

QSR International Pty Ltd. (2018). QSR - NVivo Data Analysis Software | QSR International. Retrieved February 8, 2016, from http://www.qsrinternational.com/

QSR International Pty Ltd. (2017). NVivo product range | QSR International. Retrieved November 7, 2017, from http://www.qsrinternational.com/nvivo/nvivo-products

Raglio, A., Bellelli, G., Traficante, D., Gianotti, M., Ubezio, M. C., Villani, D., & Trabucchi, M. (2008). Efficacy of music therapy in the treatment of behavioral and psychiatric symptoms of dementia. *Alzheimer Disease and Associated Disorders*, *22*(2), 158–162. https://doi.org/10.1097/WAD.0b013e3181630b6f

Rapin, I., & Dunn, M. (2003). Update on the language disorders of individuals on the autistic spectrum. *Brain and Development*, *25*(3), 166–172. https://doi.org/10.1016/S0387-7604(02)00191-2

Rastall, R. (1982). *The Notation of Western Music: An Introduction*. Retrieved from http://search.library.duke.edu/search?id=UNCb1894110

Reeves, W. T. (1983). Particle systems---a technique for modeling a class of fuzzy objects. *ACM SIGGRAPH Computer Graphics*, *17*(3), 359–375. https://doi.org/10.1145/964967.801167

Reichow, B., Doehring, P., Cicchetti, D. V., & Volkmar, F. R. (2011). Evidence-based practices and treatments for children with autism. In *Evidence-Based Practices and Treatments for Children with Autism*. https://doi.org/10.1007/978-1-4419-6975-0

Reichow, B., & Volkmar, F. R. (2010). Social skills interventions for individuals with autism: evaluation for evidence-based practices within a best evidence synthesis framework. *Journal of Autism and Developmental Disorders*, *40*(2), 149–166. https://doi.org/10.1007/s10803-009-0842-0

Reid, J. S. (2018a). Biology :: Cymascope Research. Retrieved January 3, 2018, from http://www.cymascope.com/cyma_research/biology.html

Reid, J. S. (2018b). CymaScope :: Sound Made Visible. Retrieved May 10, 2015, from 2008 website: http://cymascope.com/cyma_research/history.html

Reschke-Hernández, A. E. (2011). History of music therapy treatment interventions for children with autism. *Journal of Music Therapy [0022-2917]*, *48*(2), 169–207. https://doi.org/10.1093/jmt/48.2.169

Research Autism. (2017). Research Autism Home | Autism Interventions | Our Evaluations. Retrieved October 1, 2017, from Research Autism website: http://researchautism.net/autism-interventions/our-evaluations-interventions

Research Methodology. (2018). Questionnaires. Retrieved July 30, 2018, from https://research-methodology.net/research-methods/survey-method/questionnaires-2/

RHYME. (2016). About RHYME |. Retrieved July 31, 2018, from http://musicalfieldsforever.com/rhyme/?page_id=10

Rich, A. (2018). harmony | Definition, History, & Musical Tones | Britannica.com.

Retrieved February 18, 2018, from https://www.britannica.com/art/harmony-music

Richler, J., Huerta, M., Bishop, S. L., & Lord, C. (2010). Developmental trajectories of restricted and repetitive behaviors and interests in children with autism spectrum disorders. *Development and Psychopathology*, *22*(1), 55–69. https://doi.org/10.1017/S0954579409990265

Ricks, D. M., & Wing, L. (1975). Language, communication, and the use of symbols in normal and autistic children. *Journal of Autism and Childhood Schizophrenia*, *5*(3), 191–221. https://doi.org/10.1007/BF01538152

Ringland, K. E., Zalapa, R., Neal, M., Escobedo, L., Tentori, M., & Hayes, G. R. (2014). SensoryPaint: A Multimodal Sensory Intervention for Children with Neurodevelopmental Disorders. *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp ’14 Adjunct*, (September), 873–884. https://doi.org/10.1145/2632048.2632065

Roads, C. (1988). Introduction to Granular Synthesis. *Computer Music Journal*, *12*(2), 11. https://doi.org/10.2307/3679937

Robbins, N. (2016). *Research and Resources for Music Therapy 2016*.

Robertson, G. G., Mackinlay, J. D., & Card, S. K. (1991). Cone Trees. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems Reaching through Technology - CHI ’91*, 189–194. https://doi.org/10.1145/108844.108883

Robertson, S. S. M. (2010). Neurodiversity, Quality of Life, and Autistic Adults: Shifting Research and Professional Focuses onto Real-Life Challenges. *Disability Studies Quarterly*, *30*(1), 413–421. https://doi.org/10.18061/dsq.v30i1.1069

Robin Fox. (2018). RGB LASER SHOW « ROBIN FOX. Retrieved January 28, 2018, from http://robinfox.com.au/rgb-laser-show/

Robledo, J., Donnellan, A. M., & Strandt-Conroy, K. (2012). An exploration of sensory and movement differences from the perspective of individuals with autism.

Frontiers in Integrative Neuroscience, *6*(November), 107. https://doi.org/10.3389/fnint.2012.00107

Roland Corporation. (2018). Roland - XV-2020 | 64-Voice Expandable Synthesizer Module. Retrieved July 17, 2017, from https://www.roland.com/global/products/xv-2020/

Rosenberg, B., & Gaier, E. (1977). *The Self Concept of the Adolescent with Learning Disabilities Strassberg Rosenberg, Barbara;Gaier, Eugene L Adolescence; Winter 1977; 12, 48; Periodicals Archive Online pg. 489*.

Ruud, E. (2013). Can music serve as a “cultural immunogen”? An explorative study. *International Journal of Qualitative Studies on Health and Well-Being*, *8*(1), 1–12. https://doi.org/10.3402/qhw.v8i0.20597

Sahin, N. T., Keshav, N. U., Salisbury, J. P., Vahabzadeh, A., Author, C., Sahin, N. T., … Fl, B. (2017). *Safety and Lack of Negative Effects of Wearable Augmented-Reality Social Communication Aid for Children and Adults with Autism*. (16), 1–12. https://doi.org/10.1101/164335

Saito, M. (1996). Comparative studies on color preference in Japan and other asian regions, with special emphasis on the preference for white. *Color Research and Application*. https://doi.org/10.1002/(SICI)1520-6378(199602)21:1<35::AID-COL4>3.0.CO;2-6

Sapp, C. S. (2005). Visual hierarchical key analysis. *Computers in Entertainment*, Vol. 3, p. 3. https://doi.org/10.1145/1095534.1095544

Schaaf, R. C., Benevides, T., Mailloux, Z., Faller, P., Hunt, J., Van Hooydonk, E., … Kelly, D. (2014). An intervention for sensory difficulties in children with autism: A randomized trial. *Journal of Autism and Developmental Disorders*, *44*(7), 1493–1506. https://doi.org/10.1007/s10803-013-1983-8

Schaaf, R. C., & Miller, L. J. (2005). Occupational therapy using a sensory integrative approach for children with developmental disabilities. *Mental Retardation and Developmental Disabilities Research Reviews*, *11*(2), 143–148.

https://doi.org/10.1002/mrdd.20067

Schuler, A. L., Prizant, B. M., Wetherby, A. M., Cohen, D., & Volkmar, F. (1997). Enhancing language and communication development: Prelinguistic approaches. *Handbook of Autism and Pervasive Developmental Disorders*, 539–571.

Schulz, K. F., & Grimes, D. A. (2002, February). Generation of allocation sequences in randomised trials: Chance, not choice. *Lancet*, Vol. 359, pp. 515–519. https://doi.org/10.1016/S0140-6736(02)07683-3

Scientific American. (2018). Put Your Peripheral Vision to the Test - Scientific American. Retrieved July 6, 2018, from https://www.scientificamerican.com/article/put-your-peripheral-vision-to-the-test/

Scottish Autism. (2017). Scottish Autism - Autism Awareness Charity & Services for Children & Adults in Scotland. Retrieved April 4, 2017, from http://www.scottishautism.org/

Seattle String Studio. (2017). Circle of Fifths. Retrieved November 24, 2017, from http://www.seattlestringstudio.com/index.php/circle-of-fifths

Sense Scotland. (2017a). Sense Scotland. Retrieved August 1, 2017, from http://www.sensescotland.org.uk/what-we-do/latest-news/new-year,-new-sensatronic-lab.aspx

Sense Scotland. (2017b). TouchBase Business Centre. Retrieved February 22, 2017, from http://www.sensescotland.org.uk/business-centre.aspx

Sense Scotland. (2019). Sense Scotland. Retrieved April 4, 2017, from http://www.sensescotland.org.uk/

Serret, S., Hun, S., Iakimova, G., Lozada, J., Anastassova, M., Santos, A., … Askenazy, F. (2014). Facing the challenge of teaching emotions to individuals with low-and high-functioning autism using a new Serious game: a pilot study. *Molecular Autism*, *5*(1), 1–35. https://doi.org/10.1186/2040-2392-5-37

Shamrock, M. (1997). Orff-Schulwerk: An Integrated Foundation. *Music Educators Journal*, *83*(6), 41–44.

Shams, L., & Kim, R. (2010). Crossmodal influences on visual perception. *Physics of Life Reviews*, *7*(3), 269–284. https://doi.org/10.1016/j.plrev.2010.04.006

Shamsuddin, S., Yussof, H., Ismail, L. I., Mohamed, S., Hanapiah, F. A., & Zahari, N. I. (2012). Humanoid Robot NAO Interacting with Autistic Children of Moderately Impaired Intelligence to Augment Communication Skills. *Procedia Engineering*, *41*(Iris), 1533–1538. https://doi.org/10.1016/j.proeng.2012.07.346

Sharma, M., & Jagdev, T. (2012). Use of Music Therapy for Enhancing Self-esteem among Academically Stressed Adolescents. *Pakistan Journal of Psychological Research*, *27*(1), 53. Retrieved from http://proquest.umi.com/pqdweb/?did=2684801171&Fmt=7&clientId=27905&RQT=309&VName=PQD

Shaughnessy, J. J., & Zechmeister, E. B. (1985). *Research methods in psychology. Alfred A. Knopf series in psychology.* New York, NY, US: Knopf.

Sheldrake, M., & Sheldrake, R. (2017). Determinants of Faraday Wave-Patterns in Water Samples Oscillated Vertically at a Range of Frequencies from 50-200 Hz. *WATER Journal*, *9*, 1–27. https://doi.org/10.14294/WATER.2017.6

Shepard, R. N. (1982). Geometrical approximations to the structure of musical pitch. *Psychological Review*, *89*(4), 305–333. https://doi.org/10.1037/0033-295X.89.4.305

Shoemake, K. (1985). Animating rotation with quaternion curves. *ACM SIGGRAPH Computer Graphics*, *19*(3), 245–254. https://doi.org/10.1145/325165.325242

Shore, S. M. (2003). The Language of Music: Working with Children on the Autism Spectrum. *Journal of Education*, *183*(2).

Silberman, S. (2019). Books – Steve Silberman. Retrieved June 27, 2019, from https://www.stevesilberman.com/books/

Silverman, M. J. (2008). Quantitative comparison of cognitive behavioral therapy and music therapy research: A methodological best-practices analysis to guide future investigation for adult psychiatric patients. *Journal of Music Therapy*, *45*(4), 457–506. Retrieved from http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed8&NEWS=N&AN=19256728

Simpson, K., & Keen, D. (2011). Music interventions for children with autism: Narrative review of the literature. *Journal of Autism and Developmental Disorders*, *41*(11), 1507–1514. https://doi.org/10.1007/s10803-010-1172-y

Situation Publishing. (2018). Amount of pixels needed to make VR less crap may set your PC on fire • The Register. Retrieved August 10, 2018, from https://www.theregister.co.uk/2018/01/16/human_limits_of_vr_and_ar/

SkoogMusic. (2018). Skoogmusic | We create music technology that lets anyone make music. Retrieved July 3, 2015, from http://www.skoogmusic.com/

Small, C. (1999). Musicking — the meanings of performing and listening. A lecture. *Music Education Research*, Vol. 1, pp. 9–22.

Smalley, D. (1997). Spectromorphology: explaining sound-shapes. *Organised Sound*, *2*(2), 107–126. https://doi.org/10.1017/S1355771897009059

Smith, J. (2007). Mathematics of the Discrete Fourier Transform (DFT): with Audio Applications ---- Second Edition. Retrieved January 28, 2018, from https://ccrma.stanford.edu/~jos/mdft/Spectrograms.html

Smith, J. (2010). *Physical audio signal processing : for virtual musical instruments and audio effects*. Retrieved from https://ccrma.stanford.edu/~jos/pasp/Spherical_Waves_Point_Source.html

Smith, J. D. (2012). Single-case experimental designs: A systematic review of published research and current standards. *Psychological Methods*, *17*(4), 510–550. https://doi.org/10.1037/a0029312

Smith, L., & Sera, M. (1992). A developmental analysis of the polar structure of dimensions. *Cognitive Psychology*, *24*(1), 99–142.

Smith, S. M., & Williams, G. N. (1997). A visualization of music. *Proceedings. Visualization '97 (Cat. No. 97CB36155)*, 499–503. https://doi.org/10.1109/VISUAL.1997.663931

Smule Inc. (2017). Download Music Apps | Smule. Retrieved October 1, 2015, from http://www.smule.com/apps

Social and Technological Action Research Group. (2017). Technologies for Autism: SensoryPaint :: STAR :: Social and Technological Action Research Group. Retrieved August 25, 2017, from http://www.star-uci.org/2013/11/01/technologies-for-autism-sensorypaint/

Sonosaurus LLC. (2017). ThumbJam | Musical Instrument Platform for iPhone, iPad, and iPod Touch. Retrieved August 28, 2015, from http://thumbjam.com/

SOS. (2008). Yamaha Tenori-On |. Retrieved January 31, 2018, from https://www.soundonsound.com/reviews/yamaha-tenori

Soto-Faraco, S., Kingstone, A., & Spence, C. (2003). Multisensory contributions to the perception of motion. *Neuropsychologia*, *41*(13), 1847–1862. https://doi.org/10.1016/S0028-3932(03)00185-4

Sound Engineering Academy. (2018). Human Voice Frequency Range. Retrieved June 7, 2018, from http://www.seaindia.in/blog/human-voice-frequency-range/

Soundbeam. (2018). Soundbeam The Invisible Expanding Keyboard In Space. Retrieved November 9, 2015, from http://www.soundbeam.co.uk/

soundhealingresource. (2011). Cymatics: video images of human voice - YouTube. Retrieved February 6, 2018, from https://www.youtube.com/watch?v=stMCW6L5GXA

SoundSpectrum Inc. (2017). WhiteCap Screenshots - highly reactive visuals for your tunes. Retrieved December 2, 2015, from http://www.soundspectrum.com/whitecap/screenshots.html#

Spence, C. (2012). Managing sensory expectations concerning products and brands: Capitalizing on the potential of sound and shape symbolism. *Journal of Consumer Psychology*. https://doi.org/10.1016/j.jcps.2011.09.004

Spence, C., & Shankar, M. U. (2010). The influence of auditory cues on the perception of, and responses to, food and drink. *Journal of Sensory Studies*. https://doi.org/10.1111/j.1745-459X.2009.00267.x

Stanley, P. D., & Miller, M. M. (1993). Short-term art therapy with an adolescent male. *The Arts in Psychotherapy*, *20*(5), 397–402. https://doi.org/10.1016/0197-4556(93)90046-5

Statistics Solutions. (2018). Binomial Test of Significance - Statistics Solutions. Retrieved July 5, 2018, from http://www.statisticssolutions.com/binomial-test-of-significance/

Steinberg Media Technologies GmbH. (2017). Start : | http://www.steinberg.net/. Retrieved December 17, 2015, from http://www.steinberg.net/en/products/cubase/start.html

Stige, B., & Aaro, L. E. (2011). Invitation to Community Music Therapy. In *Australian Journal of Music Therapy*. https://doi.org/10.4324/9780203803547

Stöckmann, H. J. (2007). Chladni meets Napoleon. *European Physical Journal: Special Topics*, *145*(1), 15–23. https://doi.org/10.1140/epjst/e2007-00144-5

Strain, P. S., & Schwartz, I. (2001). ABA and the Development of Meaningful Social Relations for Young Children with Autism. *Focus on Autism and Other Developmental Disabilities*, *16*, 120–128. https://doi.org/10.1177/108835760101600208

Strick, J. (2005). *Visual Music*. Thames & Hudson.

Strickland, D., Marcus, L. M., Mesibov, G. B., & Hogan, K. (1996). Brief report: Two case studies using virtual reality as a learning tool for autistic children. *Journal of Autism and Developmental Disorders*, *26*(6), 651–659. https://doi.org/10.1007/BF02172354

Sundberg, M. L., Partington, J. W., & J.W., P. (1998). *Teaching language to children with autism or other developmental disabilities*.

Suresh, K. (2011). An overview of randomization techniques: An unbiased assessment of outcome in clinical research. *Journal of Human Reproductive Sciences*, *4*(1), 8. https://doi.org/10.4103/0974-1208.82352

SurveyGizmo. (2017). SurveyGizmo. Retrieved February 21, 2017, from https://try.surveygizmo.com/logout

Sussman, J. (2009). The Effect of Music on Peer Awareness in Preschool Age Children with Developmental Disabilities. *Journal of Music Therapy*, (1), 53–68.

Sykes, L. (2011). The augmented tonoscope. *… Conference on Electronic Visualisation and the Arts*, 1–6. Retrieved from http://phd.lewissykes.info/webdisk/UVM11-Lewis Sykes-TheAugmentedTonoscope.pdf

Sykes, L. (2015). The augmented tonoscope (Manchester School of Art). Retrieved from http://phd.lewissykes.info/webdisk/UVM11-Lewis Sykes-TheAugmentedTonoscope.pdf

Tager-Flusberg, H. (2003). Language impairment in children with complex neurodevelopmental disorders: The case of autism. In *Language competence across populations: Toward a definition of specific language impairment.* (pp. 297–321).

Tager-Flusberg, H., Paul, R., & Lord, C. (2013). Language and Communication in Autism. In *Handbook of Autism and Pervasive Developmental Disorders* (Vol. 1, pp. 335–364). https://doi.org/10.1002/9780470939345.ch12

Taheri, a. R., Alemi, M., Meghdari, A., PourEtemad, H. R., & Holderread, S. L. (2015).

Clinical Application of Humanoid Robots in Playing Imitation Games for Autistic Children in Iran. *Procedia - Social and Behavioral Sciences*, *176*, 898–906. https://doi.org/10.1016/j.sbspro.2015.01.556

Tan, S.-L., & Kelly, M. E. (2004a). Graphic Representations of Short Musical Compositions. *Psychology of Music*, *32*(2), 191–212. https://doi.org/10.1177/0305735604041494

Tan, S.-L., & Kelly, M. E. (2004b). Graphic Representations of Short Musical Compositions. *Psychology of Music*, *32*(2), 191–212.

Tang, H. H., Jheng, C. M., Chien, M. E., Lin, N. M., & Chen, M. Y. (2013). ICAN: A tablet-based pedagogical system for improving the user experience of children with autism in the learning process. *ICOT 2013 - 1st International Conference on Orange Technologies*, 177–180. https://doi.org/10.1109/ICOT.2013.6521186

Tantam, D. (2003). The challenge of adolescents and adults with Asperger syndrome. *Child & Adolescent Psychiatric Clinics of North America*, *12*(1), 143–163. https://doi.org/10.1016/S1056-4993(02)00053-6

Tarbox, J., & Persicke, A. (2014). Play. In *Evidence-Based Treatment for Children with Autism* (pp. 223–241). https://doi.org/10.1016/B978-0-12-411603-0.00012-4

Taylor, R., Boulanger, P., & Torres, D. (2005). Visualizing Emotion in Musical Performance Using a Virtual Character. In *Smart Graphics* (pp. 13–24). https://doi.org/10.1007/11536482_2

Taylor, R., Bowers, J., Nissen, B., Wood, G., Chaudhry, Q., Wright, P., … Museums, W. (2015). Making Magic: Designing for Open Interactions in Museum Settings. *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition*, 313–322. https://doi.org/10.1145/2757226.2757241

Taylor, R., Schofield, G., Shearer, J., Wright, P., Boulanger, P., & Olivier, P. (2014). Nightingallery: theatrical framing and orchestration in participatory performance. *Personal and Ubiquitous Computing*, *18*(7), 1583–1600. https://doi.org/10.1007/s00779-014-0763-6

Telfer, J. (2010). Cymatic Music | John Telfer. Retrieved November 16, 2015, from http://www.cymaticmusic.co.uk/john-telfer.htm

Teyseyre, A. R., & Campo, M. R. (2009). An overview of 3D software visualization. *IEEE Transactions on Visualization and Computer Graphics*, *15*(1), 87–105.

The Creators Project. (2017). Original Creators: Thomas Wilfred, The Father Of Multimedia | The Creators Project. Retrieved August 20, 2015, from http://thecreatorsproject.vice.com/blog/original-creators-thomas-wilfred-the-father-of-multimedia

The National Autistic Society. (2015). The National Autistic Society | We are the leading UK charity for people with autism (including Asperger syndrome) and their families. Retrieved May 10, 2015, from http://www.autism.org.uk/about-autism/research/light-sensitivity-and-autism-survey-results.aspx

The National Autistic Society. (2016). Sensory differences - NAS. Retrieved January 10, 2016, from The National Autistic Society website: http://www.autism.org.uk/about/behaviour/sensory-world.aspx

The Pianola Institute Ltd. (2016). The Pianola Institute - History of the Pianola - Piano Players. Retrieved December 1, 2015, from http://www.pianola.org/history/history_pianoplayers.cfm

The Research Council of Norway. (2016). Home page - VERDIKT. Retrieved July 31, 2018, from https://www.forskningsradet.no/prognett-verdikt/Home_page/1226993814906

The University of Edinburgh. (2018). Expert app reviews from our family in residence – DART. Retrieved August 8, 2018, from http://dart.ed.ac.uk/app-reviews-fir/

Thiese, M. S. (2014). Observational and interventional study design types; an overview. *Biochemia Medica*, *24*(2), 199–210. https://doi.org/10.11613/BM.2014.022

Thompson, J., Kuchera-Morin, J., Novak, M., Overholt, D., Putnam, L., Wakefield, G., & Smith, W. (2009). The Allobrain: An interactive, stereographic, 3D audio, immersive virtual world. *International Journal of Human Computer Studies*, *67*(11), 934–946. https://doi.org/10.1016/j.ijhcs.2009.05.005

Todos Somos Uno. (2017). Bendable sound: innovación interactiva para niños con autismo | Todos Somos Uno. Retrieved November 20, 2017, from http://todossomosuno.com.mx/portal/index.php/bendable-sound-innovacion-interactiva-para-ninos-con-autismo/

Tomchek, S. D., & Dunn, W. (2007). Sensory processing in children with and without autism: a comparative study using the short sensory profile. *The American Journal of Occupational Therapy. : Official Publication of the American Occupational Therapy Association*, *61*(2), 190–200. https://doi.org/10.5014/ajot.61.2.190

Total Pro Audio. (2018). Total Pro Audio | Phase or Polarity? Retrieved February 21, 2018, from http://totalproaudio.stevebunting.com/30/basics/phase-or-polarity/

Tracy, S. (2013). *Qualitative research methods*. Retrieved from http://okt.kmf.uz.ua/atc/oktat-atc/Basics_of_research_methodology/Tracy_2013_qualitative_research_methods_collecting_evidence_crafting_analysis_communication.pdf

Trevarthen, C. (2002). Autism, sympathy of motives and music therapy. *Enfance*, *54*(1), 86. https://doi.org/10.3917/enf.541.0086

Trevarthen, C., Aitken, K., Papoudi, D., & Robarts, J. J. (1998). Children with Autism. In D. P. & J. R. Colwyn Trevarthen, Kenneth Aitken (Ed.), *Children with Autism: Diagnosis and interventions to meet their needs* (2nd ed.). London: Jessica Kingsley Publishers.

Tsiros, A., & Leplâtre, G. (2017). The Effectiveness of Two Audiovisual Mappings to Control a Concatenative Synthesiser. *Proceedings of The Sound and Music Computing Conference (SMC)*, 320–327.

Ulfarsdottir, L. O., & Erwin, P. G. (1999). The influence of music on social cognitive skills. *The Arts in Psychotherapy*, *26*(2), 81–84. https://doi.org/10.1016/S0197-4556(98)00064-1

Ulgado, R. R., Nguyen, K., Custodio, V. E., Waterhouse, A., Weiner, R., & Hayes, G. (2013). VidCoach. *Proceedings of the 12th International Conference on Interaction Design and Children - IDC '13*, 581–584. https://doi.org/10.1145/2485760.2485870

Unity Technologies. (2018). Unity. Retrieved August 1, 2016, from https://docs.unity3d.com/Manual/Audio.html

University of Cambridge. (2016). *Chladni plates: the first step towards visualizing sound*. Retrieved from http://www.hps.cam.ac.uk/whipple/explore/acoustics/ernstchladni/chladniplates/

Van Campen, C. (2012). Psychological Experiments with. *Leonardo*, *32*(1), 9–14.

Van De Vall, T. (2013). Color-Wheel-Template. Retrieved February 6, 2018, from https://www.timvandevall.com/wp-content/uploads/2013/08/Color-Wheel-Template-02.png

Van der Burg, E., Olivers, C. N. L., Bronkhorst, A. W., & Theeuwes, J. (2008). Pip and Pop: Nonspatial Auditory Signals Improve Spatial Visual Search. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(5), 1053–1065. https://doi.org/10.1037/0096-1523.34.5.1053

Video Circuits. (2005). VIDEO CIRCUITS: Ron Pellegrino. Retrieved November 22, 2015, from http://videocircuits.blogspot.co.uk/2013/09/ron-pellegrino.html

Villafuerte, L., Markova, M., & Jorda, S. (2012). Acquisition of social abilities through musical tangible user interface. *Proceedings of the 2012 ACM Annual Conference Extended Abstracts on Human Factors in Computing Systems Extended Abstracts - CHI EA '12*, 745. https://doi.org/10.1145/2212776.2212847

Villaroman, N., Rowe, D., & Swan, B. (2011). Teaching natural user interaction using OpenNI and the Microsoft Kinect sensor. *Proceedings of the 2011 Conference on Information Technology Education - SIGITE '11*. https://doi.org/10.1145/2047594.2047654

Visual Music Archive. (2009). BioAcousticPhenomena. Retrieved May 10, 2015, from http://visualmusicarchive.org/works/w/bioacousticphenomena.html

Wagner, H. R., Glaser, B. G., & Strauss, A. L. (1968). The Discovery of Grounded Theory: Strategies for Qualitative Research. *Social Forces*, *46*(4), 555. https://doi.org/10.2307/2575405

Wainer, A. L., & Ingersoll, B. R. (2011). The use of innovative computer technology for teaching social communication to individuals with autism spectrum disorders. *Research in Autism Spectrum Disorders*, *5*(1), 96–107. https://doi.org/10.1016/j.rasd.2010.08.002

Wakabayashi, A., Baron-Cohen, S., & Wheelwright, S. (2006). Are autistic traits an independent personality dimension? A study of the Autism-Spectrum Quotient (AQ) and the NEO-PI-R. *Personality and Individual Differences*, *41*(5), 873–883. https://doi.org/10.1016/j.paid.2006.04.003

Wale, S. A. A. B. J. J. W. M. H. B. C. J. (1977). Why Do Women Consult Doctors? Social Factors and the Use of the General Practitioner. *British Journal of Preventive and Social Medicine*, *31*(4), 220–226. Retrieved from http://www.jstor.org/stable/25565979

Walker, P., Bremner, J. G., Mason, U., Spring, J., Mattock, K., Johnson, S. P., … Slater, A. (2010). *Preverbal Infants ' Sensitivit Cross-Modality Corresponde*. *21*(1), 21–25.

Walker, R. (1987). The effects of culture, environment, age, and musical training on choices of visual metaphors for sound. *Perception & Psychophysics*, *42*(5), 491–502. https://doi.org/10.3758/BF03209757

Wang, G. (2011). Designing for the iPad : Magic Fiddle. *Proceedings of the International Conference on New Interfaces for Musical Expression*, (June), 197–202.

Wang, G. (2014a). Ocarina: Designing the iPhone's Magic Flute. *Computer Music Journal*, *38*(2), 8–21. https://doi.org/10.1162/COMJ_a_00236

Wang, G. (2014b). Principles of Visual Design for Computer Music. *ICMC SMC 2014*, (September), 391–396.

Wang, G., & Clarke, A. C. (2009). Designing Smule's iPhone Ocarina. *Proceedings of the 2009 Conference on New Interfaces for Musical Expression (NIME-09)*, *1200*.

Wang, G., Oh, J., Salazar, S., & Hamilton, R. (2011). World Stage: a Crowdsourcing Paradigm for Social / Mobile Music. *Proceedings of the International Computer Music Conference*, 1–8. https://doi.org/10.1080/09298215.2014.991739

Ward, J., Huckstep, B., & Tsakanikos, E. (2006). Sound-colour synaesthesia: To what extent does it use cross-modal mechanisms common to us all? *Cortex*, *42*(2), 264–280. https://doi.org/10.1016/S0010-9452(08)70352-6

Ward, J., Moore, S., Thompson-Lake, D., Salih, S., & Beck, B. (2008). The aesthetic appeal of auditory-visual synaesthetic perceptions in people without synaesthesia. *Perception*, *37*(8), 1285–1296. https://doi.org/10.1068/p5815

Waterhouse, L. (2008). Autism Overflows: Increasing Prevalence and Proliferating Theories. *Neuropsychology Review*, *18*(4), 273–286. https://doi.org/10.1007/s11065-008-9074-x

Webster, M. (2017). Neurotypical | Definition of Neurotypical by Merriam-Webster. Retrieved January 17, 2017, from https://www.merriam-webster.com/dictionary/neurotypical

Weisstein, E. W. (2017). Lissajous Curve. Retrieved November 15, 2015, from http://mathworld.wolfram.com/LissajousCurve.html

Wells, A. (1980). Music and Visual Color: A Proposed Correlation. Retrieved September 24, 2015, from Leonardo website: http://www.jstor.org/stable/1577978?seq=1#page_scan_tab_contents

West, M. (2000). *Music as medicine: the history of music healing since antiquity* (P. Horden, Ed.). Aldershot: Ashgate.

Whatis.com. (2018). What is oscilloscope? - Definition from WhatIs.com. Retrieved

January 28, 2018, from http://whatis.techtarget.com/definition/oscilloscope

Wheeler, B. L. (2015). *Music Therapy Handbook*. Retrieved from https://books.google.com/books?hl=en&lr=&id=mfnhBQAAQBAJ&pgis=1

Wheeler, B. L., Wagner, G., Summer, L., Madsen, C., Turry, A., & Eschen, J. T. (2012, February 13). Five International Models of Music Therapy Practice. *Voices: A World Forum for Music Therapy*, Vol. 12. Retrieved from https://voices.no/index.php/voices/article/view/634/507

White, S. W., Scarpa, A., Conner, C. M., Maddox, B. B., & Bonete, S. (2015). Evaluating change in social skills in high-functioning adults with autism spectrum disorder using a laboratory-based observational measure. *Focus on Autism and Other Developmental Disabilities*, *30*(1), 3–12. https://doi.org/10.1177/1088357614539836

Whitelaw, M. (2008). Synesthesia and Cross-Modality in Contemporary Audiovisuals. *The Senses & Society*, *3*(3), 259–276. https://doi.org/10.2752/174589308X331314

Whitney, J. (1980). *Digital Harmony: On the Complementarity of Music and Visual Art*. New York: McGraw-Hill, Inc. New York, NY, USA.

Wicker, F. W. . (1968). *Mapping the Intersensory Regions of Perceptual Space*. *81*(2), 178–188.

Wigram, T. (2000). *A Method of Music Therapy Assessment for the Diagnosis of Autism and Communication Disorders in Children*. https://doi.org/doi.org/10.1093/mtp/18.1.13

Wigram, T, & Gold, C. (2006). Music therapy in the assessment and treatment of autistic spectrum disorder: clinical application and research evidence. *Child: Care, Health and Development*, *32*(5), 535–542. https://doi.org/10.1111/j.1365-2214.2006.00615.x

Wigram, Tony, & Elefant, C. (2009). Therapeutic dialogues in music: Nurturing musicality of communication in children with autistic spectrum disorder and Rett syndrome. In *Communicative musicality: Exploring the basis of human companionship.*

Wilkinson, K. M., & Jagaroo, V. (2004). Contributions of principles of visual cognitive science to AAC system display design. *AAC: Augmentative and Alternative Communication*. https://doi.org/10.1080/07434610410001699717

Wimpory, D., Chadwick, P., & Nash, S. (1995). Brief report: Musical interaction therapy for children with autism: An evaluative case study with two-year follow-up. *Journal of Autism and Developmental Disorders*, *25*(5), 541–552. https://doi.org/10.1007/BF02178299

Wing, L. (1981). Asperger ' s syndrome : a clinical account. *Psychological Medicine*, (11), 115–129.

Wing, L. (1997). The autistic spectrum. *The Lancet*, *350*(9093), 1761–1766. https://doi.org/10.1016/S0140-6736(97)09218-0

Wolfe, J. (2011). Note names, MIDI numbers and frequencies. Retrieved June 6, 2018, from 2011 website: https://newt.phys.unsw.edu.au/jw/notes.html

Yang, T.-R., Wolfberg, P. J., Wu, S.-C., & Hwu, P.-Y. (2003). Supporting children on the autism spectrum in peer play at home and school: piloting the integrated play groups model in Taiwan. *Autism : The International Journal of Research and Practice*. https://doi.org/10.1177/1362361303007004009

Yin, R. K. (2009). Case study research : design and methods. In *Applied social research methods series ;* https://doi.org/10.1097/FCH.0b013e31822dda9e

YouTube. (2015). Soundbeam, what is it? Retrieved November 3, 2015, from https://www.youtube.com/watch?v=AoqzhLbdo9Q

YouTube. (2016). Rhapsody in Blue - Music Animation Machine. Retrieved November 9, 2015, from https://www.youtube.com/watch?v=js-vlAIdCp0

Zalla, T., & Sperduti, M. (2015). The sense of agency in autism spectrum disorders: a dissociation between prospective and retrospective mechanisms? *Frontiers in Psychology*, *6*(September), 1–7. https://doi.org/10.3389/fpsyg.2015.01278

Zhang, R., Barnes, J., Howard, A. M., & Park, C. H. (2016). *Musical Robots for Children with ASD Using a Client-Server Architecture*.

Zhiglova, Y., & Yulia. (2018). The Interactive Carpet - Smart Textile Interface for Children on Autism Spectrum Disorder. *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction - TEI '18*, (March), 712–714. https://doi.org/10.1145/3173225.3173341

Appendix A - Glossary of Acronyms

6-DOF – Six degrees of freedom

AAC - Alternative and augmentative communication systems

API - Application Programming Interface

AR – Augmented Reality

ASC – Autism spectrum condition

ASD – Autism spectrum disorder

CARD - Center for Autism and Related Learning

CoMT – Community music therapy

DSP - Digital Signal Processing

GIM – Guided imagery and music model

HF – High functioning

LF – Low functioning

MIR – Music Information Retrieval

MR – Mixed Reality

MSE – Multi-Sensory Environment

MT – Music Therapy

NAC - National Autism Center (National Autism Center, 2009)

NT – Neurotypical - not displaying or characterized by autistic or other neurologically atypical patterns of thought or behaviour

NSP2 - National Standards Project Phase 2 (National Autism Center, 2009)

OpenGL - Open Graphics Library

PAS – Person or people on the autism spectrum

RMB - Repetitive and maladaptive behaviour

TUI – Tangible user interfaces

VRT – Virtual reality technology

Appendix B – Requirements Gathering Documents for Music Therapists

Informed Consent

Developing an audio-visual tool for use in music therapy to improve communication and social interaction for people on the autism spectrum.

Edinburgh Napier University requires that all persons who participate in research studies give their written consent to do so. Please read the following and sign it if you agree with what it says.

1. I freely and voluntarily consent to be a participant in the research project on the topic of the design and creation of an audio-visual tool to be conducted by John McGowan, who is a postgraduate student in the Edinburgh Napier School of Computing.

2. The broad goal of this research study is to explore the role that visual music can play in the lives of people on the autism spectrum, by examining their needs, current practices in music therapy and assistive technologies, and the potential for an interactive tool. Specifically, I have been asked to participate in an audio-recorded semi-structured interview, which should take no longer than one hour to complete.

3. I have been told that my responses will be anonymised and that the audio recordings will be kept in a locked, secure environment within the University. My name will not be linked with the research materials, and I will not be identified or identifiable in any report subsequently produced by the researcher.

4. I also understand that if at any time during the interview I feel unable or unwilling to continue, I am free to leave. That is, my participation in this study is completely voluntary, and I may withdraw from it at any time without negative consequences.

5. In addition, should I not wish to answer any particular question or questions, I am free to decline.

6. I have been given the opportunity to ask questions regarding the interview and my questions have been answered to my satisfaction.

7. I have read and understand the above and consent to participate in this study. My signature is not a waiver of any legal rights. Furthermore, I understand that I will be able to keep a copy of the informed consent form for my records.

______________________________ ______________________________

Participant's Signature Date

I have explained and defined in detail the research procedure in which the respondent has consented to participate. Furthermore, I will retain one copy of the informed consent form for my records.

______________________________ ______________________________

Researcher's Signature Date

Information Sheet for Potential Participants

Developing an audio-visual tool for use in music therapy to improve communication and social interaction for people on the autism spectrum

My name is John McGowan and I am a research student from the School of Computing at Edinburgh Napier University. As part of my PhD, I am undertaking a research project, the title of which is underlined above.

This study will explore the role that visual music can play in the lives of people on the autism spectrum, by examining their needs, current practices in music therapy and assistive technologies, and the potential for an interactive tool.

The findings of the study will inform the design of the tool and subsequently aid in its use.

I am looking for qualified music therapists to participate. There are no criteria (e.g. gender, age, or health) for being included or excluded.

If you agree to participate in the study, you will be asked to take part in a short interview. The researcher is not aware of any risks associated with the interview process. The whole procedure should take no longer than 60 minutes. You will be free to withdraw from the study at any stage, you would not have to give a reason.

All data will be anonymised, but you may be identifiable from tape recordings of your voice. Your name will be replaced with a participant number, and it will not be possible for you to be identified in any reporting of the data gathered. All data collected will be kept in a secure place (audio recordings will be kept in a locked cabinet in locked room and digital data will be stored on a PC that is password protected) to which only I, John McGowan, has access. These will be kept till the end of the PhD process, following which all data that could identify you will be destroyed.

The anonymised results may be published in a thesis, journal or presented at a conference.

If you have any questions, please feel free to contact me at any time using the details at the top of the page. If you have read and understood this information sheet, and you would like to be a participant in the study, please now see the consent form.

Many thanks for your participation.

Self-Assessment Form

To be completed by the Gatekeeper[1] and the researcher.

Project Title :	Developing an audio-visual tool for use in music therapy to improve communication and social interaction for people on the autism spectrum.
Very brief Description:	An exploration of the role that visual music can play in the lives of people on the autism spectrum, by examining their needs, current practices in music therapy and assistive technologies, and the potential for an interactive tool.
Type	Research Degree

People Involved

Name	**Role**
John McGowan	Researcher
Dr Gregory Leplatre	Director of Studies
Dr Iain McGregor	Supervisor and Gatekeeper

Issue		If 'yes" give brief details.
Children under 16 involved	N	
Interaction with patient groups, disabilities or older potentially vulnerable people	N	
Potential impact on <u>physical</u> health and safety of participants, researchers and the general public	N	
Potential impact on the <u>mental</u> health and safety of participants, researchers and the general public	N	
Data protection, intellectual property and permissions required	Y	The interviewee could mention the names of any clients they work with, which could lead to identification of the client themselves through association with the interviewee.
Socially or culturally 'controversial' investigations (e.g. pornography, extremist politics)	N	
Privacy issues (e.g. use of social media, ethnographic studies) • See the assumed consent form	N	

[1] A gatekeeper is an experienced member of staff who is familiar with ethical good practice. This gatekeeper will typically be the student's supervisor or module leader. For members of staff this may be the project's principle investigator, centre or Institute director.

If each question has been answered ‘No’ to every question the project may proceed. This checklist should be retained.
If any of the questions have been answered “Yes” then continue to the next page.

Completed by: John McGowan

Briefly describe the ethical problem:

There are data protection issues surrounding the possibility that the interviewee will mention the names of any clients they work with, which could lead to identification of the client themselves through association with the interviewee.

If this can be satisfactorily resolved by the gatekeeper and researcher, describe the resolution:

All data will be anonymised, but the interviewee may be identifiable from tape recordings of their voice. Their name will be replaced with a participant number, and it will not be possible for them to be identified in any reporting of the data gathered. All data collected will be kept in a secure place (audio recordings will be kept in a locked cabinet in locked room and digital data will be stored on a PC that is password protected) to which only John McGowan has access. These will be kept till the end of the PhD process, following which all data that could identify them will be destroyed.

Review of action taken conducted by: Dr Iain McGregor

If the problem has **not** been resolved, then either (tick one):

1. Re-formulate the research proposal and repeat the self-assessment process with a fresh form ☐

2. Pass this on to the ethics committee (send this together with any other project documentation to Phil Turner, School of Computing, [redacted]) ☐

Appendix C – Mapping Survey - Application for Cross-University Ethical Approval

1. Research Details

Name:	John McGowan
School or Professional service department:	School of Computing
Email:	[redacted]
Contact number:	[redacted]
Project Title:	Developing an audio-visual tool for use in creative arts to improve experience for people on the autism spectrum.
Start Date:	March 2015
Duration of Project:	3 Years
Type of Research: Doctoral Student	

2. Screening Questions

Please answer the following questions to identify the level of risk in the proposed project:
If you answer 'No' to all questions, please complete Section 3a only.
If you have answered 'Yes' to any of the questions 5-14 please complete Section 3a and 3b.
If you have answered 'Yes to any of the questions 1-4, complete all of Section 3.

	You Must Answer All Questions	**Yes**	**No**
1.	Is the research clinical in nature?	☐	☒
2.	Is the research investigating socially or culturally 'controversial' topics (for example pornography, extremist politics, or illegal activities)?	☐	☒
3.	Will any covert research method be used?	☐	☒
4.	Will the research involve deliberately misleading participants (deception) in any way?	☐	☒
5.	Does the Research involve staff or students within the University?	☒	☐
6.	Does the Research involve vulnerable people? (For example people under 18 or over 70 years of age, disabled (either physically or mentally), those with learning difficulties, people in custody, migrants etc).	☐	☒
7.	Is the information gathered from participants of a sensitive or personal nature?	☐	☒
8.	Is there any realistic risk of any participants experiencing either physical or psychological distress or discomfort?	☒	☐
9.	Have you identified any potential risks to the researcher in carrying out the research? (for example physical/emotional/social/economic risks?)	☐	☒

10.	Are there implications from a current or previous professional relationship i.e. staff/student/line manager/managerial position that would affect the voluntary nature of the participation?	☒	☐
11.	Will the research require the use of assumed consent rather than informed consent? (For example when it may be impossible to obtain informed consent due to the setting for the research – e.g. observational studies/videoing/photography within a public space)	☐	☒
12.	Is there any risk to respondents' anonymity in any report/thesis/publication from the research, even if real names are not used?	☒	☐
13.	Will any payment or reward be made to participants, beyond reimbursement or out-of-pocket expenses?	☐	☒
14.	Does the research require external ethics clearance? (For example from the NHS or another institution)	☐	☒
15.	Does the research involve the use of secondary data?	☐	☒

3A. Details of Project

In this section please provide details of your project and outline data collection methods, how participant consent will be given as well as details of storage and dissemination.

Please give a 300 word overview of the research project
The broad goal of this research study is to explore the role that visualisation of music can play in the lives of people on the autism spectrum, by examining their responses to the use of an interactive audio-visual tool. Specifically, this survey will examine responses to the use of audio visual mappings within an interactive audio-visual tool. The findings of the survey will inform how the audio-visual tool can be used to augment creative arts practice for the benefit of improving communication, social interaction and self-esteem for people on the autism spectrum. However, this survey will involve non-autistic, Neuro Typical, participants' feedback and responses. Participants are invited to take part in experimentation with a new audio-visual tool, followed by a video clip based survey where they will be asked to select and rate a series of clips that they deem to be the best match for each sound. A short demonstration of the audio-visual tool will be conducted using a small MIDI (musical instrument digital interface) keyboard, headphones and a computer running the prototype. Data gathered from sessions will be done anonymously through the survey, hosted through Survey Gizmo. All data will be anonymised. Following processing of the completed survey, data will be downloaded to the researcher's secured digital storage. All data collected will be kept in a secure place (audio and video recordings will be kept on campus at Edinburgh Napier University in a locked cabinet in locked room, and digital data will be stored on a PC that is password protected) to which only the researcher has access. These will be kept till the end

of the PhD process, following which all data that could identify you will be destroyed. The anonymised results may be published in a thesis, journal or presented at a conference.	
Data Collection	
1.	**Who will be the participants in the research?**
	Staff and students from Edinburgh Napier University.
2.	**How will you collect and analyse the research data? (please outline all methods e.g. questionnaires/focus groups/internet searches/literature searches/interviews/observation)**
	Data gathered from the survey sessions will be done anonymously through the Survey Gizmo.
3.	**Where will the data will be gathered (e.g. in the classroom/on the street/telephone/on-line)**
	The data will be gathered in: • The Auralisation Suite, Room C72, Merchiston Campus.
4.	**Please describe your selection criteria for inclusion of participants in the study**
	The criteria for inclusion include participants that are 18 or older, and younger than 70 years of age.
5.	**If your research is based on secondary data, please outline the source, validity and reliability of the data set**
	n/a
Consent and Participant Information	
7.	**How will you invite research participants to take part in the study? (e.g. letter/email/asked in lecture)**
	Through personal invitation and/or email.
8.	**How will you explain the nature and purpose of the research to participants?**
	Verbally and through demonstration of the prototype, as well as the accompanying participant information sheet.
9.	**How will you record obtaining informed consent from your participants?**
	Through informed consent forms that will be signed by participants prior to the survey.
Data storage and Dissemination	
10.	**How and in what format will data be stored? And what steps will be taken to ensure data is stored securely?**

	All data collected will be kept in a secure place - audio and video recordings will be kept on campus at Edinburgh Napier University in a locked cabinet in locked room, and digital data will be stored on a PC that is password protected.
11.	**Who will have access to the data?**
	Only I, John McGowan, will have access to the data.
12.	**Will the data be anonymised so that files contain no information that could be linked to any participant?**
	Yes. All data will be anonymised. Participant names will be replaced with a participant number, and it will not be possible for them to be identified in any reporting of the data gathered.
13.	**How long will the data be kept?**
	The data will be kept till the end of the PhD process, following which all data that could identify any participant will be destroyed.
14.	**What will be done with the data at the end of the project?**
	The data will be destroyed.
15.	**How will the findings be disseminated?**
	The anonymised results may be published in a thesis, journal or presented at a conference.
16.	**Will any individual be identifiable in the findings?**
	No.

3B. Identification and Mitigation of Potential risks

This section is designed to identify any realistic risks to the participants and how you propose to deal with it.

1. **Does this research project involve working with potentially vulnerable individuals?**

Group	Yes	NO	Details (for example programme student enrolled on, or details of children's age/care situation, disability)
Students at Napier	☒	☐	School of Computing Students at Merchiston Campus
Staff at ENU	☒	☐	School of Computing Staff at Merchiston Campus
Children under 18	☐	☒	

Elderly (over 70)	☐	☒	
Disabled	☐	☒	
Migrant workers	☐	☒	
Prisoners / people in custody	☐	☒	
Learning difficulties	☐	☒	

2. **If you are recruiting children (under 18 years) or people who are otherwise unable to give informed consent, please give full details of how you will obtain consent from parents, guardians, carers etc.**

n/a

3. **Please describe any identified risks to participants or the researcher as a result of this research being carried out**

- There is potential risk for damage to participants hearing, through the use of audio equipment and the volume levels being set too high.
- As I am a part-time lecturer, with regard to inviting students to participate, there could be the risk that students would feel obliged to participate as requested by their lecturer.
- There is always a small risk regarding the anonymity of the participants.

4. **Please describe what steps have been taken to reduce these identified risks? (for example providing contact details for appropriate support services (e.g. University Counselling, Samaritans), reminding participants of their right to withdraw and/or not answering questions, or providing a full debriefing to participants)**

The researcher, who has normal hearing for his age, will set the maximum volume level before introducing the participants to the audio. The participants will not be able to control the volume of the audio clips, but their level has been set at an average level of 83 dBC which is 2 dB below the UK workplace safety requirements for an eight hour working day.

Any potential students will be assured that participation is voluntary and that there will be no consequences in not participating.

All data will be anonymised. Participant names will be replaced with a participant number, and it will not be possible for them to be identified in any reporting of the data gathered.

5. **If you plan to use assumed consent rather than informed consent please outline why this is necessary**

n/a

6. **If payment or reward will be made to participants please justify that the amount and type are appropriate (for example the amount should not be so high that participants would be financially coerced into taking part, or that the type of reward is appropriate to the research topic).**

n/a

3C. Justification of High Risk Projects

If you answered 'Yes' to the screening questions 1-4 this section asks for justification on the choice of research topic and methodology.

1. **If you have answered yes to question 1 please give a full description of all medical procedures to be used within the research and provide evidence that the project has obtained NHS ethical approval.**

N/A

2. **If you have answered yes to questions 2 (research into a controversial topic) please provide a justification for your choice of research topic, and describe how you would deal with any potential issues arising from researching that topic.**

N/A

3. **If you have answered yes to questions 3 or 4 (use of deception or covert research methods) please provide a justification for your choice of methodology, and state how you will mitigate the risks associated with these approaches**.

N/A

Declaration		
☒	I consider that this project has no significant ethical implications to be brought to the attention of Research Integrity Committee	
☐	I consider that this project may have significant ethical implications to be brought to the attention of the Research Integrity Committee	
Researcher Signature: [redacted]		**Date:** 28/11/2016
Second Supervisor: [redacted]		**Date:** 2nd of December 2016

Checklist

All applications require the following to be submitted with the application form

Participant Information Sheet	☒
Informed Consent Form	☒
Interview/Survey Questions	☒

Appendix D – Mapping Survey Information Sheet for Potential Participants

Developing an audio-visual tool for use in creative arts to improve experience for people on the autism spectrum

About the study - My name is John McGowan and I'm a PhD student at Edinburgh Napier University. The broad goal of this survey is to explore the role that visualisation of music can play in the lives of people on the autism spectrum. Specifically, by examining the responses to the use of audio-visual mappings within an interactive audio-visual tool. The findings of the survey will inform how the audio-visual tool can be used to augment creative arts practice for the benefit of improving communication, social interaction and self-esteem for people on the autism spectrum. In this survey, non-autistic (Neuro Typical) participant's feedback will be compared to the views of those on the autism spectrum for analysis.

What will taking part involve? – Participants are invited to take part in experimentation with a new audio visual tool, followed by a video clip based survey where they will be asked to select and rate a series of clips that they deem to be the best audio-visual match. A short demonstration of the audio-visual tool will be conducted using a small MIDI (musical instrument digital interface) keyboard, headphones and a computer running the prototype. You will not be able to control the volume of the audio clips, but their level has been set at an average level of 83 dBC which is 2 dB below the UK workplace safety requirements for an eight hour working day. The survey will take approximately 30 minutes to complete and take place in The Auralisation Suite, Room 72, at Merchiston Campus. Data gathered from sessions will be done anonymously through the survey, hosted through Survey Gizmo.

What will be done with the data? - All data will be anonymised. Following processing of the completed survey, data will be downloaded to the researcher's secured digital storage. All data collected will be kept in a secure place (audio and video recordings will be kept on campus at Edinburgh Napier University in a locked cabinet in locked room, and digital data will be stored on a PC that is password protected) to which only the researcher has access. These will be kept till the end of the PhD process, following which all data that could identify you will be destroyed. The anonymised results may be published in a thesis, journal or presented at a conference.

Who can take part? – The criteria for inclusion include participants that are 18 or older, and younger than 70 years of age.

If you have any questions or would like to find out more, please feel free to contact the researcher using the details below. If you have read and understood this information sheet, and you would like to be a participant in the study, please now see the consent form.

Many thanks for your participation.

Appendix E – Mapping Survey Informed Consent Form for Participants

Developing an audio-visual tool for use in creative arts to improve experience for people on the autism spectrum

Edinburgh Napier University requires that all persons who participate in research studies give their written consent to do so. Please read the following and sign it if you agree with what it says.

1. I freely and voluntarily consent to be a participant in the research project on the topic of the design and creation of an audio-visual tool to be conducted by John McGowan, who is a postgraduate student in the Edinburgh Napier School of Computing.

2. The broad goal of this research survey is to explore the mapping techniques employed within a prototype tool, by examining the responses to the use of an interactive audio-visual tool. Specifically, I have been asked to participate within a survey to select and rate recorded video clips and associated audio clips. The survey should take approximately 30 minutes to complete.

3. I have been told that my responses will be anonymised and will be kept in a locked, secure environment within the University. My name will not be linked with the research materials, and I will not be identified or identifiable in any report subsequently produced by the researcher.

4. I also understand that if at any time during the survey I feel unable or unwilling to continue, I am free to leave. That is, my participation in this study is completely voluntary, and I may withdraw from it at any time without negative consequences.

5. In addition, should I not wish to participate in any part of a survey, I am free to decline.

6. I have been given the opportunity to ask questions regarding the survey and my questions have been answered to my satisfaction.

7. I have read and understand the above and consent to participate in this study. My signature is not a waiver of any legal rights. Furthermore, I understand that I will be able to keep a copy of the informed consent form for my records.

____________________________ ______________________

Participant’s Signature Date

I have explained and defined in detail the research procedure in which the respondent has consented to participate. Furthermore, I will retain one copy of the informed consent form for my records.

____________________________ ______________________

Researcher’s Signature Date

Appendix F – Mapping Survey - *CymaSense* Survey Questions

Welcome and Instructions Page:

Welcome to the Cymulator Survey.

You will have had the opportunity to play around with the *Cymulator* prototype for a few minutes.
Please now read the following instructions for the survey which should take approximately 30 minutes to complete.

Instructions

You are about to watch and rate 17 questions, with 3 video clips per question, that compare a variety of sampled sounds with their associated *Cymulator* images.

For each page, you are asked to:

1. Watch the clips as many times as you wish
2. Select the one you think is the best match
3. Rate your answer on a sliding scale in terms of how confident you are with your answer

Please fill in both answers before pressing the submit button and moving onto the next question.
If you wish to return to the previous question, press the back button.

Please note:

- Your identity will be kept anonymous
- The pages will be randomized, so please do not expect the page numbers to follow in a linear fashion
- If you decide that you want to withdraw from the survey, you are welcome to do so at any time by selecting the 'save and continue later' link at the top of each page
- When you are ready to begin, please press the next button below

Demographic Questions Page:

2. What is your gender?

○ Female

○ Male

3. What is your age?

○ 18 to 24

○ 25 to 34

- 35 to 44
- 45 to 54
- 55 to 64
- 75 or older

4. What nationality are you?

5. Do you have any significant hearing or visual impairments?

- None
- Hearing
- Visual

6. Do you play a musical instrument?

- No
- Yes

7. How would you classify your level of expertise regarding the question above?

- None
- Basic
- Intermediate
- Advanced

8. Have you had formal training in music theory?

- No
- Yes

9. How many years of formal training have you had?

- None
- Half a year
- One year
- Two years
- Three years
- Four to Seven years
- Eight or more..

10. Do you use digital and/or analogue audio production equipment?

- ○ No
- ○ Yes

11. Which of the following audio equipment do you use? Please choose more than one if apply.

- ☐ None
- ☐ Audio recording devices
- ☐ Sound synthesis
- ☐ Sequencer/ Digital audio workstation
- ☐ Digital and analogue signal processing
- ☐ Audio programming tools

12. How would you classify your level of expertise regarding question 11 above?

- ○ None
- ○ Basic
- ○ Intermediate
- ○ Advanced

Remaining Video Clip Pages: (Which have the same format on each page)

- ○ Clip A
- ○ Clip B
- ○ Clip C

Q. Choose the one clip from the three above you think is the best match:

Q. Please rate on the sliding scale, how confident you are about your choice.

Optional Question - Please feel free to leave any comments below:

Appendix G – Behaviour Change Survey

Your name: Date:

Name of observed participant:

Please indicate your responses by circling the most appropriate number for each question:

		Much less	**Somewhat less**	**Slightly less**	**Same**	**Slightly more**	**Somewhat more**	**Much more**
1	How often has the participant responded to you **verbally** since the first session?	1	2	3	4	5	6	7
2	How often has the participant responded to you **vocally** since the first session?	1	2	3	4	5	6	7
3	How often has the participant maintained **eye contact** in response to you since the first session?	1	2	3	4	5	6	7
4	How often has the participant **responded to you through gestures** since the first session?	1	2	3	4	5	6	7
5	How often has the participant been **influenced by your actions** since the first session?	1	2	3	4	5	6	7

6	How often has the participant **initiated actions** since the first session?	1	2	3	4	5	6	7
		Much less	**Somewhat less**	**Slightly less**	**Same**	**Slightly more**	**Somewhat more**	**Much more**
7	How would you rate the participant's **level of social interaction** following participation in the study?	1	2	3	4	5	6	7
8	How would you rate the participant's level of **self-awareness** following participation in the study?	1	2	3	4	5	6	7
9	How would you rate the participant's level of **self-control/emotional regulation** following participation in the study?	1	2	3	4	5	6	7
10	How would you rate the participant's level of **repetitive behaviour** following participation in the study?	1	2	3	4	5	6	7
11	How would you rate the participant's level of **happiness** following participation in the study?	1	2	3	4	5	6	7
12	How would you rate the participant's **level of isolation** following participation the study?	1	2	3	4	5	6	7

13	How would you rate the participant's level of **motivation** following participation in the study?	1	2	3	4	5	6	7
14	How would you rate the participant's level of **daily living skills** following participation in the study?	1	2	3	4	5	6	7
15	How often does the participant **sing or play music by themselves** following participation in the study?	1	2	3	4	5	6	7
16	How often does the participant **respond** to musical activity following participation in the study?	1	2	3	4	5	6	7
		Much less	**Somewhat less**	**Slightly less**	**Same**	**Slightly more**	**Somewhat more**	**Much more**
17	How often does the participant **initiate** musical activity following participation in the study?	1	2	3	4	5	6	7
18	Please feel free to leave any additional comments below:							

Please feel free to contact me using the details below:

John McGowan

Email: [redacted]

Phone: [redacted]

Many thanks for your participation.

Appendix H - Communicative and Acts Response Sheet (CRASS)

Client Name:

Date:

Session Number:

Communicative and Acts Response Sheet (CRASS) Instructions:

One sheet is to be used per music session.

Enter the client's details above.

Playback the recorded video, stopping and starting where necessary.

For both worksheets (Musical and Non-Musical Responses), enter a number in the appropriate cell to indicate a communicative response or act, noting the time and adding comments for ease of understanding. Begin numbering at 1 and add in subsequent numbers (2, 3, 4, etc.) to indicate repeated actions within the same session. Please note the associated times and comments using the same numbering system.

Note the musical and non-musical sub-totals at the end of each session in the appropriate cells.

Save and close the file.

Musical						
Communicative Responses	**Tempo**	**Rhythm**	**Structure/ form**	**Pitch**	**Watching Screen?**	**Session time /comments**
Verbal						
Vocal						
Gestural						
Instrumental behaviours influenced by the tutor's improvisation/behaviours	**Tempo**	**Rhythm**	**Structure/ form**	**Pitch**		**Session time / comments**
Matches a beat						
Simultaneously imitates a melodic motif						
Simultaneously imitates the rhythm of a melodic motif						
Participates in a rhythmic give and take						
Other						
Communicative acts	**Tempo**	**Rhythm**	**Structure/ form**	**Pitch**		**Session time/comments**
Verbal						
Vocal						
Gestural						
Instrumental behaviours initiated to influence the tutor's improvisation/behaviours	**Tempo**	**Rhythm**	**Structure/ form**	**Pitch**		**Session time/comments**
Creates a rhythmic pattern						
Develops a melodic give and take						
Spontaneously creates a new melodic phrase						
Other						
Musical sub totals						

Non-musical					
Communicative responses	**Speech production skills**	**Communicative interactive skills**	**Communicative intent skills**	**Watching Screen?**	**Session time/comments**
Verbal					
Vocal					
Gestural					
Eye Contact					
Communicative acts	**Speech production skills**	**Communicative– interactive skills**	**Communicative - intent skills**		**Session time/comments**
Verbal					
Vocal					
Gestural					
Eye Contact					
Non-musical sub totals					
Total					

Appendix I - Informed Consent Form for Parents/Guardians

Developing an audio-visual tool for use in creative arts to improve experience for people on the autism spectrum

Edinburgh Napier University requires that all persons who participate in research studies give their written consent to do so. Please read the following and sign it if you agree with what it says.

1. I, as a guardian/parent of the participant, freely and voluntarily consent to their participation in the research project on the topic of the design and creation of an audio-visual tool to be conducted by John McGowan, who is a postgraduate student in the Edinburgh Napier School of Computing.

2. The broad goal of this research study is to explore the role that visualisation of music can play in the lives of people on the autism spectrum, by examining their responses to the use of an interactive audio-visual tool. Specifically, I have been asked to provide informed consent for the participant, and to complete a questionnaire, which should take no longer than 30 minutes to complete.

3. I have been told that all responses will be anonymised and will be kept in a locked, secure environment within the University. My name, nor the participant whom I am providing consent, will not be linked with the research materials, and neither they nor myself will be identified or identifiable in any report subsequently produced by the researcher.

4. I also understand that if at any time during the sessions or questionnaire I, or the participant whom I am providing consent, feel unable or unwilling to continue, we are free to leave. That is, our participation in this study is completely voluntary, and we may withdraw from it at any time without negative consequences.

5. In addition, should I not wish to answer any particular question or questions, I am free to decline.

6. I have been given the opportunity to ask questions regarding the questionnaire and my questions have been answered to my satisfaction.

7. I have read and understand the above and consent to participate in this study. My signature is not a waiver of any legal rights. Furthermore, I understand that I will be able to keep a copy of the informed consent form for my records.

____________________________ ______________________

Participant’s Signature Date

I have explained and defined in detail the research procedure in which the respondent has consented to participate. Furthermore, I will retain one copy of the informed consent form for my records.

____________________________ ______________________

Researcher’s Signature Date

Appendix J - Informed Consent Form for Session Participants

Developing an audio-visual tool for use in creative arts to improve experience for people on the autism spectrum

Edinburgh Napier University requires that all persons who participate in research studies give their written consent to do so. Please read the following and sign it if you agree with what it says.

1. I freely and voluntarily consent to be a participant in the research project on the topic of the design and creation of an audio-visual tool to be conducted by John McGowan, who is a postgraduate student in the Edinburgh Napier School of Computing.

2. The broad goal of this research study is to explore the role that visualisation of music can play in the lives of people on the autism spectrum, by examining their responses to the use of an interactive audio-visual tool. Specifically, I have been asked to participate within a video recorded music session for 30-45 minutes each week over a 6 week period.

3. I have been told that my responses will be anonymised and will be kept in a locked, secure environment within the University. My name will not be linked with the research materials, and I will not be identified or identifiable in any report subsequently produced by the researcher.

4. I also understand that if at any time during the sessions I feel unable or unwilling to continue, I am free to leave. That is, my participation in this study is completely voluntary, and I may withdraw from it at any time without negative consequences.

5. In addition, should I not wish to participate in any part of a music session, I am free to decline.

6. I have been given the opportunity to ask questions regarding the questionnaire and my questions have been answered to my satisfaction.

7. I have read and understand the above and consent to participate in this study. My signature is not a waiver of any legal rights. Furthermore, I understand that I will be able to keep a copy of the informed consent form for my records.

____________________________ ______________________

Participant's Signature Date

I have explained and defined in detail the research procedure in which the respondent has consented to participate. Furthermore, I will retain one copy of the informed consent form for my records.

____________________________ ______________________

Researcher's Signature Date

Appendix K - Application for Cross-University Ethical Approval - Music Study Sessions

3. Research Details

Name:	John McGowan
School or Professional service department:	School of Computing
Email:	[redacted]
Contact number:	[redacted]
Project Title:	Developing an audio-visual tool for use in creative arts to improve experience for people on the autism spectrum.
Start Date:	March 2015
Duration of Project:	3 Years
Type of Research: Doctoral Student	

4. Screening Questions

Please answer the following questions to identify the level of risk in the proposed project:

If you answer 'No' to all questions, please complete Section 3a only.

If you have answered 'Yes' to any of the questions 5-14 please complete Section 3a and 3b.

If you have answered 'Yes to any of the questions 1-4, complete all of Section 3.

	You Must Answer All Questions	**Yes**	**No**
1.	Is the research clinical in nature?	☐	☒
2.	Is the research investigating socially or culturally 'controversial' topics (for example pornography, extremist politics, or illegal activities)?	☐	☒
3.	Will any covert research method be used?	☐	☒
4.	Will the research involve deliberately misleading participants (deception) in any way?	☐	☒
5.	Does the Research involve staff or students within the University?	☒	☒
6.	Does the Research involve vulnerable people? (For example people under 18 or over 70 years of age, disabled (either physically or mentally), those with learning difficulties, people in custody, migrants etc).	☒	☐
7.	Is the information gathered from participants of a sensitive or personal nature?	☒	☐
8.	Is there any realistic risk of any participants experiencing either physical or psychological distress or discomfort?	☐	☒
9.	Have you identified any potential risks to the researcher in carrying out the research? (for example physical/emotional/social/economic risks?)	☐	☒
10.	Are there implications from a current or previous professional relationship i.e. staff/student/line manager/managerial position that would affect the voluntary nature of the participation?	☐	☒
11.	Will the research require the use of assumed consent rather than informed consent? (For example when it may be impossible to obtain informed consent due to the setting for the research – e.g. observational studies/videoing/photography within a public space)	☐	☒
12.	Is there any risk to respondents' anonymity in any report/thesis/publication from the research, even if real names are not used?	☐	☒
13.	Will any payment or reward be made to participants, beyond reimbursement or out-of-pocket expenses?	☐	☒
14.	Does the research require external ethics clearance? (For example from the NHS or another institution)	☐	☒

15.	Does the research involve the use of secondary data?	☐	☒

3A. Details of Project

In this section please provide details of your project and outline data collection methods, how participant consent will be given as well as details of storage and dissemination.

Please give a 300 word overview of the research project

The broad goal of this research study is to explore the role that visualisation of music can play in the lives of people on the autism spectrum, by examining their responses to the use of an interactive audio-visual tool. The findings of the study will inform how the tool can be used to augment creative arts practice for the benefit of improving communication, social interaction and self-esteem for people with autism.

Participants are invited to take part in a study for 30-45 minutes each week over a 12 week period run by a music tutor. Participant consent will be granted by the clients themselves or by parents/guardians following discussion with the music tutor. Data gathered from sessions will be done through the following ways:

- **Service users** - music sessions with the tutor will be video recorded for a 12 week period
- **Parents/Guardians** – will be asked to fill in a behaviour change survey following the study
- **Music tutors** – music sessions with the service user will be video recorded and will be asked to fill in a questionnaire following the study

All data will be anonymised. Following processing of video through specialised software for statistical analysis, facial features and sound will be digitally masked, participant names will be replaced with a participant number, and it will not be possible for them to be identified in any reporting of the data gathered. All data collected will be kept in a secure place on campus at Edinburgh Napier University in a locked cabinet in a locked room, and digital data will be stored on a PC that is password protected to which only I, John McGowan, has access. These will be kept till the end of the PhD process and then destroyed. The anonymised results may be published in a thesis, journal or presented at a conference.

Data Collection

1.	**Who will be the participants in the research?**
	Autistic service users from Touchbase (in Glasgow) and clients from Scottish Autism.
2.	**How will you collect and analyse the research data? (please outline all methods e.g. questionnaires/focus groups/internet searches/literature searches/interviews/observation)**
	• Music sessions will be video recorded and analysed through an observational checklist designed to look for musical and non-musical communicative acts and responses (CRASS) • Behaviour Change Questionnaires will be used for music tutors and parents/guardians following the music sessions to ask whether any observable changes have taken place since the beginning of the sessions Both the music tutor and myself are currently registered members of the Protection of Vulnerable Groups (PVG) scheme: • Music Tutor details: David McCluskey, c/o Touchbase, Middlesex St, Glasgow G41 1EE; PVG Scheme ID: 1512 0331 1998 0334 • John McGowan PVG Scheme ID: 1303 0609 8867 0332
3.	**Where will the data will be gathered (e.g. in the classroom/on the street/telephone/on-line)**
	The data will be gathered in:

	• The music session room (video observation, questionnaires, interviews)
4.	**Please describe your selection criteria for inclusion of participants in the study**
	There is a criteria for inclusion of the participant being clinically diagnosed on the autism spectrum.
5.	**If your research is based on secondary data, please outline the source, validity and reliability of the data set**
	n/a
Consent and Participant Information	
7.	**How will you invite research participants to take part in the study? (e.g. letter/email/asked in lecture)**
	Through Touchbase music tutor, who works with the clients already, who will provide them with a participant information sheet as created by myself.
8.	**How will you explain the nature and purpose of the research to participants?**
	Through the music tutor who works with the clients on a regular basis.
9.	**How will you record obtaining informed consent from your participants?**
	Through informed consent forms that will be signed by able clients or their parents/guardians following discussion of the nature and content of the music sessions.
Data storage and Dissemination	
10.	**How and in what format will data be stored? And what steps will be taken to ensure data is stored securely?**
	All data will be anonymised. Following processing of video through specialised software for statistical analysis, facial features and sound will be digitally masked, participant names will be replaced with a participant number, and it will not be possible for them to be identified in any reporting of the data gathered. These will be kept till the end of the PhD process, following which all data that could identify you will be destroyed. The anonymised results may be published in a thesis, journal or presented at a conference.
11.	**Who will have access to the data?**
	All data collected will be kept in a secure place (audio and video recordings will be kept on campus at Edinburgh Napier University in a locked cabinet in locked room, and digital data will be stored on a PC that is password protected) to which only I, John McGowan, has access.
12.	**Will the data be anonymised so that files contain no information that could be linked to any participant?**
	Yes. All data will be anonymised. Following processing of video through specialised software for statistical analysis, facial features and sound will be digitally masked, participant names will be replaced with a participant number, and it will not be possible for them to be identified in any reporting of the data gathered.
13.	**How long will the data be kept?**
	The data will be kept till the end of the PhD process, following which all data that could identify any participant will be destroyed.
14.	**What will be done with the data at the end of the project?**
	The data will be destroyed.
15.	**How will the findings be disseminated?**
	The anonymised results may be published in a thesis, journal or presented at a conference.
16.	**Will any individual be identifiable in the findings?**
	No.

3B. Identification and Mitigation of Potential risks

This section is designed to identify any realistic risks to the participants and how you propose to deal with it.

7. **Does this research project involve working with potentially vulnerable individuals?**

Group	Yes	NO	Details (for example programme student enrolled on, or details of children's age/care situation, disability)
Students at Napier	☐	☒	
Staff at ENU	☐	☒	
Children under 18	☒	☐	Children with ASD aged between 12 and 18 years
Elderly (over 70)	☐	☒	
Disabled	☒	☐	Children/Adults with ASD
Migrant workers	☐	☒	
Prisoners / people in custody	☐	☒	
Learning difficulties	☒	☐	Children/Adults with ASD

8. **If you are recruiting children (under 18 years) or people who are otherwise unable to give informed consent, please give full details of how you will obtain consent from parents, guardians, carers etc.**

Informed consent forms will be signed by able clients or their parents/guardians following discussion of the nature and content of the music sessions with the music tutor at Touchbase**.** Sessions will be tailored toward the abilities of the clients in terms of the length of the session, the types of musical instruments they might use, and any additional support needs.
In addition, children under the age of 16 years can give their consent to take part in a research study if they satisfy the criteria by stated by The Age of Legal Capacity (Scotland) Act 1991, if: they have been counselled and to do not wish to involve their parents: and have sufficient maturity to understand the nature, purpose and likely outcome of the proposed research.

9. **Please describe any identified risks to participants or the researcher as a result of this research being carried out**

n/a

10. **Please describe what steps have been taken to reduce these identified risks? (for example providing contact details for appropriate support services (e.g. University Counselling, Samaritans), reminding participants of their right to withdraw and/or not answering questions, or providing a full debriefing to participants)**

n/a

11. **If you plan to use assumed consent rather than informed consent please outline why this is necessary**

n/a

12. **If payment or reward will be made to participants please justify that the amount and type are appropriate (for example the amount should not be so high that participants would**

be financially coerced into taking part, or that the type of reward is appropriate to the research topic).

n/a

3C. Justification of High Risk Projects

If you answered 'Yes' to the screening questions 1-4 this section asks for justification on the choice of research topic and methodology.

4. **If you have answered yes to question 1 please give a full description of all medical procedures to be used within the research and provide evidence that the project has obtained NHS ethical approval.**

N/A

5. **If you have answered yes to questions 2 (research into a controversial topic) please provide a justification for your choice of research topic, and describe how you would deal with any potential issues arising from researching that topic.**

N/A

6. **If you have answered yes to questions 3 or 4 (use of deception or covert research methods) please provide a justification for your choice of methodology, and state how you will mitigate the risks associated with these approaches**.

N/A

Declaration		
☒	I consider that this project has no significant ethical implications to be brought to the attention of Research Integrity Committee	
☐	I consider that this project may have significant ethical implications to be brought to the attention of the Research Integrity Committee	
Researcher Signature: [redacted]		**Date:** 28/11/2016
Second Supervisor: [redacted]		**Date:** 2nd of December 2016

Checklist
All applications require the following to be submitted with the application form

Participant Information Sheet	☒
Informed Consent Form	☒
Interview/Survey Questions	☒

Appendix L - Information Sheet for Potential Participants

Developing an audio-visual tool for use in creative arts to improve experience for people on the autism spectrum

About the study - My name is John McGowan and I'm a PhD student at Edinburgh Napier University. The broad goal of this research study is to explore the role that visualisation of music can play in the lives of people on the autism spectrum, by examining their responses to the use of an interactive audio-visual tool. The findings of the study will inform how the audio-visual tool can be used to augment creative arts practice for the benefit of improving communication, social interaction and self-esteem for people on the autism spectrum.

What will taking part involve? - Service users are invited to take part in a study within Touchbase, for 30-45 minutes each week over a 6/8 week period, from January 2017 till March 2017, if they are willing and available. Details of each participant's involvement will be discussed and tailored to their needs prior to the study. The audio-visual tool can be used in a way that suits each individual client. For example, via electronic or acoustic instruments, via use of the voice through a microphone, or through an interactive audio-visual surface. Data gathered from sessions will be done through some, or all, of the following ways, if appropriate:

- **Service users** - music sessions with the tutor will be video recorded
- **Parents/Guardians** – will be asked to fill in a questionnaire following the study. There is an optional request to keep a weekly diary, following each session, detailing any observable changes at home with short excerpts
- **Music tutors** – the music session with the service user will be video recorded and will be asked to fill in a questionnaire following the study

What will be done with the data? - All data will be anonymised. Following processing of video through specialised software for statistical analysis, facial features and sound will be digitally masked, participant names will be replaced with a participant number, and it will not be possible for them to be identified in any reporting of the data gathered. All data collected will be kept in a secure place (audio and video recordings will be kept on campus at Edinburgh Napier University in a locked cabinet in locked room, and digital data will be stored on a PC that is password protected) to which only the researcher has access. These will be kept till the end of the PhD process, following which all data that could identify you will be destroyed. The anonymised results may be published in a thesis, journal or presented at a conference.

Who can take part? - There is a criteria for inclusion of the participant being on the autism spectrum.

If you have any questions or would like to find out more, please feel free to contact the researcher using the details below. If you have read and understood this information sheet, and you would like to be a participant in the study, please now see the consent form.

Many thanks for your participation.

Appendix M - David McCluskey Interview - 06/02/2017

Week 2 of Study – Discussion on each client and the direction of remaining sessions

Key:
JM – John McGowan (Researcher)
DM – David McCluskey (Music Tutor)
C1, C2, C3, C4, C5, C6, C7, C8 – Clients 1-8

0.10
JM – So, just a quick chat about the clients for next week, session 3, focusing on what instruments and thinking about how best to set up the cymatics prototype for them. I was suggesting setting up a basic microphone set up in the room and that would allow you to use the instruments that you normally do, and we can review it as the weeks go by and specialise or phase that in over the sessions. So what are your thoughts?

DM – Yes, I think it would be nice almost to look at the specific instrumentation that I've been using over the last 2 weeks and go with that and try and link those in with cymatics. So, as you're suggesting, with C1 he seems to be interested in percussion instruments, and if we brought in that extra element then he realises that his percussion instruments can be triggering visuals through the cymatics. We could go with that. It's whether you see it like that or whether you see it as a totally different activity, you know we stop half way through and then we change the activity and then we switch the cymatics on and that becomes separate, you see it more organic?

1.40

JM – Well, from my point of view you should just do what you're doing and bring it in, initially, as one of your instruments. Rather than changing the whole style of what you're doing.

DM – Yes, right sure, that suits me.

JM – That way you're going to know if that changes the relationship with you.

DM – Yes. A phased approach.

JM – So, C2, he was interested in percussion?

DM – Yes, keyboard as well. He does quite like subtle sounds, it's not really about volume. Not about loud and sharp sounds, he's likes quite subtle sounds, tones. So that could be interesting finding something that's sensitive enough to have the visual responses to his sounds. It's like all the guys, there's a kind of perimeter of volume that they set.

JM – So if I just set up the mic in the room…and you can turn on the projector whenever you want and see what happens.

DM – And I can move the mic wherever if needed to pick up less loud sounds. Great. And then C3, he was interested in percussion again today. I think vocally I was trying to bring out some vocal sounds but it seems, and it's only the second time I've met C3, the second session, and it seems he's not really ready to use his voice expressively. He'll use it to communicate but not really fully expressively yet. Whereas he's using other instruments and he's being quite physical with the percussion, so maybe we should go with that.

JM – Give him a bit of time and see how it goes?

DM – Yeah.

4.00

JM – C4, it would probably be a good idea to use a microphone for her?

DM – Yes, I think she's got great sounds there but a lot of het sounds are very quiet. A lot of her sounds are whispered, so how would we do that? I don't know if you've got one of those wee clip on mics or whether she would accept that? We could do something to pick up the subtleties of her voice? Sometimes she sing into, she'll use a mic.

JM – We've got contact mics, I don't know how well that would work as I've not tested them with the system yet.

DM – So maybe vocal, possibly keyboard as well. C4's quite into her keys, there's more specific notes that she'll focus around.

5.04

JM – Ok. C5 and C6, again, I could just set up a microphone and let them do what they're doing?

DM – Yes. And I think it will be interesting for them once they make the connections between the sounds and the visual responses, if we can allow them to change the visual parameters. I think they would be interested in that, having some sort of control. You see they're quite fluent with computers and stuff.

JM – So I can set it up so that the interface is taking over the whole screen and the visuals are on the projector. I'll set up a mouse and they can use that.

DM – That would be brill.

JM – Pretty obvious how you want to do C7?

DM – Yes, C7 I think voice.

JM – And C8, because he's a man of many talents, a room mic for him?

DM – Yes, what was I going to say? So C7, obviously mic and vocals, I wonder if I should try…maybe this is later on…but he's very interested in the long sustaining sounds and vibration. So something like the singing bowl, I'm wondering how the cymatics would respond to that? It's almost like a big kind of wave. It's a sound that's generating, a sound that's sustained. That's maybe something that we can try over the weeks. Certainly vocal to start with. I think he might be interested in that, something that represents that kind of vibration that you get from the length and the decay of the note of the singing bowl.

7.03

JM – So in terms of the visualisation of the cymatics do you just want to play it by ear and see how it goes with each of your clients?

DM – Yeah, I can imagine your default setting there that's pretty kind of definite and simple. I think that would be a good starting point. And then maybe some of the guys we can show them that we can manipulate or we can add colour or layers of movement or make it a bit more complex if they want, to give them the choice of that. I was also going to say with C1, the first guy we've got in – I've got him down for percussion, the other thing he was really into was the guitar, that big open tuning guitar that was through the effects pedal? Just through a simple delay pedal but he seemed to be really into that and the big chord…sometimes he was strumming and sometimes he was just picking with his fingers . That could be interesting to see what he can create visually.

JM – Obviously we could set up a room mic, but we could also take a line out of just the guitar so that if you're playing the drums, for example, it's not picking up the sound of the drums as well.

DM – Yeah, yeah.

JM – That's not difficult to do. I don't know if you want to do that right away or we can see how the general set up goes and then specialise in specific instruments?

9.00

DM – Yes, I think that would be best. And you know C8, what we need for C8. I mean C8's quite set in that he creates improvised songs. So he likes to sing and he likes to play an instrument with his voice so we can have some stuff and it's just C8 that's playing on his own. And then we can have parts we do where he'll ask me to play drums or accompany him. It'll be interesting to see C8 create a kind of visual scape with all the dynamics of his songs.

JM – And just for the record we should mention C7's skill, what he can do with a microphone?

DM – That music setting is really important to C7, because he really expresses himself fully and emotionally but with his voice and within music. And obviously it doesn't need to be verbal, a lot of his sounds are non-verbal, but amazing how he really starts to manipulate his voice and just the range of sounds he creates. He's just totally in his element when he creates this big, almost like soundscape with his voice. And then at points he lets me know when wants me to accompany, to come in, whether that with accompanying chords – trying to tune into what kind of key he's in or the dynamics of his song. And then at other points quite clearly he indicates when he just wants to hear his own voice. It's great.

JM – It'll be interesting to see how the visuals back that up.

DM – And it's just a case of how dark we can go? Maybe demo that in the morning. Because if you don't want it total black out…we can find out a lighting set up that is workable.

JM – Yes, we can do a little test run in the morning. Ok, thank you very much for that.

Appendix N – Phase 3 Interview Questions for *CymaSense* Study Participant Parents/Guardians

Prior/Post Therapy

1. What was his/her behaviour like before the sessions began?
    a. Before non-intervention stage?
    b. Before the intervention stages once the study was up and running?
2. What was his/her emotional state like before the sessions began?
    a. Before non-intervention stage?
    b. Before the intervention stages once the study was up and running?
3. What were they like immediately after the sessions?
4. Were there any signs of musical anticipation or excitement before the sessions?
5. Did you notice any short-term differences in the hours following each session?
6. Have you noticed any long term differences in the weeks after the sessions?
7. Have there been any noticeable changes in behaviour after the first 8 week block?

Personal Preferences/Influences/Sensory Influences

8. How easily distracted are they by moving objects in general?
9. How does the speed of an object, that your child sees, affect their state of mind?
10. What is their behaviour like towards technology? For example, the use of computers, screens, games?
11. What kind of image aesthetics are they drawn towards?
12. How do they react to animations?
13. Is he/she hypersensitive or hyposensitive to light, and if so, how?
14. Is he/she hypersensitive or hyposensitive to sound, and if so, how?
15. Is he/she hypersensitive or hyposensitive to touch, and if so, how?
16. How does colour affect them on a day-to-day basis?
17. Please describe any objects that can be distracting for your child in a positive or negative manner when they are in a session.

Musical Preferences

18. What type of music does they listen to at home?
19. Does this change when they are outside or away from home?
20. Do they play a musical instrument or similar at home?

Technology and *CymaSense*

21. What are your initial impressions?
22. What do you think doesn’t work?
23. Has your child talked to you about the *CymaSense* tool? Can you describe which aspects?
24. Would you like to use this again?
25. Do you think others would use it? Why?
26. Any comments you would like to add?

Appendix O - Application for Cross-University Ethical Approval – Phase 3 Interviews

5. Research Details

Name:	John McGowan
School or Professional service department:	School of Computing
Email:	[redacted]
Contact number:	[redacted]
Project Title:	Developing an audio-visual tool for use in creative arts to improve experience for people on the autism spectrum.
Start Date:	March 2015
Duration of Project:	3 Years
Type of Research: Doctoral Student	

6. Screening Questions

Please answer the following questions to identify the level of risk in the proposed project:
If you answer 'No' to all questions, please complete Section 3a only.
If you have answered 'Yes' to any of the questions 5-14 please complete Section 3a and 3b.
If you have answered 'Yes to any of the questions 1-4, complete all of Section 3.

	You Must Answer All Questions	**Yes**	**No**
1.	Is the research clinical in nature?	☐	☒
2.	Is the research investigating socially or culturally 'controversial' topics (for example pornography, extremist politics, or illegal activities)?	☐	☒
3.	Will any covert research method be used?	☐	☒
4.	Will the research involve deliberately misleading participants (deception) in any way?	☐	☒
5.	Does the Research involve staff or students within the University?	☐	☒
6.	Does the Research involve vulnerable people? (For example people under 18 or over 70 years of age, disabled (either physically or mentally), those with learning difficulties, people in custody, migrants etc).	☐	☒
7.	Is the information gathered from participants of a sensitive or personal nature?	☒	☐
8.	Is there any realistic risk of any participants experiencing either physical or psychological distress or discomfort?	☐	☒
9.	Have you identified any potential risks to the researcher in carrying out the research? (for example physical/emotional/social/economic risks?)	☐	☒
10.	Are there implications from a current or previous professional relationship i.e. staff/student/line manager/managerial position that would affect the voluntary nature of the participation?	☐	☒
11.	Will the research require the use of assumed consent rather than informed consent? (For example when it may be impossible to obtain informed consent due to the setting for the research – e.g. observational studies/videoing/photography within a public space)	☐	☒
12.	Is there any risk to respondents' anonymity in any report/thesis/publication from the research, even if real names are not used?	☒	☐
13.	Will any payment or reward be made to participants, beyond reimbursement or out-of-pocket expenses?	☐	☒
14.	Does the research require external ethics clearance? (For example from the NHS or another institution)	☐	☒

15.	Does the research involve the use of secondary data?	☐	☒

3A. Details of Project

In this section please provide details of your project and outline data collection methods, how participant consent will be given as well as details of storage and dissemination.

Please give a 300 word overview of the research project	
The broad goal of this research study is to explore the role that visualisation of music can play in the lives of people on the autism spectrum, by examining their responses to the use of an interactive audio-visual tool. The research aims to identify participants' musical preferences and abilities within a therapy session, and to enhance their levels of communication and sense-of-agency through use of a prototype application. By creating an accessible tool for both participant and therapist, it is hoped current practices within music and arts based therapy can be augmented with audio-visual technology in a meaningful way. The tool itself is inspired by Cymatics, which are the physical impressions sound creates when vibrated through a medium like water. The CymaSense prototype has taken the aesthetic qualities of water-based Cymatics, including symmetry and translucency, and added additional features including colour choice. The tool has been used within an 8-week music therapy study, tailored to the needs of each of the eight autistic participants. For example, some participants prefer to use a microphone to project the Cymatic visualisation of sound onto a screen, while others prefer to use a percussive approach where vibrations are detected and projected beneath a custom built interactive table. Initial results have indicated that the tool was successful in increasing communicative behaviours. The aim of this interview is to explore reasons behind the potential success of the CymaSense tool by gathering background information on the participant's behaviours before and after the TouchBase sessions, sensory influences and aspects of home life. The findings of the study will inform reasons behind its successful use and how the audio-visual tool can be further developed for the benefit of improving communication, social interaction and self-esteem for people on the autism spectrum.	
Data Collection	
1.	**Who will be the participants in the research?**
	Parents/Guardians of autistic service users from Touchbase (in Glasgow) and clients from Scottish Autism, and the autistic service users themselves, if available.
2.	**How will you collect and analyse the research data? (please outline all methods e.g. questionnaires/focus groups/internet searches/literature searches/interviews/observation)**
	Semi-structured interviews.
3.	**Where will the data will be gathered (e.g. in the classroom/on the street/telephone/on-line)**
	Music session room in TouchBase, Middlesex St, Glasgow G41 1EE
4.	**Please describe your selection criteria for inclusion of participants in the study**
	A parent or guardian of a participant from the Touchbase CymaSense study.
5.	**If your research is based on secondary data, please outline the source, validity and reliability of the data set**
	n/a
Consent and Participant Information	
7.	**How will you invite research participants to take part in the study? (e.g. letter/email/asked in lecture)**

	Through the Touchbase music tutor, who already works with the clients.
8.	**How will you explain the nature and purpose of the research to participants?**
	Participant information sheet.
9.	**How will you record obtaining informed consent from your participants?**
	Signed informed consent forms.
Data storage and Dissemination	
10.	**How and in what format will data be stored? And what steps will be taken to ensure data is stored securely?**
	All data collected will be kept in a secure place (audio recordings will be kept on Merchiston Campus at Edinburgh Napier University in a locked cabinet in locked room C35a, and digital data will be stored on PC number 2 that is password protected).
11.	**Who will have access to the data?**
	John McGowan only.
12.	**Will the data be anonymised so that files contain no information that could be linked to any participant?**
	Yes. All data will be anonymised. Participant names will be replaced with a participant number (for example, P01, P02 for parents; C01, C02 for clients) and it will not be possible for them to be identified in any reporting of the data gathered.
13.	**How long will the data be kept?**
	The data will be kept till the end of the PhD process, estimated to be March 2018.
14.	**What will be done with the data at the end of the project?**
	The data will be destroyed.
15.	**How will the findings be disseminated?**
	The anonymised results may be published in a thesis, journal or presented at a conference.
16.	**Will any individual be identifiable in the findings?**
	No.

3B. Identification and Mitigation of Potential risks

This section is designed to identify any realistic risks to the participants and how you propose to deal with it.

13. Does this research project involve working with potentially vulnerable individuals?

Group	Yes	NO	Details (for example programme student enrolled on, or details of children's age/care situation, disability)
Students at Napier	☐	☒	
Staff at ENU	☐	☒	
Children under 18	☐	☒	
Elderly (over 70)	☐	☒	
Disabled	☐	☒	
Migrant workers	☐	☒	
Prisoners / people in custody	☐	☒	
Learning difficulties	☐	☒	

14. If you are recruiting children (under 18 years) or people who are otherwise unable to give informed consent, please give full details of how you will obtain consent from parents, guardians, carers etc.

n/a

15. Please describe any identified risks to participants or the researcher as a result of this research being carried out

n/a

16. Please describe what steps have been taken to reduce these identified risks? (for example providing contact details for appropriate support services (e.g. University Counselling, Samaritans), reminding participants of their right to withdraw and/or not answering questions, or providing a full debriefing to participants)

n/a

17. If you plan to use assumed consent rather than informed consent please outline why this is necessary

n/a

18. If payment or reward will be made to participants please justify that the amount and type are appropriate (for example the amount should not be so high that participants would be financially coerced into taking part, or that the type of reward is appropriate to the research topic).

n/a

3C. Justification of High Risk Projects

If you answered 'Yes' to the screening questions 1-4 this section asks for justification on the choice of research topic and methodology.

7. If you have answered yes to question 1 please give a full description of all medical procedures to be used within the research and provide evidence that the project has obtained NHS ethical approval.

n/a

8. If you have answered yes to questions 2 (research into a controversial topic) please provide a justification for your choice of research topic, and describe how you would deal with any potential issues arising from researching that topic.

n/a

9. If you have answered yes to questions 3 or 4 (use of deception or covert research methods) please provide a justification for your choice of methodology, and state how you will mitigate the risks associated with these approaches.

n/a

Declaration	
☒	I consider that this project has no significant ethical implications to be brought to the attention of Research Integrity Committee

☐	I consider that this project may have significant ethical implications to be brought to the attention of the Research Integrity Committee

Researcher Signature: [redacted]	**Date:** 14/05/2017
Second Supervisor: [redacted]	**Date:**

Checklist

All applications require the following to be submitted with the application form

Participant Information Sheet	☒
Informed Consent Form	☒
Interview/Survey Questions	☒

Appendix P - Information Sheet for Potential Participants – Phase 3 Interview

Developing an audio-visual tool for use in creative arts to improve experience for people on the autism spectrum

About the study - My name is John McGowan and I'm a PhD student at Edinburgh Napier University. The broad goal of this interview is to explore reasons behind the potential success of the CymaSense tool by gathering background information on the participant's behaviours before and after the TouchBase sessions. The findings of the study will inform reasons behind the tool's successful use within TouchBase and inform how the audio-visual tool can be further developed for the benefit of improving communication, social interaction and self-esteem for people on the autism spectrum.

What will taking part involve? – Parents or Guardians of the study participants are invited to take part in an interview within Touchbase, for no more than 60 minutes. The CymaSense prototype will be available for use via a laptop, microphone and small keyboard. Details of each participant's involvement in the study will be discussed and background information concerning their reactions to use of the CymaSense tool. For example: any noticeable changes in behaviour before and after the sessions; how sensory information affects them normally; and musical preferences. In addition, questions regarding the participant's use technology and any potential changes concerning the CymaSense prototype. Data gathered from sessions will be done through audio recording and note taking.

What will be done with the data? - All data will be anonymised. Participant names will be replaced with a participant number, and it will not be possible for participants to be identified in any reporting of the data gathered. All data collected will be kept in a secure place (audio recordings and notes will be kept on campus at Edinburgh Napier University in a locked cabinet in locked room, and digital data will be stored on a PC that is password protected) to which only the researcher has access. These will be kept till the end of the PhD process, following which all data that could identify you will be destroyed. The anonymised results may be published in a thesis, journal or presented at a conference.

Who can take part? - There is a criteria for inclusion of being a parent or guardian of the TouchBase study participant's.

If you have any questions or would like to find out more, please feel free to contact the researcher using the details below. If you have read and understood this information sheet, and you would like to be a participant in the study, please now see the consent form.

Additional information concerning the research may be found on-line at:

johnmcgowanphdwork.wordpress.com

Many thanks for your participation.

Appendix Q - Informed Consent Form for Parents or Guardians – Phase 3 Interviews

Developing an audio-visual tool for use in creative arts to improve experience for people on the autism spectrum

Edinburgh Napier University requires that all persons who participate in research studies give their written consent to do so. Please read the following and sign it if you agree with what it says.

1. I, as a guardian or parent of the study participant, freely and voluntarily consent to participate in the research project on the topic of the analysis of an audio-visual tool to be conducted by John McGowan, who is a postgraduate student in the Edinburgh Napier School of Computing.

2. The broad goal of this research study is to explore the role that visualisation of music can play in the lives of people on the autism spectrum, by examining their responses to the use of an interactive audio-visual tool. Specifically, I have been asked to provide informed consent for the participant, and to participate in an interview, which should take no longer than 60 minutes to complete.

3. I have been told that all responses will be anonymised and will be kept in a locked, secure environment within the University. My name, nor the participant whom I am providing consent, will not be linked with the research materials, and neither they nor myself will be identified or identifiable in any report subsequently produced by the researcher.

4. I also understand that if at any time during the interview I, or the participant whom I am providing consent, feel unable or unwilling to continue, we are free to leave. That is, our participation in this study is completely voluntary, and we may withdraw from it at any time without negative consequences.

5. In addition, should I not wish to answer any particular question or questions, I am free to decline.

6. I have been given the opportunity to ask questions regarding the questionnaire and my questions have been answered to my satisfaction.

7. I have read and understand the above and consent to participate in this study. My signature is not a waiver of any legal rights. Furthermore, I understand that I will be able to keep a copy of the informed consent form for my records.

______________________________ ______________________

Participant's Signature Date

I have explained and defined in detail the research procedure in which the respondent has consented to participate. Furthermore, I will retain one copy of the informed consent form for my records.

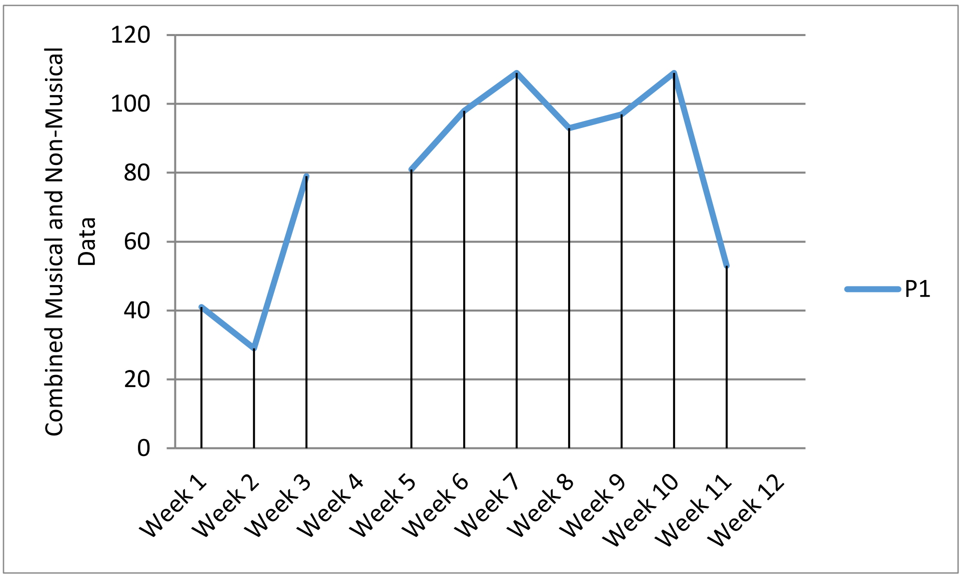
______________________________ ______________________

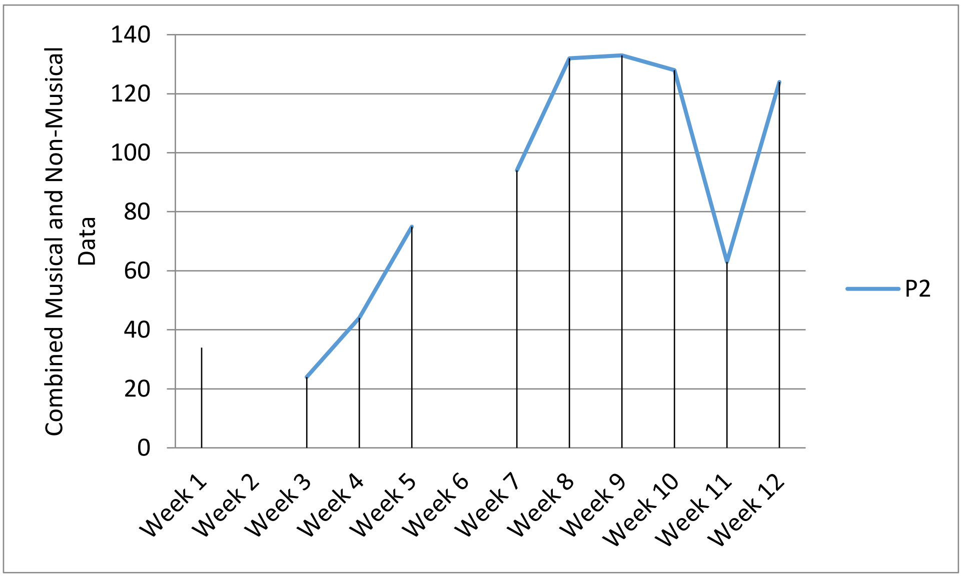
Researcher's Signature Date

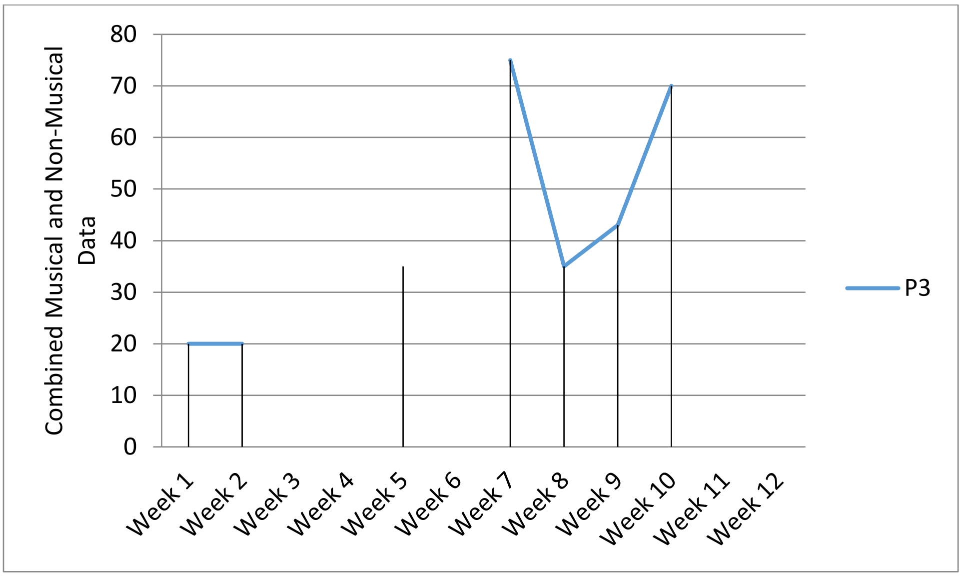
Appendix R: *CymaSense* Study Individual Participant and Group Graphs

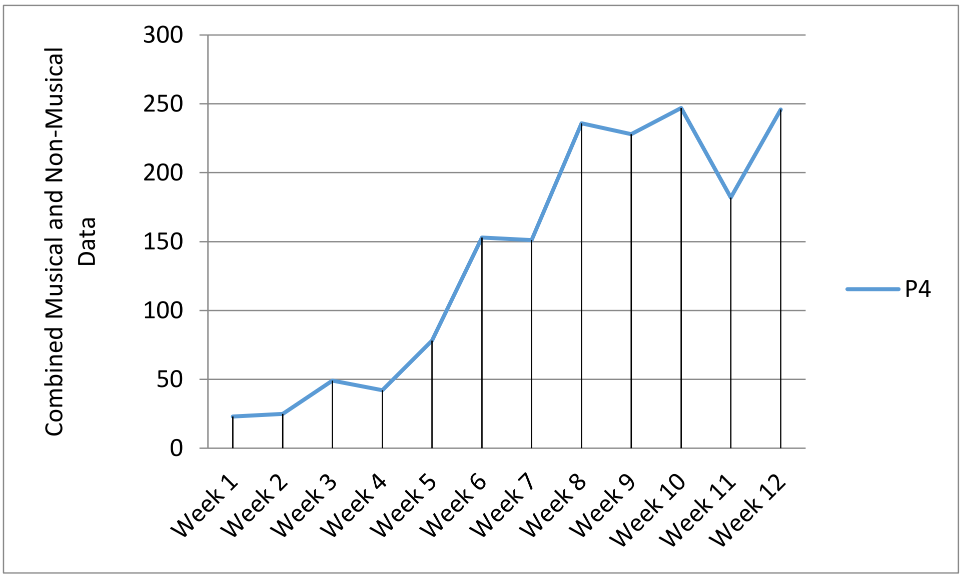
P1 – P6 referes to participants 1 to 6.

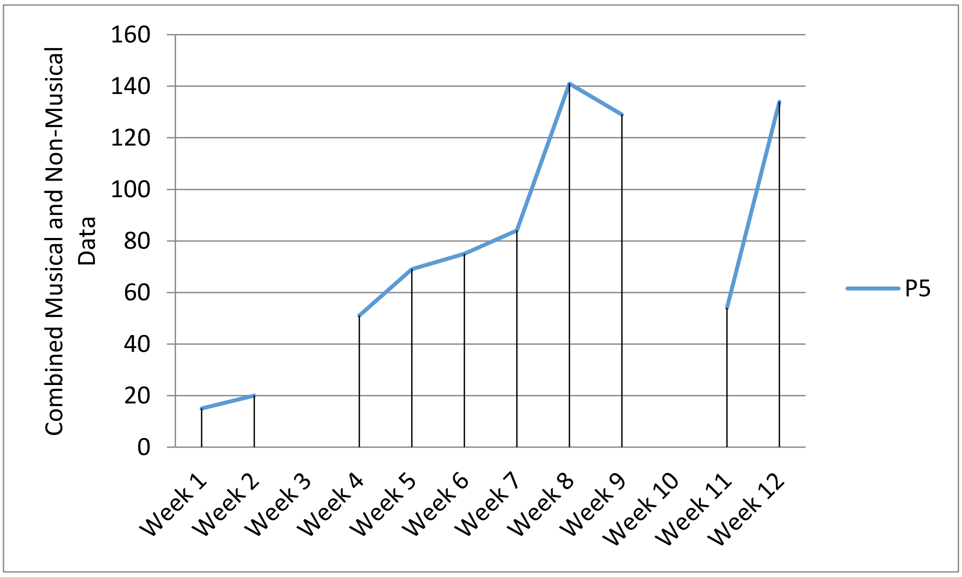
G1 refers to group 1.

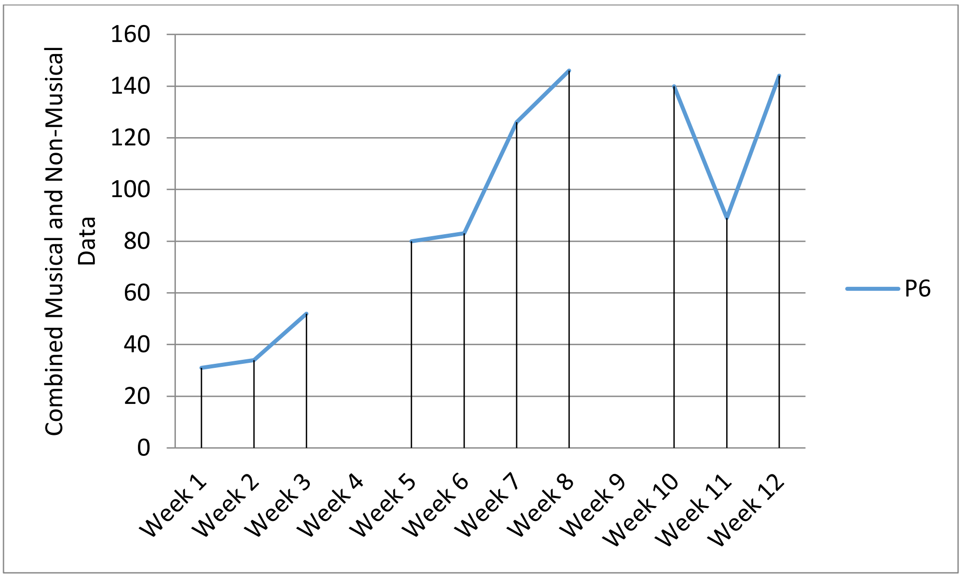


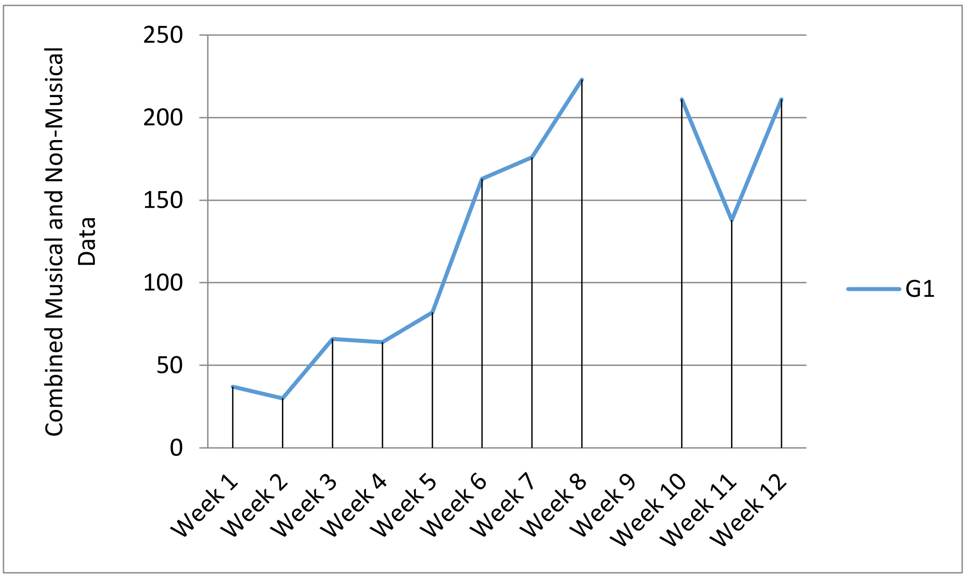



Combined Musical and Non-Musical Data
80
70
60
50
40
30
20
10
0
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12
P3


Combined Musical and Non-Musical Data
300
250
200
150
100
50
0
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12
P4


Combined Musical and Non-Musical Data
160
140
120
100
80
60
40
20
0
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12
P5


Combined Musical and Non-Musical Data
160
140
120
100
80
60
40
20
0
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12
P6


Combined Musical and Non-Musical Data
250
200
150
100
50
0
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Week 12
G1