ESTABLISHING KEY DIMENSIONS FOR REIFYING SOUNDFIELDS AND SOUNDSCAPES FROM AUDITORY PROFESSIONALS

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ABSTRACT

This paper presents a unique insight into the way acousticians, computing specialists and sound designers describe the dimensions of sound they use. Seventy-five audio professionals completed a detailed questionnaire created to elicit common definitions of the words *noise* and *soundscape,* and to establish common methods of reifying sound, architectural acoustics and hearing abilities. The responses in have contributed to a better understanding of sound from a practitioner's perspective, the impact of the physical environment on sound perception and also effects experienced by those with hearing difficulties. We report a method of data analysis and that is appropriate for use by diverse groups of professionals engaged in the design and evaluation of auditory displays for shared environments. This research suggests that a far simpler approach to the measurement and evaluation of sounds and soundscapes is practiced than might be assumed from studying the exhaustive lists of measures and methods detailed in current textbooks and published standards.

[Keywords: Soundfields, Soundscapes, Classification, Measurement, Description, Visualization]

1. INTRODUCTION

This work is part of a larger project which is developing a method for reifying shared auditory environments through soundscape mapping. The resultant maps will enable sound designers to better visualise the existing soundscape into which their work will blend, as well as providing a method of evaluation of their intervention. Previous studies by the authors have concentrated on the experience of the soundscape inhabitants, as well as investigating published methods, whereas this study focuses on the potential requirements of designers and evaluators of auditory environments [1, 2, 3].

2. METHOD

A twenty-question questionnaire was e-mailed unsolicited, to approximately 2000 auditory professionals in total, over a period of 12 months, until such time as twenty-five responses had been obtained from individuals working in the three professions of interest: Acoustics, Computer Science and Design. E-mail addresses were gleaned from published papers, membership rolls, newsgroups, and web sites. The response rate was approximately four percent. Care was taken not to email a candidate more then once. Respondents included authors of texts in their fields, established practitioners within international companies and cited researchers at universities with a track record in the relevant fields. There was no attempt to match additional criteria, such as age, sex or country of domicile.

Responses came in the form of text files, which were transcribed to a spreadsheet. This process was done manually, with square root sampling to assure accuracy. Results were compiled under four headings: *Acoustics*, *Computing*, *Design* and *Combined*. The most common responses were listed and ranked. Following this, the data was collapsed to explore the dimensions of sound used, each of which had their frequency of occurrence, mean, median, mode and standard deviation calculated. Finally, all the results were ranked both as dimensions, and their constituents for ease of comparison, with a square root sample taken to confirm accuracy.

3. RESPONSES

Twenty-five highly experienced individuals from each of three professional groups, seventy-five people in all, completed the questionnaire. Experience was judged from their current position and either their relevant qualifications or through industrial experience. The first group comprised *practitioners in acoustics* from a variety of fields, such as architectural and building acoustics through to psychoacoustics. They provided formal methods of measurement, description and analysis, which could potentially be used by both intended user groups (computing specialists and designers) for the mapping tool. The second group, *designers* came from a variety of disciplines, they were rarely formally trained, and their work was more concerned with the delivery of audio, rather than its measurement. The final group of *computing practitioners* was all involved with either developing interfaces which incorporated sound, or writing software to manipulate sound.

3.1. Participants

The job type most common among the respondents, collapsed across professional groups, was *researcher* (25%), closely followed by *sound designer* (24%) (see Table 1). Researchers formed the largest group in both the acoustics and computing groups and sound designers formed 72% of the design group. The preponderance of researchers in the sample is the result of targeting people who either published, or who were members of news groups or international organizations, such as the Acoustic Society of America, which are predominantly research-based.

This bias is partially counter-balanced by the design group which was heavily practitioner-based, with only a single professor. The computing group had a more even spread, with 44% practitioners and 56% academics.

Combined Job Titles	**n**	**%**
Researcher	19	25%
Sound Designer	18	24%
Professor	9	12%
Consultant	7	9%
Software Developer	6	8%
Sound Engineer	3	4%
Phonetician	2	3%
Software Engineer	2	3%
Sound Artist	2	3%
Engineering Physicist	1	1%
Flight Surgeon	1	1%
Noise Program Coordinator	1	1%
Physicist	1	1%
Pro Audio Manager	1	1%
Project Manager	1	1%
Psychologist (Engineering)	1	1%

Table 1: Job titles of the 75 respondents

When the responses were combined, the three fields of employment most commonly represented were Music (13%), Software Development (13%) and Psychoacoustics (12%) (see Table 2 for a complete list).

Combined Fields	**n**	**%**
Music	10	13%
Software Development	10	13%
Psychoacoustics	9	12%
HCI	7	9%
Architectural & Building Acoustics	5	7%
Noise & Vibration Acoustics	5	7%
Theatre	5	7%
Games	4	5%
Film	3	4%
Multimedia	3	4%
Neuroinformatics	3	4%
Phonetics	2	3%
Physics	2	3%
Physiology	2	3%
Technology Development	2	3%
Television	2	3%
Radio	1	1%

Table 2: Combined employment fields of the 75 respondents

The categories of responsibility represented by the respondents were development (60%), research (39%), administration (27%), education (23%), evaluation (23%) and sales (4%). Note that the majority of respondents had more than one area of responsibility, which is reflected in the results. Of the 39% who had research responsibilities, 29% were involved in sound design, 25% in management and 23% reported teaching (see Table 3).

Main Responsibilities	**Acoustics**		**Computing**		**Design**		**Combined**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Development	7	28%	15	60%	23	92%	45	60%
Research	15	60%	12	48%	2	8%	29	39%
Administration	8	32%	10	40%	2	8%	20	27%
Education	4	16%	10	40%	3	12%	17	23%
Evaluation	9	36%	2	8%			11	15%
Sales	1	4%	1	4%	1	4%	3	4%

Table 3: Main responsibilities of the 75 respondents

Overall, 61% of respondents had been formally trained, the remainder having only industrial experience. The *acoustics group* was the most highly qualified (76% formal training, 44% PhD). The *computing* and *design groups* were more evenly spread between formal qualifications and industrial experience only. Table 4 provides more detail of the breakdown. Apprenticeship has always been the traditional way of being trained within *design;* those with formal qualifications were almost all in music or composition.

Sound Related Qualification	**Acoustics**		**Computing**		**Design**		**Combined**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
PhD	11	44%	8	32%	3	12%	46	61%
Masters	5	20%	3	12%	4	16%	12	16%
Bachelors	3	12%	3	12%	4	16%	10	13%
HND					2	8%	2	3%
Formal	19	76%	14	56%	13	52%	46	61%
Industrial Experience	6	24%	11	44%	12	48%	29	39%

Table 4: Sound-related qualifications of the 75 respondents

Fifty-five percent of the participants had no current hearing impairment, with the remainder ranging from frequency loss through to a couple of cases of severe deafness (see Table 5). This contrasts sharply with 6.7% of the UK population between ages 16 and 60 having some form of hearing impairment [4]. The incidence in our sample is probably due to increased exposure to sound through work, and a greater awareness and regularity of ear testing. A few individuals reported more than one hearing impairment, some of these were permanent (such as tinnitus and frequency loss) and others were temporary but not currently present (like temporary threshold shift or ear wax). Specific frequencies were identified as being a problem; these were all in the mid to high range (1kHz through to 13.5 kHz) and in a single case was greater than 40 dB, although in most cases it was notches at specific frequencies.

Hearing Loss	**Acoustics**		**Computing**		**Design**		**Combined**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
None	10	40%	12	48%	8	32%	30	40%
Frequency Loss	5	20%	7	28%	9	36%	21	28%
Tamporary Threshold Shift	2	8%	3	12%	6	24%	11	15%
Tinnitus	4	16%	1	4%	2	8%	7	9%
Mild Deafness	1	4%	2	8%	2	8%	5	7%
Moderate Deafness	2	8%					2	3%
Severe Deafness	2	8%					2	3%
Ear Wax	1	4%	1	4%			2	3%

Table 5: Hearing losses of the 75 respondents

Hearing loss was linked to a number of specific causes: the first was senility; then over exposure to sources identified such as instruments and firing ranges; and finally physical damage due to accidents or health issues. The *design group* had an elevated level of frequency loss, but no cases of moderate or severe deafness that would preclude employment. The *computing group* had the lowest level of hearing problems, almost certainly due to lower levels of auditory exposure. The *acoustics group* contained four respondents who were either moderately or severely deaf (this did not prevent their working in the field because much of the work involves quantified measurement, rather than the qualitative evaluation more commonly associated with computing and especially with design). Respondents were clearly aware of personal hearing issues, with references made to temporary threshold shift but no mention of temporary minor shifts due to common colds or other ailments.

3.2. Defining Noise

Respondents were asked to provide "definitions of noise and rank them according to relevance to your [their] field." A wide variety of definitions were provided which were subsequently classified. This provided three clear dimensions that were shared across all three groups, *preference* (47%), *artefacts* (40%) and *spectral* (28%) Table 6 gives more detail of the definitions offered. The most common definition was *unwanted sound* (44%), which was classified within *preference*, but there was no consensus beyond that, which corresponds with Hellstrom's findings [5]. *Artefacts* included both analogue and digital, as well as more generic terms, such as buzz and hum. *Spectral* referred to specific types of noise such as white, pink or brown.

Definition of noise	**Acoustics** n	%	**Computing** n	%	**Design** n	%	**Combined** n	%
Preference	11	44%	14	56%	10	40%	35	47%
Artefacts	6	24%	15	60%	9	36%	30	40%
Spectral	5	20%	10	40%	6	24%	21	28%
Environment	4	16%	4	16%	4	16%	12	16%
Mechanical	2	8%	5	20%	4	16%	11	15%
Emotions	5	20%	3	12%	2	8%	10	13%
Information Content	4	16%	4	16%	1	4%	9	12%
Type	3	12%	2	8%	4	16%	9	12%
Architectural Acoustics	2	8%	4	16%	3	12%	9	12%
Transport	4	16%	2	8%	1	4%	7	9%
Dynamics	2	8%	1	4%	3	12%	6	8%
Human	3	12%			3	12%	6	8%
Perception			2	8%	3	12%	5	7%
Clarity	1	4%	2	8%	1	4%	4	5%
Source	1	4%	1	4%	1	4%	3	4%
Alerts					2	8%	2	3%

Table 6: Definitions of noise provided by the 75 respondents

3.3. Defining Soundscapes

All of the participants understood the concept of the *soundscape* from either the natural or constructed perspective, but rarely both. One acoustician referenced Schafer [6], while none made reference to the importance of psychoacoustics when inhabiting soundscapes. One acoustician did refer to the importance of the point [of listening], and range of time. Eighty-eight percent had encountered the term, with 43% defining it as 'a synthesized auditory environment', 33% as 'the auditory environment' and 21% as 'the perceived auditory environment' which is an accepted definition in the acoustic ecology literature [7].

3.4. Measurement, Description and Visualization of Audio

The quantitative and qualitative elements of sound events were frequently confused, with classifications or descriptions cropping up in both formal and informal sections of the questionnaire. Participants' educational background correlated positively both with the number of quantitative methods used for measuring sound and with use of formal methods for classifying sounds. Sound Pressure was the most commonly cited (55%), followed by Frequency in Hz (40%) and Amplitude in dB (40%). Table 7 shows the collapsed dimensions used for measuring sound.

Dynamics was by far the most commonly used measurement (93%). *Designers* and *acousticians* both referred to sound pressure level (SPL) the most, whereas the *computing group* was more concerned with amplitude. This illustrates the difference between the approach of designing for the personal environment of the computer interface compared to the shared environment that the acousticians and designers inhabit. There was little difference between the three groups in when referring to *spectral dimensions* (65% overall). All three groups were interested in *frequency* in *Hertz* primarily, but only the *computing specialists* and *designers* mentioned *pitch*. As would be expected by such a diverse technical group, the *acousticians* had a considerably broader range of measuring spectra, such as *modal build up* and *engine order levels*. Overall, *clarity* was the next most popular term (28%). Both the *acousticians* and *designers* measured this dimension in terms of *percentage of distortion*, which was not applied by the *computing group* who uniquely referred to *colouration*, illustrating the lesser importance of the reproduction of audio within computing compared to more traditional fields.

Measuring audio	**Acoustics** n	%	**Computing** n	%	**Design** n	%	**Combined** n	%
Dynamics	24	96%	24	96%	22	88%	70	93%
Spectral	16	64%	16	64%	17	68%	49	65%
Clarity	8	32%	6	24%	7	28%	21	28%
Architectural Acoustics	9	36%	7	28%	4	16%	20	27%
Temporal	5	20%	5	20%	7	28%	17	23%
Reproduction	5	20%	4	16%	6	24%	15	20%
Spatial	2	8%	5	20%	6	24%	13	17%
Hearing Abilities	6	24%	2	8%			8	11%
Perceptual	1	4%	3	12%	1	4%	5	7%
Aesthetics	1	4%	3	12%			4	5%

Table 7: Dimensions for measuring audio

As would be expected, *acousticians* were more concerned with architectural acoustics as well as having a more diverse range of measurements than the other two groups. All of the groups referred to *reverberation time* (RT) as being the most important, with one of the acousticians and two of the computing specialists mentioning *impulse response*. But when compared to the published literature, the total number of 13 measurements made by the acousticians is very much lower than the potential, with the *designers* only referring to four: *RT, excitement*, *isolation* and *behaviour*.

Temporal aspects were measured firstly in seconds, and then when applied to phase shifting, in milliseconds, with the designers being slightly more concerned than the other two groups. *Reproduction* was almost equally referred to in terms of power in watts and sampling rate, followed by *coherency* and *bit depth*, with the acousticians again having a slightly broader range of measurements as would be expected with such a diverse group. There was no real consensus on measuring spatial dimensions, with all of the methods being informal, such as *panning* or *distance* on an unspecified scale. *Hearing abilities* were unsurprisingly mostly referred to by the *acousticians* with no instances from the designers, and only generic descriptions from the computing specialists: hearing loss and limitations. *Perceptual* and *Aesthetic* dimensions were only briefly alluded to, which was to be expected, as they both are traditionally described in qualitative terms rather than measured in quantitative terms. The participants employed a greater range of adjectives to describe sound events than to describe formal measurements, and these bore a closer relationship to the sounds themselves, specifically their dynamic, spectral and aesthetic qualities, than to the events that created them (see Table 8).

Describing audio	**Acoustics** n	%	**Computing** n	%	**Design** n	%	**Combined** n	%
Dynamics	19	76%	21	84%	21	84%	61	81%
Spectral	14	56%	17	68%	13	52%	44	59%
Aesthetics	11	44%	12	48%	15	60%	38	51%
Clarity	14	56%	11	44%	11	44%	36	48%
Architectural Acoustics	8	32%	8	32%	6	24%	22	29%
Perceptual	9	36%	5	20%	6	24%	20	27%
Spatial	9	36%	7	28%	4	16%	20	27%
Type	5	20%	5	20%	4	16%	14	19%
Temporal	2	8%	8	32%	3	12%	13	17%
Reproduction	3	12%	5	20%	5	20%	13	17%
Musical			5	20%	3	12%	8	11%
Interacting Materials	3	12%	2	8%			5	7%
Onomateopia	3	12%			1	4%	4	5%
Hearing Abilities	2	8%					2	3%

Table 8: Dimensions for describing sound

The most commonly referred to dimension was *dynamics* which was detailed as either volume or loudness. *Spectral* descriptions were more varied, in terms of pitch, timbre or tone. *Aesthetics* mostly related to brightness, harshness or warmth, all of which referred to spectral aspects as cited by Katz [8]. *Clarity* was the first dimension on which there was not a consensus, the acousticians and computing specialists both cited sound quality and clarity, which were not referred to at all by the designers, who used unique terms such as 'dirty', 'unclear' and 'overdriven'. *Architectural acoustics* were mentioned by all three groups but without any commonalities, as were all of the remaining dimensions.

The most common forms of visualizing sound were *spectral, dynamics* and to a lesser degree *spatial*. A surprising result was that spectral representations were the most commonly cited, this was consistent across all three groups, with the most common method a spectrogram. Next was *dynamics* with a waveform being the only visualization method selected by more than a single individual. Finally, *spatial* dimensions, but without any consensus, forms used were contour mapping and ray tracing. All of the other dimensions were not used to any significant extent. Especially surprising was the limited reference to *musical notation* (7%), despite 40% of the participants working in the field of music (see Table 9), although it did figure much more prominently when referring to notating sound.

Graphically	**Acoustics**		**Computing**		**Design**		**Combined**	
representing audio	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Spectral	20	80%	20	80%	17	68%	57	76%
Dynamics	12	48%	18	72%	15	60%	45	60%
Spatial	5	20%	7	28%	5	20%	17	23%
Sound Type	1	4%	2	8%	4	16%	7	9%
Hearing Abilities			5	20%	1	4%	6	8%
Reproduction			2	8%	3	12%	5	7%
Architectural Acoustics	1	4%	3	12%	1	4%	5	7%
Music	1	4%	2	8%	2	8%	5	7%
Temporal			1	4%	2	8%	3	4%
Synthesis			1	4%	1	4%	2	3%
Linguistic					1	4%	1	4%

Table 9: Dimensions for graphically representing sound

3.5. Measurement and Description of Room Acoustics

When quantifying room acoustics only *reverberation time* had any significant response across all three groups (65%). There was, however, a broad range of measurements the most common being *temporal* (76%), with *reverberation time* and *decay rate* being shared by all three groups (see Table 10). *Reflection,* surprisingly, had a more diverse set of measurements (24) within the computing group than either the acousticians (10) or the designers (16) with no correlation across all three groups. With regards to *spectral* only *frequency response* was shared, mostly attended to by the designers. *Dynamics* related to impulse response but only by the acousticians and computer scientists with the designers being relatively unconcerned.

Measuring	**Acoustics**		**Computing**		**Design**		**Combined**	
Room Acoustics	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Temporal	20	80%	17	68%	20	80%	57	76%
Reflection	6	24%	13	52%	11	44%	30	40%
Spectral	7	28%	9	36%	10	40%	26	35%
Dynamics	10	40%	9	36%	5	20%	24	32%
Absorption	7	28%	8	32%	6	24%	21	28%
Clarity	10	40%	4	16%	4	16%	18	24%
Spatial	6	24%	4	16%	3	12%	13	17%
Room Type	1	4%	1	4%	1	4%	3	4%

Table 10: Dimensions for measuring room acoustics

When describing room acoustics the most important dimension was *reflections* specifically dead/dry and reverberant/live (see Table 11). *Spectral* was next, referring to bright, boomy and warmth. *Clarity* was used in terms of dull, muddy/muffled and clear. Finally *dynamics* produced a diverse group of responses the only shared being by the acousticians and designers who referred to both noisy and quiet.

Describing	**Acoustics**		**Computing**		**Design**		**Combined**	
Room Acoustics	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Reflections	13	52%	19	76%	21	84%	53	71%
Spectral	10	40%	13	52%	21	84%	44	59%
Clarity	9	36%	9	36%	11	44%	29	39%
Dynamics	7	28%	6	24%	5	20%	18	24%
Spatial	7	28%	4	16%	6	24%	17	23%
Temporal	3	12%	6	24%	3	12%	12	16%
Absorption	2	8%	3	12%	3	12%	8	11%
Room Type	1	4%	2	8%	2	8%	5	7%

Table 11: Dimensions for describing room acoustics

3.6. Measurement and Description of Hearing Abilities

When measuring hearing abilities by far the most common dimension was *dynamics* in terms of hearing level in dB, threshold and amplitude sensitivity (see Table 12). The slightly more precise *spectral* measurements of frequency sensitivity/response and hearing loss came next. There was no consensus on any other dimensions apart from localization within *spatial.* Overall almost all the measurements were concerned with hearing damage rather than acuity.

Measuring	**Acoustics**		**Computing**		**Design**		**Combined**	
Hearing Abilities	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Dynamics	15	60%	13	52%	15	60%	43	57%
Spectral	12	48%	13	52%	12	48%	37	49%
Clarity	5	20%	6	24%	2	8%	13	17%
Spatial	4	16%	4	16%	3	12%	11	15%
Type of Impairment	4	16%	3	12%	3	12%	10	13%
Temporal			6	24%			6	8%

Table 12: Collapsed dimensions for measuring hearing abilities

When describing hearing abilities *spectral* attributes became more prominent, specifically frequency loss, and high frequency roll off/loss, these were followed by *dynamics* which were mostly described in terms of hearing loss in decibels and sensitivity to level changes again in decibels (see Table 13).

Describing	**Acoustics**		**Computing**		**Design**		**Combined**	
Hearing Abilities	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Spectral	12	48%	13	52%	12	48%	37	49%
Dynamics	12	48%	11	44%	8	32%	31	41%
Type of Impairment	11	44%	13	52%	7	28%	31	41%
Clarity	4	16%	4	16%	3	12%	11	15%
Spatial	2	8%	3	12%	3	12%	8	11%
Temporal	1	4%	3	12%	1	4%	5	7%

Table 13: Collapsed dimensions for describing hearing abilities

Types of impairment was applied predominantly to deafness and tinnitus. *Clarity, spatial* and *temporal* were without any real consensus beyond the ability to localize a sound source, which related to both the computing and design groups.

3.7. Notation and Classification of Sound

By far the most common single form of notation, as would be expected, was musical notation. Other forms were both formal and informal, within the collapsed dimensions *spectral* pitch and frequency were the only two methods shared by all three groups, with timbre being used by the computing specialists and acousticians but surprisingly not by the designers, who were more interested in spectrograms/fast fourier analyses (Table 14). *Music* notation was consistent across all groups, both the computing specialists and the designers utilized non-western notations as well as piano rolls, tablature and chords. This was also the case when it came to the traditional comparison of amplitude versus time, other methods were usually informal and unique to individual respondents such as intensity maps and relative levels. Duration was the only *temporal* dimension shared by all three groups, other dimensions, with the exception of MIDI within *programming languages*, were disparate.

Notating	**Acoustics**		**Computing**		**Design**		**Combined**	
Sound	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Spectral	18	72%	18	72%	18	72%	54	72%
Music	11	44%	19	76%	21	84%	51	68%
Dynamics	10	40%	12	48%	18	72%	40	53%
Temporal	5	20%	7	28%	6	24%	18	24%
Programming Language	2	8%	11	44%	3	12%	16	21%
Linguistic	4	16%	4	16%	3	12%	11	15%
Spatial	3	12%	3	12%	5	20%	11	15%
Type	1	4%	3	12%	3	12%	7	9%
Clarity	2	8%	2	8%	1	4%	5	7%
Perceptual	1	4%	2	8%	2	8%	5	7%

Table 14: Collapsed dimensions for notating sound

The classification of sounds was equally diverse but when combined with the notation and descriptions a single effective method for classification can be derived, suitable for three groups, as well as indicating each dimension's relative importance. This is useful when visualizing the results, as the more relevant dimensions use the more easily identifiable aspects such as size and shape, with the more subtle visual cues being utilized for the esoteric dimensions. A few published methods were included by the respondents such as Smalley's spectro-morphology [9], Schaeffer's typo-morphology [10], Gaver's *interacting materials* [11], Schafer's environmental method [6], Wake and Asahi's verbal expressions [12], along with the ANSI 1994 acoustical terminology [13]. These represent a broad area from the technical through to the aesthetic but all were only cited singly, so are obviously not utilized as part of standard practice across any of the three groups. The most popular method of classification was by *sound type*, which mostly fell into speech, music and non-speech/natural /artificial/everyday (see Table 15).

Classifying	**Acoustics**		**Computing**		**Design**		**Combined**	
Sound	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Sound Type	11	44%	14	56%	12	48%	37	49%
Music	2	8%	7	28%	5	20%	14	19%
Interacting Materials	4	16%	6	24%	4	16%	14	19%
Artificial	3	12%	7	28%	3	12%	13	17%
Temporal	4	16%	1	4%	8	32%	13	17%
Spectral	6	24%	4	16%	2	8%	12	16%
Environment	6	24%	2	8%	4	16%	12	16%
Interaction	3	12%	5	20%	4	16%	12	16%
Perceptual	4	16%	5	20%	3	12%	12	16%
Linguistic	4	16%	5	20%	2	8%	11	15%
Dynamics	4	16%	4	16%	3	12%	11	15%
Clarity	3	12%	2	8%	3	12%	8	11%
Spatial	1	4%	3	12%	3	12%	7	9%
Reproduction	1	4%	2	8%	3	12%	6	8%
Clompexity	1	4%	1	4%	1	4%	3	4%
Aesthetics	1	4%	2	8%			3	4%
Room Acoustics					1	4%	1	1%

Table 15: Collapsed dimensions for classifying sound

Musical classifications fell mostly into the type of music or its instrumentation, again without consensus. *Interacting materials* was interesting in that 5% of the respondents referred to Gaver's taxonomy, a further 9 detailed dimensions contained within it. A sound's artificiality was noted in terms of either being natural or mechanical/man made/artificial, yet again without consensus. The quantifiable dimensions of sound such as *temporal, dynamics, spectral clarity* and *spatial* were rarely used to classify it, which is unsurprising, but what was initially surprising that the qualitative *perceptual* and *aesthetic* dimensions were so rarely applied. But with hindsight this is less of a surprise considering the emphasis on *sound type*.

3.8. Reifying auditory environments

Participants were asked what parameters (characteristics) they would wish to be included if there was a technique to represent and auditory environment. This provided an insight into what dimensions are currently under utilized, or difficult to capture. The first dimension was *spatial* which was mostly of interest to the computing specialists, and the designers, this was broken down into location, direction and diffuseness. *Dynamics* was mostly related to either SPL, power or perceived intensity. *Architectural acoustics* revolved around reverberation time and to a limited extent, absorption, with *spectral* relating mostly frequency followed by timbre. Time and duration represented the *temporal* dimension, with source and type being suggested under *sound type*. The was no agreement on the dimensions of *perception*, *hearing abilities*, *all*, *clarity* and *emotions*.

When respondents were asked which 'auditory environments would they be interested in capturing' *acoustics* was the most commonly cited. This was mostly made up of everyday sounds and music. Next, which were equally important were *natural environments* and *commercial interiors*, closely followed by *every*. This data provides a set of environments to test the resultant method upon, as well as informing us about which environments would be of interest to specific groups. The most common single environment with an fairly equal response across all three groups was unsurprisingly auditoria (21%).

3.9. Summary

The questionnaire has generated a list of the parameters that participants wish to be mapped, these include: absorption co-efficients; amplitude; category; context; direction; frequency; periodicity; reverberance; room acoustics; source; spatial location and type. This corresponds with many of the physical aspects that are already mapped in the soundfield, and suggests that the more advanced sound designers are interested in many of the dimensions that the current method incorporates. Participants also requested that exterior environments are mapped as well as interior and individual sound events.

Overall there was little overlap of terminology within the professional fields, except in the most general terms. There was also little evidence of established methods to notate, classify and visualise sound events, beyond those of waveform and spectrograph. There were specific exceptions within acoustics, but sound designers and computer scientists evidenced little need of methods of visualization, despite a number of them working on the auralization of data. However, one of the computing technologists used a very simple, but effective, method of describing audio: sense of direction; sense of depth; sense of space; sense of movement; distance to events; broadness; naturalness; richness; tone colour and emphasis.

Computing participants were comfortable with the term 'sound event', whereas sound designers preferred the terms 'sound' or 'audio', disassociating them from the source. The overall response to the research varied from not seeing the relevance, to requesting access to any published results. An acoustic phonetician suggested that the proposed methods would prove ideal for use within their field, which they felt that sound designers and engineers had traditionally ignored. None of the participants referred to any other researchers working in this area. The questionnaire has established the methods and terminologies audio professionals currently use when notating, classifying and visualizing sounds. It has confirmed that there is a wide range of skills and understanding across the fields closely associated with education, and that many concepts such as the ‘soundscape’ and ‘noise’ have no standard accepted definitions, even within the same professional field.

4. REIFICATION METHOD

The results were collapsed into a single method for reifying auditory environments. This produced a two-tier approach, where the physical sound field, room acoustics and hearing abilities could be measured or described, and the perceived soundscape could be classified.

4.1. Measurements

As Augoyard points out, the measurement of a single sound is an abstract concept, as it is impossible, outside of an anechoic chamber, to separate it from its environment or the listener’s perception [14]. This combination of the physical measurements provides an insight into the quantifiable elements preceding individual interpretation, of what Rodaway defines as the soundfield compared to the soundscape [15]. The choice of physical measurements was based on the most commonly cited term within the highest rated dimensions. These measurements represent the original source or sound field, the affect that the physical environment has upon it and the effect that an individual’s hearing will have upon its subsequent perception (see Table 16). A single measurement was chosen for each dimension, which have been clearly defined both by international standards and by common practice within the respondents’ respective fields.

Audio	
Dynamics	sound pressure level
Spectral	Frequency
Clarity	Distortion
Temporal	Duration
Spatial	Location
Room Acoustics	
Temporal	Reverberation Time
Reflections	Early Reflections
Spectral	Frequency Response
Dynamics	Impulse Response
Absorption	Absorption coefficient
Clarity	Speech Transmission Index
Hearing Abilities	
Dynamics	Hearing Level
Spectral	Frequency Response

Table 16: Methods of Measurement

The audio measurements of *dynamics*, *spectral* and *temporal,* which are applied across all three groups, represent the most basic of techniques, typically measured in decibels, hertz and seconds respectively [16]. *Clarity* is measured as percentage distortion, and is much more specific and predominantly concerned with reproduction quality, the standardized method is Total Harmonic Distortion, which Whitlock points out is a poor measure [17]. Location was a dimension listed as being a parameter which respondents would like to be included, it is proposed that it would be measured using Euclidean coordinates, although as Carlile points out the listener will not necessarily perceive it anywhere near as accurately [18].

When addressing room acoustics, the most commonly utilized measurement was reverberation time (RT_{60}), this is an excellent gauge of what the intelligibility will be like in a specific environment [19]. It is also the longest established and most commonly applied measurement for room acoustics [20], but in conjunction with other equally important measurements [21]. Also if only a single measurement was to be taken, then this would be by far the most important for all three groups. Early reflections measured in ms again provide an insight into intelligibility, as if it is between 35 – 50ms the listener can integrate the reflections, if it is shorter or longer than this it can colour the sound [19]. The frequency response of a room measured in decibels against hertz provides the room’s spectral variations, compared to the impulse response measured in decibels against seconds provides the room’s dynamics response.

Absorption coefficient is another well established measurement, it is calculated as a ratio between 0-1, with 0 being 100% reflection and 1 representing 100% absorption [16], this is typically applied to specific surfaces, rather than the room as a whole. The Speech Transmission Index is most commonly used in Europe whereas Speech Intelligibility as %Alcons is more popular in the USA [19]. Using the rapid procedure, values are produced as a ratio between 0-1, 0 representing unsatisfactory syllable intelligibility and 1 excellent [20]. Hearing abilities only 2 measurements have been specified. Hearing level is more accurately described as the pure-tone average (PTA) of 500, 1000 and 2000 Hz, and is expressed in dB. This is commonly used to identify speech thresholds with -10–15 having no impact, with anything greater than -90 being profound [22]. There are very obvious problems with this measurement, in that it is only an average, whereas frequency loss more accurately represents the specific loss. So the frequency response is represented via an audiogram, which typically measures the hearing thresholds of 9 frequencies per ear with or without masking. This can be extended with bone conduction measurements across 6 frequencies from right, forehead and left [22].

4.2. Descriptions

The descriptions in this instance can be used either instead of the measurements, as a form of shorthand utilizing a consensus vocabulary, or to support or extend them. In the case of describing audio, rather than measuring it, the *temporal* dimension has been replaced by a brief description of a sound’s aesthetics (see Table 17). This dimension is also missing from the description of the room acoustics where it has been combined with *reflections* and *absorption* into a single dimension of *reflections,* in its binary form of dead or reverberant.

Audio			
Dynamics	soft	loud	
Spectral	low (pitch)	mid (pitch)	high (pitch)
Aesthetics	warm	harsh	bright
Clarity	poor	good	
Room Acoustics			
Reflections	dead	reverberant	
Spectral	boomy	bright	
Clarity	dull	clear	
Dynamics	quiet	noisy	
Spatial	intimate	diffuse	
Hearing Abilities			
Spectral	frequency loss		
Dynamics	hearing loss		
Type	Deaf	Tinnitus	

Table 17: Methods of Description

Traditionally it would be expected that loud would be contrasted with quiet with regards to dynamics, which is a common descriptive dimension in sound quality evaluation [23], but in this case it was compared to soft by 53% of the respondents with quiet only being applied twice (3%). This corresponds with practice within the film industry where intensity is routinely described in terms of being soft or loud [24]. The partitioning of pitch into low, mid and high is familiar to anyone who has ever utilized a budget mixer and is applied to pitch within mainstream sound design, right through to the highly specialized field of envirotecture [25]. The *aesthetic* dimension is very closely related to the *spectral*, in that all three of the categories are typically associated with a specific range of frequencies, warm and bright being positive versions of low and high while harsh is a negative form of mid.

Clarity is described in binary terms as either poor or good, it was noticed consistently throughout all of the responses, that apart from with regards to pitch there were very few neutral or mid point terms for any of the dimensions. This corresponds with Hellstrom [26] as well as Hedfors and Berg [27] who established word pairs when describing properties or characteristics of soundscapes. When it comes to hearing abilities, the descriptions are very close to the measurements in both *spectral* and *dynamics* except they are specifically about loss, whereas the measurements provide details about acuity as well. *Type* has replaced the dimension of *clarity* with the choice being confined to two very specific types of hearing loss: deaf or tinnitus. It could be argued that almost every other type of hearing loss could be described through the relative combinations of the *spectral* and *dynamic* descriptions, but in their current form they are only described in general terms.

4.3. Classification

By combining the methods of notating sound with the terms used for the classification of sound, it was possible to create a method of classifying sound events that represents the perceived soundscape. The dimensions are used to classify each individual sound within an auditory environment, and as such are unique to each environment and listener, as argued for by Porteous and Mastin [28]. Bech and Zacharov confirm that auditory attributes can be both identified and elicited for perceptual evaluations of sound quality, as well as there being no one correct way [29].

The descriptions of audio detailed above are usually applied in general terms to a complete signal rather than individual elements. This approach allows us to capture what Altman refers to as the 'heterogeneity of sound events', where it is dependent on the unique context and the individual listener [30]. This combination also helps compensate for the typical problem of a participant only providing a list of sound events, rather than an analysis of its attributes [11]. This is further compounded by the individual's tendency to visualise the event's source rather than 'hear' the sound [31] or even by memories of what interviewees used to hear being affecting concurrent sounds [32].

The hierarchy has been determined by the level of response from the participants (see Table 18). It is unsurprising that *sound type*, *interacting material* and *interaction* are the first three dimensions, as these are rarely measured in normal practice so their classification extends the information gleaned from measurement. *Temporal* provides a useful description of the length of a sound using four categories, all of which are related to the duration in the context of the entire soundscape, as the length is established by comparison, rather than isolated measurement. The *spectral* dimension matches almost exactly the descriptions, except that varying has been added, as is the case with *dynamics*.

Sound Type			
Music	Speech	Artificial	Natural
Interacting Material			
Aerodynamic	Liquid	Material	Structure
Interaction			
blown	impact	scraping	vibration
Temporal			
Impulse	Short	Long	Continuous
Spectral			
high	mid	low	varying
Dynamics			
loud	soft	varying	

Table 18: Classification of sound events

The separation of artificial and natural within *sound type* can provide an insight into the possible preference for a sound event, as Kageyama found, often natural sounds are preferred to artificial [33]. The *interacting material* is similar to Gaver's classification of *solids*, *gasses* and *liquids*, except that *solids* has been split into *material* and *structure* providing information about whether the object is malleable [11]. I*nteraction* provides information about the method of sound generation, but is missing at least splash and drip, which was not mentioned by any of the respondents. The *temporal* dimension not only provides information about the frequency of individual instances but can also indicate potentially how annoying the sound event might be, as this typically increases with the amount of time the sound event is present [34].

5. CONCLUSIONS

We have presented an approach to soundfield and soundscape mapping that provides acousticians, computing specialists, and traditional sound designers with a common set of methods for reifying an acoustic environment based upon their current practice. They can choose to either measure or describe the physical dimensions, followed by a classification that can be used to elicit responses from end users, to establish whether their experience of a sound or soundscape matches the designers intention. Asking listeners to classify the sound events that they hear helps compensate for their natural desire (as Ballas *et al.* found) to describe them according to their semantics rather than the event's acoustic properties [35]. The method can be used to describe an environment prior to design, so that augmentation is achieved to the benefit of end users. We are aware that there are omissions such as interactive function, which is routinely applied by consumer product sound designers [36, 37], as well as any detail about emotions which is key to film sound design [38, 39].

The next stage of this research is to revisit the combination of the results from this study with terms used by inhabitants when describing their soundscape, so that a set of dimensions and terms that are clearly understood by both groups can be established. This should result in a method that can be used to evaluate the effectiveness of auditory interfaces, both in isolation and in their intended auditory environments. The dimensions will be used as a form of questionnaire for auditory environment inhabitants, with their responses being collapsed and then visualized in map form for ease of comparison.

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