The format of children's mental images: Evidence from mental scanning

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Abstract

The present study examined the development and format of children’s mental images. Children (4-, 5-, 6-7-, 8-9-, and 11-year-olds) and adults (*N* = 282) viewed a map of a fictitious island containing various landmarks and two misleading signpost markers, indicating that some equally distant landmarks were different distances apart. Children as young as 5 years showed the linear time-distance scanning effect, which has been well-documented in adults (Experiments 1 and 2): They took longer to mentally scan their image of the island with longer distances between the corresponding landmarks, thus indicating the depictive quasi-pictorial nature of children’s mental images. Unlike adults however, their scanning times were not affected by the misleading top-down distance information on the signposts until age 8 (Experiment 1) unless they were prompted to the difference from the outset (Experiment 2). This is the first study to a) provide insight into the format of children’s mental images using a mental scanning paradigm and b) show that children’s mental images can be susceptible to top-down influences as are adults’.

Keywords: Cognitive development, mental imagery, image scanning, format, visuo-spatial processes

Mental imagery, "seeing with the mind's eye" such as "seeing" an event, and object or a scene in our mind in the absence of immediate sensory input (Kosslyn, 2006), is ubiquitous in children's and adults' every-day life. It has also been of great theoretical debate for over 30 years which format our mental images have. In particular, it has been argued that mental images are depictive, pictorial-based representations that preserve metric qualities such as space and distance (Kosslyn, 1980; Kosslyn, Ganis & Thompson, 2003) or that they have no particular format but simply underlie tacit knowledge of how a scene might look (Pylyhsyn, 1981; 2002; 2003).

Depictive theory (Kosslyn, 1981; Kosslyn et al., 2003) suggests that mental images are quasi pictorial in nature and share common features with visual perception such as structural representational overlap. There is an "isomorphism" between the spatial structure of the representation that occurs during both perception and imagery (Denis & Kosslyn, 1999). Indeed, Kosslyn (1994) defines depictive representations as "…a type of picture, which specifies the locations and values of configurations of points in a space… each part of an object is represented by a pattern of points, and the spatial relation among these patterns correspond to the spatial relations among the parts 'themselves'…" (p.5, as cited in Pylyshyn, 2003). In support of the depictive imagery account, a number of studies have demonstrated that adults take longer to scan a mental image as a function of the actual distance between the to-be-scanned-objects (e.g., Beech, 1979; Borst & Kosslyn, 2008; Borst & Kosslyn, 2010; Borst, Kosslyn, & Denis, 2006; Finke & Pinker, 1983; Kosslyn, Ball & Reisser, 1978), which also holds for three-dimensional space in mental images (Pinker & Kosslyn, 1978). As this effect also occurs in congenitally blind people, a visual perceptual experience is not a prerequisite but can also be achieved through haptic experience (Iachini & Ruggiero, 2010). Such findings demonstrate that mental images incorporate the metric information present in the original object or scene and that newly constructed images are not simply unstructured patterns but possess a structure that has a number of similarities with the structure of representations that arise from perception and haptic exploration (Kosslyn et al., 2003).

Conversely, *tacit knowledge theory* (Pylyshyn, 2002; 2003) posits that mental images do not have any particular format but underlie tacit knowledge. When we imagine a scene or an object we consider what it would look like if we saw it. Thus, mental imagery is driven by tacit knowledge, the knowledge of what things would look like (Pylyshyn, 2002; 2003). In support of this notion, participants do not report certain visual properties in their mental image when they are unaware of those properties in the real world and *vice versa* they do report properties when they are aware of them. For example, they focus on a distance between two places in a scanning paradigm when instructed to do so but do not represent the visuo-spatial properties of scene in their mental images. That is, participants' performance on mental imagery tasks is dependent on how they understand the task or the instructions rather than underlying a particular format (Pylyshyn, 1981; 2002; 2003).

One way of gaining insight into the format of people's mental images is to ask them to scan their mental image of a previously presented image, for example between landmarks on an island map (Kosslyn et al., 1978). Findings that adults show a linear time-distance relationship (taking longer to scan further distances) are generally interpreted as demonstrating the depictive nature of imagery (see Denis & Kosslyn, 1999). However, adults' performance on these tasks has been shown to be penetrable by top-down influences such as verbal codes. Scanning times are influenced by misleading mileage signpost markers on the map that indicate different distances between the landmarks when actual distances are equal (Richman, Mitchell & Reznick, 1979). This indicates that people's mental scanning performance is cognitively penetrable by top-down factors and is often cited in support of the tacit knowledge account. Tacit knowledge about perception and understanding of the task produces responses like those people believe would occur in the corresponding perceptual situation (Pylyshyn, 1981; 2003). Thus, performance on mental scanning tasks is cognitively penetrable by the semantic content of participants' beliefs and goals (see Pylyshyn, 2003). Tacit knowledge theorists argue that if mental images were quasi pictorial in nature they would not be influenced by top-down processes and demand characteristics in this way (Pylyshyn, 1981, 2003). However, both adults' and children's visual perception is cognitively penetrable by top-down processes as is evidenced, for example, by visual illusions (Doherty & Wimmer, 2005; Gregory, 2009; Long & Toppino, 2004; Wimmer & Doherty, 2011). As visual perception is guided by knowledge and how we interpret what we see so too is mental imagery (Kosslyn et al., 2003). For example, adults reverse (switch) alternative interpretations of ambiguous figures in mental imagery when cues of features are provided (Mast & Kosslyn, 2002; Peterson, Kihlstrom, Rose, & Glisky, 1992). Thus, proponents of a depictive account argue that mental imagery performance should be penetrable by top-down processes as is visual perception (Kosslyn et al., 2003).

Developmental research may shed more light on the question whether our mental images are depictive in nature or based on *tacit knowledge* and susceptible to top-down processes. If it is the case, for example, that 5- to 8-year-olds' mental imagery retains physical properties such as distance, then this would provide support for the depictive account since metacognitive strategies and insight develop during this age range (Bjorklund & Douglas, 1997; Flavell, Green, & Flavell, 2000; Lyons & Ghetti, 2010; Ghetti, Mirandola, Angelini, Cornoldi, & Ciaramelli, 2011; Kee, 1994; Perner, Kloo, & Rohwer, 2010; Schneider, 1986). For example, 5-year-olds are much less able to introspect into their own thought processes than 8-year-olds (Flavell et al., 2000) and 6-year-olds are less able to assess their own subjective experience of recollecting details of events compared to 9-year-olds (Ghetti et al., 2011). As tacit knowledge such as mental simulation of how a scene might look requires metacognitive insight and strategies, it is unlikely to be applied in 5- to 8-year-olds.

Indeed, there are a number of reasons to suspect that younger children's mental images may be depictive in nature. Research from mental rotation in both 5- to 6-year-old children and adults demonstrates that response time increases linearly with increasing difference in rotation angle between objects (Estes, 1998; Frick, Daum, Walser, & Mast, 2009; Frick, Möhring, & Newcombe, 2014; Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990; Marmor, 1975; Shepard & Cooper, 1982; Shepard & Metzler, 1971; see also Möring, Newcombe, & Frick, 2014 for recent findings of linear increases in spatial scaling). Thus, mental images incorporate the spatial information present in the original object. Further, adults do not reliably predict a linear rotation effect (Denis & Carfantan, 1985; Lobmaier, Mast, & Hecht, 2010) ruling out a tacit knowledge explanation for mental rotation.

Apart from robust findings in mental rotation, there is limited evidence relevant to the question of whether children's mental images are depictive in nature. Moreover, to our knowledge no research to date has examined whether children's mental imagery performance is susceptible to top-down processes. Given that children's visual perceptual processes are influenced by top-down processes (Doherty & Wimmer, 2005; Wimmer & Doherty, 2011), one would then also predict top-down influences on children's mental imagery processes.

To gain insight into the format of children's and adults' mental images we adapted Kosslyn et al.'s (1978) famous "island task" and asked participants to scan their mental image of a previously presented image between landmarks on an island map. Additionally, we examined how distance information on a map (top-down knowledge) affects its representation. For example, if one distance between landmarks is labelled as further away on a signpost (5 footsteps) than another (1 footstep), will it take children longer to mentally scan even though the distances are the same length (see Richman et al., 1979 for adult findings)?

Thus, the aim of the present research was first, to examine whether children show the typical time-distance linear relationship (taking longer to mentally scan as function of the actual distance between the to-be-scanned items), suggesting they preserve metric distance in their mental images. Alternatively, if they fail to show the time-distance linear relation this would indicate that children's mental images do not retain spatial properties of a visual scene. This will provide us with insight into the format of their images. Second, we ask at what age children's mental images become penetrable to the sort of top-down information that adults' are. If children preserve metric distance in their mental images but their scanning is influenced by top-down factors then this strongly favours the idea that children's mental images are similar to visual perception in being pictorial in nature while still influenced by conceptual factors.

Experiment 1

Method

Participants

In total 152 participants (76 females) took part: 24 4-year-olds (*M* = 60 months, range = 54-65), 26 5-year-olds (*M* = 71 months, range = 66-77), 26 6-year-olds (*M* = 83 months, range = 78-89), 25 8-year-olds (*M* = 107 months, range = 99-113), 25 11-year-olds (*M* = 132 months, range = 126-137) and 26 adults (*M* = 21 years, range = 19-31). In both experiments children were recruited from local primary schools and adults via the university sign-up system and received financial reimbursement. Participants were predominantly from middle-class backgrounds.

Materials and procedure

A map of a fictitious island (see Kosslyn et al., 1978; Richman et al., 1979) was constructed on a standard 17.3 inch laptop screen, containing a Lighthouse, Volcano, Hut, Pond and Tree (Figure 1). Additionally, two signposts pointed between the Lighthouse-

Volcano and the Hut-Volcano (both of which were equal distances). Following piloting, the signposts were adapted from the 20- and 80-mile ones used by Richman et al. (1979) for 4-5-year-olds: one signpost showed 1 footstep and the number 1, and the other 5 footsteps and the number 5. The positions of the signposts were counterbalanced between the two pairs of landmarks between participants.

Figure 1. *Island map with landmarks and signposts.*

Participants were tested individually and introduced to a 'Percy the Pirate Parrot' character, which walked across a map of a fictitious park. They were told that Percy always walked in this way, in a straight line and at the same speed. Participants received three practice trials and were asked to close their eyes and, on the experimenter's 'Start' command, imagine Percy walking between specified landmarks, and to say 'Stop' when he had arrived at the second landmark. After each imagery attempt they watched Percy walking between said landmarks, with the instruction to compare this to how they imagined him walking. If participants reported that they imagined Percy walking differently, they were questioned on this and the instruction to imagine him walking in exactly the same way as they could see him walking was repeated.

In the imagery trials participants viewed the island for 45 seconds. They were instructed to name and memorise everything on it. After 45 seconds the landmarks disappeared to leave an empty island. To ensure efficient encoding, using the mouse participants dragged and dropped each landmark and the two signposts in turn into its correct position on the island. Once the landmark was within a 30 pixel radius of its correct location it shifted and locked into place.

The island then disappeared (the younger participants received a cover story about it being night-time). Participants were instructed to close their eyes and imagine the island with Percy standing at the Lighthouse. They then imagined Percy walking between landmarks in the following order (actual distances between each landmarks in parentheses): Lighthouse-Tree (262mm), Lighthouse-Volcano (81mm), Lighthouse-Pond (154mm), Lighthouse-Hut (70mm), Hut-Lighthouse (70mm), Hut-Pond (100mm), Hut-Volcano (81mm), Hut-Tree (260mm). The computer recorded the time taken to mentally scan between each of the landmark pairs.

Finally, participants completed ‘perception control’ trials, where this process was repeated, but with the island visible on the screen. Participants were instructed to follow their eyes between the landmarks to imagine Percy walking between them. After the experiment participants were asked what the signs meant and which sign represented further.

Results Experiment 1

Bonferroni confidence interval adjustments and post-hoc analyses were used throughout. Outlier response times that were 2 standard deviations from the mean per distance and age group were removed.

Preliminary analyses

There were no effects of the positions of the signposts (pointing up or down, $F(1, 150) = 1.92$, $p = .17$, $\eta p^2 = .01$). To the question about what the signposts were and which one meant further, 96% of 4-year-olds, 92% of 5-year-olds, 96% of 6-year-olds, and 100% of 8-, 11-year-olds and adults responded correctly (e.g., "they're arrows, that [5 footsteps sign] means further because it's got more footprints" or "that's a sign and it has the number 5 on it which means it [the hut] is 5 away from that [the volcano]"). Participants who responded incorrectly were excluded from the analysis of the signposts.

Mental imagery scanning times over different distances

To control for any effects of the signposts on the time-distance linear relationship, the two distances (both 81mm) which had a signpost between each of them were excluded from the analysis. Overall, there was an effect of age, $F(5, 146) = 3.40$, $p = .006$, $\eta p^2 = .10$. Four-year olds took less time to scan than 11-year-olds ($p = .01$). The other age groups did not differ (all *p*s > .11) (Table 1).

To examine whether all ages showed a linear increase in scanning times with increasing distance, we calculated the best-fitting linear function by the method-of-least-squares within each age group separately. Scanning times increased linearly with increasing distance for all age groups: 4-year-olds, $R^2 = .03$, $F(1, 142) = 4.26$, $p = .04$; 5-year-olds, $R^2 = .17$, $F(1, 154) = 30.80$, $p < .001$; 6-year-olds, $R^2 = .08$, $F(1, 154) = 12.52$, $p < .001$; 8-year-olds $R^2 = .17$, $F(1, 148) = 30.91$, $p < .001$; 11-year-olds, $R^2 = .27$, $F(1, 148) = 55.09$, $p < .001$; and adults, $R^2 = .53$, $F(1, 154) = 173.55$, $p < .001$ (Table 1).

Table 1

Mental image scanning task: Overall mean scanning times and association of actual distance and scanning time for each age group in Experiment 1.

Age group	4-year-olds	5-year-olds	6-year-olds	8-year-olds	11-year-olds	Adults
Mean (SD)	7165 (4534)	8194 (3756)	10583 (5838)	10264 (5122)	11555 (4264)	10307 (2488)
Intercept	5385	4077	6815	5254	6093	3944
β	.17	.41	.27	.42	.52	.73
t	2.06	5.55	3.54	5.56	7.42	13.17
p	= .04	< .001	< .001	< .001	< .001	< .001

Note. β = standardized beta.

However, on closer inspection of the data (see Figure 2), for the 4-year-olds this relationship was solely due to a large increase in scanning times between the similar distances of 260mm (hut-tree) and 262mm (lighthouse-tree), whilst there was no increase in scanning times between the other distances. When scanning times for the 262mm distance (lighthouse to tree) were removed from the analyses, 4-year-olds no longer showed a time-distance linear relationship, R^2 = .002, F (1, 118) = .22, p = .64. The model did, however, remain significant for all older age groups (all R^2s > .07, ps < .005).

To examine the similarity and developmental trajectory of the time-distance-scanning relationship across age, we calculated the steepness of the slopes of the best fitting lines (i.e., scanning rates) for each participant, and then submitted these slopes to a one-way ANOVA. The mean slopes differed between age groups, F(5, 146) = 4.36, p < .001, ηp^2 = .13. Four-year-olds' slopes (B = 11.66 ms/mm) were less steep than 8- (B = 32.78 ms/mm), 11-year-olds' (B = 35.78 ms/mm) and adults' slopes (B = 41.51 ms/mm) (all ps < .05). There were no further slope differences between the remaining age groups (5-year-olds: B = 26.97 ms/mm; 6-year-olds: B = 24.69 ms/mm), thus, indicating that the scanning time-distance linear relationship did not change from age 5 onwards.

To exclude the possibility that younger children did not show a linear time-distance scanning relationship simply because they failed to understand the task, we examined perception control scanning times. Scanning times generally increased with age, $F(5, 146) = 11.29$, $p < .001$, $\eta p^2 = .28$. Specifically, 4- (*M* = 5821ms), 5- (*M* = 5992ms), 6- (*M* = 7941ms) and 8-year-olds' (*M* = 8522ms) perception control scanning times did not differ (*p*s > .13). Adults (*M* = 11642ms) took longer to scan than all age groups (*p*s < .03) except 11-year-olds (*M* = 10679ms) who in turn took longer to scan than both 4- and 5-year-olds (*p*s < .001).

All ages showed a linear time-distance relationship (all R^2s > .08, *F*s >11.46, *p*s < .001). Further, comparison of slopes revealed an effect of age, $F(5, 146) = 13.59$, $p < .001$, $\eta p^2 = .32$: 4-year-olds'slopes were less steep than all age groups (*p*s < .03) except 5-year-olds'. Further adults' slopes were steeper than all younger age groups (all *p*s < .001) except 11-year-olds' (*p* = .08).

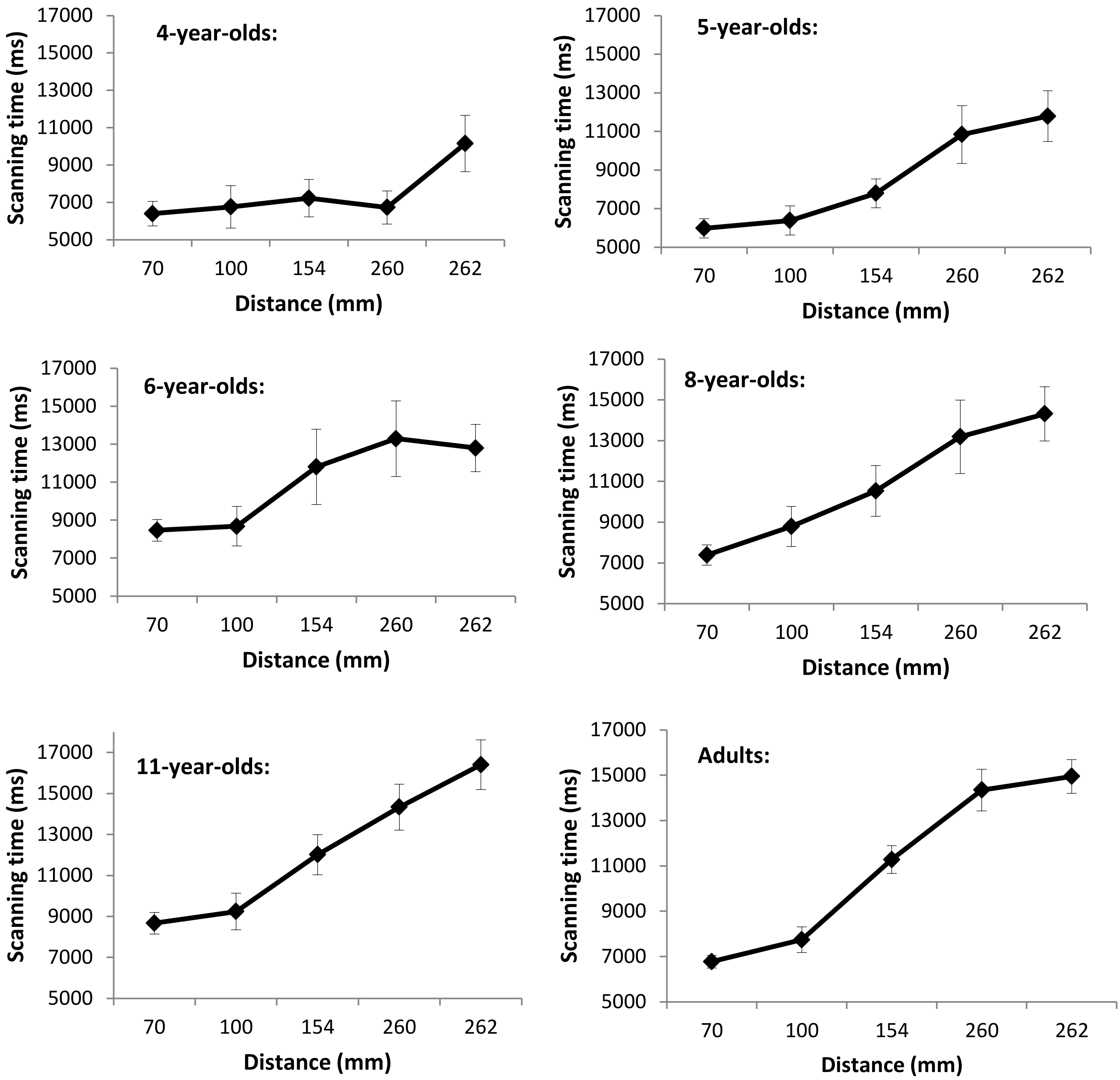

Figure 2. *Time to scan the different distances for each age group in Experiment 1*

Effect of signposts on scanning times

Finally, we examined the effect of the two signposts on scanning times. A 2 (sign: 1 vs. 5 footsteps) x 6 (age) mixed ANOVA revealed a main effect of sign, $F(1, 142) = 4.51$, $p = .04$, $\eta p^2 = .03$. Participants showed longer scanning times for the 5 footsteps sign (*M* = 7841, *SD* = 4453) compared to the 1 footstep sign (*M* = 7265ms, *SD* = 3959). There was no main effect of age, $F(5, 142) = 1.08$, $p = .382$, $\eta p^2 = .04$, but there was a sign x age interaction, $F(5, 142) = 2.40$, $p < .05$, $\eta p^2 = .08$. Only 8-, 11-year-olds and adults showed longer scanning times for the 5 footsteps sign than the 1 footstep sign, whilst 4-, 5- and 6-year-olds showed no difference (Table 2).

Table 2

Mean scanning times for each age group for each of the distances showed by the 1 and the 5 footsteps signposts in Experiment 1.

Age group	4-year-olds	5-year-olds	6-year-olds	8-year-olds	11-year-olds	Adults
1 footstep Mean (SD)	7500 (4938)	6696 (4411)	7801 (4335)	7510 (4139)	7947 (3307)	6175 (2327)
5 footsteps Mean (SD)	6708 (5547)	6230 (4033)	8371 (5023)	8524 (5047)	9263 (3895)	7795 (2201)

This pattern was not present on the perception control trials, where there was no effect of sign, $F(1, 142) = .04$, $p = .84$, $\eta p^2 < .001$, or sign x age interaction, $F(5, 142) = 1.22$, $p = .30$, $\eta p^2 = .04$. Perception control sign-post scanning times increased with age, $F(5, 142) = 5.00$, $p < .001$, $\eta p^2 = .15$, particularly, between 4-year-olds and both 11-year-olds and adults (*p*s < .04), 5-year-olds and both 11-year-olds and adults (*p*s < .006).

Discussion Experiment 1

Two important findings emerged from Experiment 1. First, 5- but not 4-year-olds clearly showed the linear time-distance scanning effect previously observed in adults, indicating that children's mental images may be depictive in format from a young age. Second, children younger than 8 years were not affected by the misleading sign-post information, despite understanding what it meant.

Although a linear-distance relationship was found in mental scanning for all age groups, the finding was less robust in 4-year-olds. A possible explanation is that working memory demands may have interfered with young children's scanning more than older age groups. This would coincide with improvements in related cognitive processes such as visual working memory (e.g., Riggs, McTaggart, Simpson & Freeman, 2006), memory for spatial locations (see Plumert & Spencer, 2007), accuracy in coding distance in spatial navigation tasks (Bullens, Nardini, Doeller, Braddick, Postma, & Burgess, 2010), and spatial scaling abilities (Frick & Newcombe, 2012) (but see Möring, et al., 2014 for linear effects in spatial scaling in 4-year-olds). Thus, it is possible that successful scanning emerges between 4 and 5 years and is driven by developments in working memory capacity. Therefore, 4-year-olds' current scanning times are hard to interpret and no inferences on mental imagery format can be drawn for this age group. In contrast, 5 year-olds' scanning times clearly revealed a linear-distance relation, indicating that they may preserve metric properties in their mental images. To our knowledge this is the first demonstration of a linear time-distance relation in children's mental images in a scanning paradigm. It supports the notion that our mental images are depictive in nature (Kosslyn et al., 2003) and that this is already evident in children. However, to be fully sure that linear scanning effects imply a quasi-pictorial nature of mental images, we need to check whether similar scanning effects emerge when participants are not instructed to scan. Therefore, in Experiment 2 a 'Rapid Verification task' was implemented (Kosslyn et al., 1978). This required participants to decide whether two landmarks were present rather than to scan between them. If the linear scanning-distance effect in the island task genuinely reflects the depictive nature of mental images across ages then it should not emerge under rapid verification which does not require mental scanning.

A further interesting finding from Experiment 1 was that 8-year-olds' and older children's scanning times were affected by the misleading sign-post information, a phenomenon previously found in adults (Richman et al., 1979). Thus, older children's and adult's mental images are affected by top-down influences. That there was no effect of the signposts on scanning times for the perception control task for any of the age groups indicates that the difference observed in the imagery trials reflected more than just task demands (Pylyshyn, 2003; Richman et al., 1979). Despite being aware of the different distances indicated by the sign-posts, participants were not perceptually influenced by their misleading content when the landmarks were fully visible during perception control trials. If imagery performance underlay tacit knowledge of how a scene looks, then one would expect participants to show similar behaviour in both perception and imagery trials. As this was not case, a tacit knowledge explanation can be ruled out for the sign-post effects in imagery.

The question, however, arises why children younger than 8 years were not affected by the misleading sign posts. There are three potential explanations for this latter finding, which Experiment 2 addresses. Young children may understand the nature of sign-post information but not use this information spontaneously in a scanning task. Alternatively, young children may have more difficulty thinking simultaneously about the sign-posts and the distance information, or children at different ages may weight one source of information over another (signposts *vs*. distance). To address these alternatives, children were prompted towards the difference in sign-post distance by asking the conceptual check question ("which one of these is further?") before the scanning trials and were asked to recall what was written on each of the sign-posts (sign-post recall) at the end of the experiment. If children younger than 8 years have difficulty thinking simultaneously about sign-posts and distance or weight them differently during scanning, then prompting should have no effect. Additionally, if distance information is weighted over and above sign-post information one would also expect them to have difficulty recalling what was written on the original sign-posts. Alternatively, if young children understand the nature of sign-posts but do not spontaneously use this information in a distance task then prompting should have an effect and one would expect sign-post effects also to emerge in younger children.

Experiment 2

Method

Participants

Overall 130 participants (73 females) took part: 27 5-year-olds (*M* = 65 months, range = 58-73), 27 7-year-olds (*M* = 87 months, range = 75-93), 26 9-year-olds (*M* = 114 months, range = 107-126), 25 11-year-olds (*M* = 137 months, range = 128-141), and 26 adults (*M* = 37 years, range = 20-70). As in Experiment 1, the youngest children were in their first year of formal schooling, and the older groups in their second year and so on, but for Experiment 2 testing was conducted towards the end of the school year and so the mean ages are somewhat higher.

Materials and Procedure

The materials and procedure were exactly the same as in Experiment 1 with the following three exceptions. The sign-post conceptual question was posed before the imagery trials, a 'Rapid Verification task' was added to the procedure and a sign-post recall phase was implemented.

Island Scanning. During the 45 second period in which the island was studied and its landmarks were named, participants were explicitly prompted towards the difference in sign-post length by asking the conceptual check question, what each signpost meant and which one was further. The rest of the procedure was exactly the same as in Experiment 1.

Rapid Verification Task. This followed after the island perception control phase. In this task participants heard 10 pre-recorded pairs of words (the first two were practice trials, the remaining eight were experimental trials). The first word in each pair was always a landmark present on the map (e.g., palm tree). The second word was either a landmark also on the map (pond, volcano, hut, palm tree, lighthouse), or a landmark not present on the map (waterfall, bushes, cave, rock, umbrella). First, participants viewed the island map for 45 seconds. Then they were instructed to close their eyes and imagine the map in their heads. Once they heard the first word, participants were instructed to 'try and imagine what (e.g.) volcano looks like in your head'. They were then told that the second word would be something that was either present or not present on the map. The experimenter gave the example 'volcano' for something that could be present and 'chair' was the example used for something that was not present on the map. Participants were asked to give their own examples to check that they understood the task. Then they were presented with the first landmark (e.g., palm tree). When they heard the second landmark (e.g., pond) participants were instructed to answer, as quickly as they could, 'Yes' if the landmark was on the map or 'No' if the landmark was not on the map. As soon as the participant had answered the experimenter pressed a button on the laptop to indicate a 'yes' or 'no' answer and the second practise trial followed. This was then continued with the remaining 8 experimental trials.

Sign-Post Recall phase. At the end of the experiment participants were shown a power point slide of the two signposts side by side, however, the number and footsteps had been removed. The experimenter said 'Look these are the signs you saw on the island earlier. Can you remember what was written on them?' Participants' correct or incorrect recall was recorded.

Results Experiment 2

Bonferroni confidence interval adjustments and post-hoc analyses were used throughout. Outlier response times that were 2 standard deviations from the mean per distance and age group were removed.

Preliminary analyses

To the conceptual question about what the signposts were and which one meant further, 96% of 5-year-olds and 100% of the remaining participants responded correctly. Additionally in the signpost recall phase, 89% of 5-year-olds, 92% of 7-year-olds, 92% of 9-year-olds, 88% of 11-year-olds, and 87% of adults, correctly recalled both numbers written on the signposts and there was no difference between age groups, $F(4, 127) = .16$, $p = .96$, $\eta p^2 = .005$. Participants ($N = 17$) who responded incorrectly either on the conception check or signpost recall or both were excluded from the analysis.

There were no effects of the positions of the signposts (pointing up or down), $F(1, 74) = 2.35$, $p = .13$, $\eta p^2 = .03$.

Mental imagery scanning times over different distances

To control for any effects of the signposts on the time-distance linear relationship, the two distances (both 81mm) which had a signpost between each of them were excluded from the analysis. Scanning time increased with increasing age, $F(4, 112) = 11.37$, $p < .001$, $\eta p^2 =.30$. Five-year-olds did not differ from 7-year-olds but took less time to scan than older children and adults (all *p*s < .005) (Table 3). Seven-year-olds were equal to 9-year-olds but took less time than both 11-year-olds and adults (*p*s < .02). There were no differences in scanning times from 9-year-olds upwards (all *p*s > .21).

To examine the linearity of the distance-scanning time relation, scanning times were submitted to linear regressions for each age group separately. Scanning times increased linearly with increasing distance for all age groups (Figure 3): 5-year-olds, $R^2 = .12$, *F*(1,

135) = 18.67, p < .001; 7-year-olds, R^2 = .08, F(1, 142) = 11.58, p < .001; 9-year-olds, R^2 = .21, F(1, 139) = 37.02, p < .001; 11-year-olds R^2 = .11, F(1, 131) = 16.81, p < .001; and adults, R^2 = .42, F(1, 115) = 82.39, p < .001 (Table 3).

Table 3

Mental image scanning task: Overall mean scanning times and association of actual distance and scanning time for each age group in Experiment 2.

Age group	5-year-olds	7-year-olds	9-year-olds	11-year-olds	Adults
Mean (SD)	6071 (4175)	8585 (4025)	10644 (2736)	13658 (5987)	12813 (4342)
Intercept	2661	6173	7221	8541	4992
β	.35	.28	.46	.34	.65
t	4.32	3.40	6.08	4.10	9.08
p	< .001	< .001	< .001	< .001	< .001

Note. β = standardized beta.

To compare the trajectory of the time-distance-scanning relation between age groups (Figure 3), the steepness of the slopes was calculated for each participant and then submitted to a one-way ANOVA. The mean slopes differed between age groups, F(4, 112) = 7.19, p < .001, ηp^2 = .21. The three youngest age groups' slopes (5-year-olds: B = 18.23 ms/mm; 7-year-olds: B = 19.43 ms/mm; 9-year-olds: B = 22.22 ms/mm) did not differ from each other (all *p*s > .99) but were all less steep than adults' slopes (B = 50.21 ms/mm) (all *p*s < .002). There was no difference between 10-year-olds' slopes (B = 35.97 ms/mm) and the remaining age groups (all *p*s > .13) (Table 3).

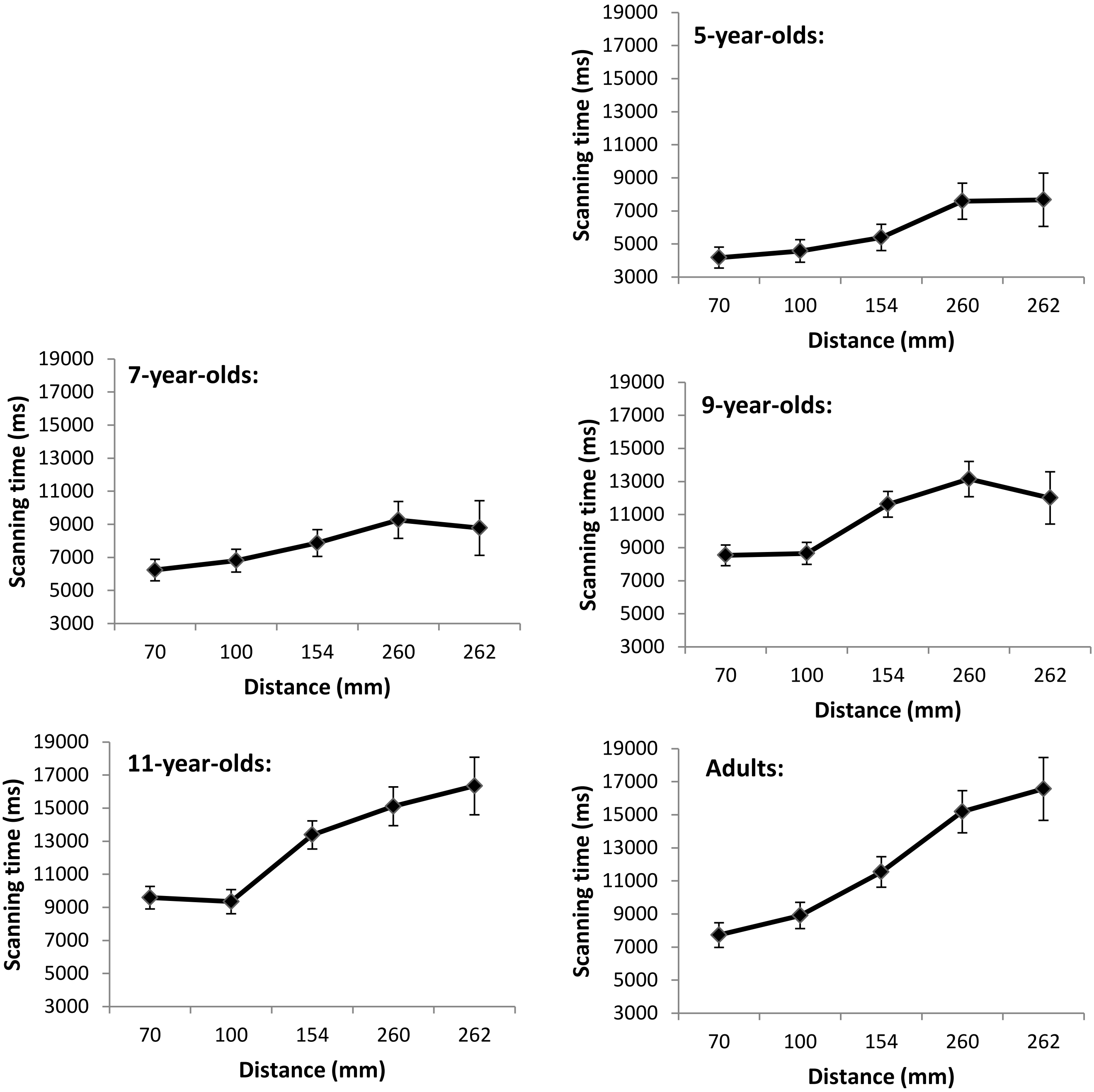

Figure 3. *Time to scan the different distances for each age group in Experiment 2*

A similar result pattern to the imagery trials was found for perception control trials. Scanning times generally increased with age, $F(4, 111) = 32.42$, $p < .001$, $\eta p^2 = .55$, where 5-year-olds (*M* = 3449ms) scanned faster than all older age groups (*p*s < .001) except 7-year-olds (*M* = 6520ms, *p* = .10) who in turn scanned faster than all older age groups (*p*s < .003). Moreover, 9-year-olds (*M* = 10795ms) scanned faster (*p*s < .05) than both 11-year-olds (*M* = 14216ms) and adults (*M* = 14627ms) where the latter two did not differ. All ages showed a linear time-distance relationship (all R^2s > .08, *F*s >12.27, *p*s < .001). Further, comparison of slopes revealed an effect of age, $F(4, 110) = 30.72$, $p < .001$, $\eta p^2 = .56$. Slopes increased in steepness between all adjacent age groups (all *p*s < .05) except between 5- and 7-year-olds (*p* = 1) and 11-year-olds and adults (*p* = .16).

Effect of signposts on scanning times

Finally, the effect of the two signposts on scanning times was examined. A 2(sign: 1 vs. 5 footsteps) x 5(age) mixed ANOVA revealed a main effect of sign, $F(1, 71) = 21.00$, $p < .001$, $\eta p^2 = .23$. Participants showed longer scanning times for the 5 footsteps sign (*M* = 7686, *SD* = 3383) compared to the 1 footstep sign (*M* = 6176ms, *SD* = 2128). There was a main effect of age, $F(4, 71) = 8.96$, $p < .001$, $\eta p^2 = .34$, where 5-year-olds scanned equally fast as 7-year-olds but faster than 9-, 11-year-olds and adults (all *p*s < .004) (Table 4). Additionally 7-year-olds scanned faster than adults (*p* = .01). There were no further differences between age groups (all *p*s > .10). There was no sign x age interaction, $F(4, 71) = .29$, $p = .88$, $\eta p^2 = .02$ (Table 4).

On the perception control trials, there was no effect of sign, $F(1, 100) = .02$, $p = .90$, $\eta p^2 < .001$, or sign x age interaction, $F(1, 100) = 1.67$, $p = .16$, $\eta p^2 = .06$. Participants' perception control signpost scanning times increased with age, $F(4, 100) = 31.30$, $p < .001$, $\eta p^2 = .56$, particularly between 5-year-olds and all older age groups (all *p*s < .001) except 7-

year-olds. Signpost control scanning time also increased between 7-year-olds and all older age groups (all *p*s < .001) and between 9-year-olds and adults (*p* < .001).

Table 4

Mean scanning times for each age group for each of the distances showed by the 1 and the 5 footsteps signposts in Experiment 2.

Age group	5-year-olds	7-year-olds	9-year-olds	11-year-olds	Adults
1 footstep Mean (SD)	4337 (1920)	5341 (1615)	7285 (2076)	7141 (1327)	7773 (914)
5 footsteps Mean (SD)	5653 (3497)	6953 (3131)	8787 (2617)	8226 (2494)	10090 (3817)

Rapid verification

Accuracy. All age groups performed at ceiling in verifying whether a landmark was present or not (5-year-olds: *M* = .97; 7-year-olds: *M* = .98; 9-year-olds: *M* = .99; 11-year-olds: *M* = 1.00; Adults: *M* = 1.00), therefore, no further statistical analyses were conducted.

Response Time. Age differences in mean response times in landmark verification were examined in a one-way ANOVA. Participants' response times decreased with age, $F(4, 129) = 7.84$, $p < .001$, $\eta p^2 = .20$, where 5-year-olds (*M* = 912 ms) responded more slowly than all older age groups (9-year-olds: *M* = 313 ms; 11-year-olds: *M* = 227 ms; adults: *M* = 193 ms) (*p*s < .002) except 7-year-olds (*M* = 646 ms) who in turn responded more slowly than adults (*p* = .05). The remaining age groups did not differ.

For the 4 test trials containing landmark pairs that were present, we examined whether there was a relation between landmark verification times and their distance on the map. There were no linear increases in verification times with increasing distance for all age groups: 5-

year-olds, $R^2 = .06$, $F(1, 115) = .45$, $p = .50$; 7-year-olds, $R^2 = .05$, $F(1, 103) = .30$, $p = .58$; 9-year-olds, $R^2 = .15$, $F(1, 103) = 2.18$, $p = .14$; 11-year-olds $R^2 = .08$, $F(1, 91) = .55$, $p = .46$; and adults, $R^2 = .06$, $F(1, 103) = .39$, $p = .53$. Thus, when the task requires verification rather than mental scanning, the linear time-distance relation disappeared.

Discussion Experiment 2

As in Experiment 1 findings revealed a linear increase in scanning time with increasing distance across all age groups from age 5 onwards, suggesting that when children and adults scan a scene they preserve metric properties in their mental images. This interpretation is further strengthened by the finding that when the task does not require scanning but verification of whether a landmark was or was not present (rapid verification task), then the linear time-distance effect disappears. This lack of effect was found for all child age groups and adults and adds to results from the adult literature so far demonstrating these effects in adults (Kosslyn et al., 1978). Taken together findings across both experiments indicate that children's mental images are quasi-pictorial in nature, previously only documented in adult scanning tasks (Borst & Kosslyn, 2008; Borst & Kosslyn, 2010; Kosslyn et al., 1978; Kosslyn et al., 2003).

One difference from Experiment 1 is that overall scanning time increased with age in both imagery and perception trials whereas in Experiment 1 only 4-year-olds, who did not show a linear increase, differed in absolute scanning times. This was somewhat unanticipated but because 5- and 7-year-olds scanned faster in both imagery and scanning trials, it may suggest that their representation of Percy the Pirate's speed was faster than that of older children and adults. Moreover, the finding of a decrease in response time with age in rapid verification suggests that younger children are not faster *per se* but supports the notion that young children differ in their speed representation (Gross, Soken, Rosengren, Pick, Pillow, & Melendez, 1991; Smits-Engelsman & Wilson, 2013).

In contrast to Experiment 1, when participants were prompted to the difference in signpost distances before the imagery trials, then 5- to 8-year-olds' scanning times were also affected by the misleading signpost information. This finding, together with the lack of an effect in these age groups in Experiment 1, indicates that young children do not use conceptual information such as signposts spontaneously in a distance task but require prompting to do so. Thus, children younger than 8 years have *apriori* no difficulty in thinking simultaneously about signposts and distance. Further, as children had no difficulties in recalling what was written on the original signposts (signpost recall) it is unlikely that they weight distance and signpost information differently during scanning. Overall, findings of Experiment 2 suggest that even 5-year-olds' mental scanning performance can be susceptible to top-down factors. The notion that this signpost effect reflects susceptibility to top-down factors in mental imagery (Kosslyn et al., 2003) rather than task demands (Pylyshyn et al., 2003) is further strengthened by the finding that participants were not susceptible to the misleading signposts under perception control when the island was fully visible.

General Discussion

To our knowledge this is the first study to provide insight into the format of children's mental images in a mental scanning paradigm. First, by age 5 children show the time-distance scanning effect previously observed in adults, indicating that they represent images depictively from a young age. This supports the notion that young children preserve spatial properties in their mental image, previously found in mental rotation paradigms (Estes, 1998; Frick, et al., 2009; Frick et al., 2014; Kosslyn, et al., 1990; Marmor, 1975) and in a recent study on spatial scaling (Möring, et al., 2014). Second, young children's mental imagery performance can be affected by top-down influences, indicating that their mental images are susceptible to conceptual factors.

No research to date has examined if and when young children show the linear time-distance scanning relationship in their mental scanning. That the 4-, but not the 5-year-olds, failed to show a linear-time distance relationship (Experiment 1) indicates that the ability to scan mental images undergoes rapid developments around this age. It is possible that this youngest age group had difficulty holding the island map in mind whilst scanning at the same time, and this coincides with improvements in related cognitive processes such as visual working memory (e.g., Riggs, et al., 2006), memory for spatial locations (Plumert & Spencer, 2007), coding distance in spatial navigation tasks (Bullens, et al., 2010), and the ability to scale distances (Frick & Newcombe, 2012; Möring, et al., 2014). The developmental cognitive mechanisms underlying why 4-, but not 5-year-olds' scanning performance is so poor is an interesting avenue for future research.

While children showed a linear time-distance relationship from age 5, their imagery performance was also susceptible to top-down influences such as misleading distance markers when prompted towards the distance difference (Experiment 2). The finding that there was no effect of the signposts on scanning times for the perception control task (Experiments 1 and 2) also indicates that the difference we observed in the imagery trials reflects more than just task demands (e.g., Pylyshyn, 2003; Richman et al., 1979). Overall, this indicates an early reliance on the perceptual properties of images during mental imagery, with children utilising conceptual information in their mental imagery performance as previously found analogously in visual perceptual phenomena such as visual ambiguous stimuli (Doherty & Wimmer, 2005; Wimmer & Doherty, 2011). Thus, not only is adults' mental imagery performance susceptible to top-down influences (Mast & Kosslyn, 2002; Peterson, et al., 1992) but also children's (current experiments) and this emerges as soon as children show the linear time-distance scanning effect.

The developmental approach makes unique contributions to the imagery debate of whether the time-distance scanning relationship shown in the island task is simply a result of task demands (Pylyshyn, 2002; 2003), with participants inferring from the experimental situation the expected results and using their tacit knowledge about times and distance or underlies mental representation of spatial properties (Kosslyn et al., 1978; Kosslyn et al., 2003). Because metacognitive abilities are still developing (e.g., Bjorklund, 1987; Bjorklund & Douglas, 1997; Flavell et al., 2000; Kee, 1994), it is unlikely that particularly younger children would succumb to the task demands and perform the task by imagining how it would look if they saw it, as Pylyshyn (2002; 2003) argues. Thus, our findings indicate that children are in fact preserving metric properties in their mental images rather than simply applying their tacit knowledge and this is already the case for 5-year-olds; the age at which their mental images also begin to be influenced by top-down processes. In sum, this research provides an important contribution to theory for understanding the format and development of mental scanning.

References

Beech, J. R. (1979). Scanning visual images: implications for the representation of space. *Perception*, *8*, 621–628. doi:10.1068/p080621

Bjorklund, D. (1987). How age changes in knowledge base contribute to the development of children's memory: An interpretive review. *Developmental Review, 7*, 93-130. doi:10.1016/0273-2297(87)90007-4

Bjorklund, D. F., & Douglas, R. N. (1997). The development of memory strategies. In M. L. Courage & N. Cowan (Eds.), *The Development of Memory in Childhood* (pp. 201-246). New York, US: Psychology Press.

Borst, G., & Kosslyn, S. M. (2008). Visual mental imagery and visual perception: Structural equivalence revealed by scanning processes. *Memory & Cognition*, *36*, 849-862. doi: 10.3758/MC.36.4.849

Borst, G., & Kosslyn, S. M. (2010). Individual differences in spatial mental imagery. *The Quaterly Journal of Experimental Psychology*, *63*, 2031-2050. doi: 10.1080/17470211003802459

Borst, G., Kosslyn, S. M., & Denis, M. (2006). Different cognitive processes in two image-scanning paradigms. *Memory & Cognition, 34*, 475-490. doi: 10.3758/BF03193572

Bullens, J., Nardini, M., Doeller, C. F., Braddick, O., Postma, A., & Burgess, N. (2010). The role of landmarks and boundaries in the development of spatial memory. *Developmental Science, 13,* 170-180. doi: 10.1111/j.1467-7687.2009.00870.x

Denis, M., & Carfantan, M. (1985). People's knowledge about images. *Cognition, 20*, 49–60. doi:10.1016/0010-0277(85)90004-6.

Denis, M., & Kosslyn, S. M. (1999). Scanning visual mental images: A window on the mind. *Cahiers de Psychologie Cognitive/Current Psychology of Cognition*, *18*, 409-465.

Doherty, M. J., & Wimmer, M. C. (2005). Children's understanding of ambiguous figures: Which cognitive developments are necessary to experience reversal? *Cognitive Development, 20,* 407-421. doi:10.1016/j.cogdev.2005.05.003

Estes, D. (1998). Young Children's Awareness of Their Mental Activity: The Case of Mental Rotation. *Child Development*, *69*(5), 1345. doi:10.2307/1132270

Finke, R. A., & Pinker, S. (1983). Directional scanning of remembered visual paths. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 398-410. doi: 10.1037/0278-7393.9.3.398

Flavell, J. H., Green, F. L., & Flavell, E. R. (2000). Development of children's awareness of their own thoughts. *Journal of Cognition and Development, 1*, 97-112. doi: 10.1207/S15327647JCD0101N_10

Frick, A., Daum, M. M., Walser, S., & Mast, F. (2009). Motor processes in children's mental rotation. *Journal of Cognition and Development, 10,* 18-40. doi: 10.1080/15248370902966719

Frick, A., Möhring, W., & Newcombe, N. (2014). Development of mental transformation abilities. *Trends in Cognitive Sciences, 18*, 536-542. doi: 10.1016/j.tics.2014.05.011

Frick, A. & Newcombe, N. S. (2012). Getting the big picture: Development of spatial scaling abilities. *Cognitive Development, 27*, 270-282. doi: 10.1016/j.cogdev.2012.05.004

Ghetti, S., Mirandola, C., Angelini, L., Cornoldi, C., & Ciaramelli, E. (2011). Development of subjective recollection: Understanding of and introspection on memory states. *Child Development, 82*, 1954-1969. doi:10.1111/j.1467-8624.2011.01645.x

Gregory, R. L. (2009). *Seeing through illusions.* New York: Oxford University Press.

Gross, D., Soken, N., Rosengren, K. S., Pick, A. D., Pillow, B. H., & Melendez, P. (1991). Children's understanding of action lines and the static representation of speed of locomotion. *Child Development, 62*, 1124-1141. doi: 10.1111/j.1467-8624.1991.tb01594.x

Iachini, T., & Ruggiero, G. (2010). The role of visual experience in mental scanning of actual pathways: Evidence from blind and sighted people. *Perception, 39*, 953-969. doi: 10.1016/j.bandc.2005.04.004

Kee, D. W. (1994). Developmental differences in associative memory: Strategy use, mental effort, and knowledge access interactions. In H. W. Reese (Ed.), *Advances in Child Development and Behavior* (Vol. 25). San Diego, CA, US: Academic Press.

Kosslyn, S. M. (1980). *Image and mind*. Cambridge, MA: Harvard University Press.

Kosslyn, S. M. (1994). *Image and brain: The resolution of the imagery debate*. *Cambridge*. Cambridge, MA: The MIT Press.

Kosslyn, S. M. (2006). Mental image. In C. A. Jones (Ed.), *Sensorium: Embodied experience, technology, and contemporary art*. Cambridge, MA: MIT Press.

Kosslyn, S. M., Ball, T. M., & Reiser, B. J. (1978). Visual images preserve metric spatial information: Evidence from studies of image scanning. *Journal of Experimental Psychology: Human Perception and Performance*, *4*, 47-60. doi:10.1037/0096-1523.4.1.47

Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2003). Mental imagery: against the nihilistic hypothesis. *Trends in Cognitive Sciences*, *7*, 109-111. doi:10.1016/S1364-6613(03)00025-1

Kosslyn, S. M., Margolis, J. A., Barrett, A. M., Goldknopf, E. J., & Daly, P. F. (1990). Age differences in imagery abilities. *Child Development*, *61*, 995-1010. doi:10.2307/1130871

Lobmaier, J. S., Mast, F. W., & Hecht, H. (2010). For the mind's eye the world is two-dimensional. *Psychonomic Bulletin & Review, 17*, 36-40. doi:10.3758/PBR.17.1.36

Long, G. M., & Toppino, T. C. (2004). Enduring Interest in Perceptual Ambiguity: Alternating views of reversible figures. *Psychological Bulletin, 130*, 748-768. doi:10.1037/0033-2909.130.5.748.

Lyons, K. E., & Ghetti, S. (2010). Metacognitive development in early childhood: New questions about old assumptions. In A. Efklides & P. Misialida (Eds.), *Trends and prospects in metacognition research* (pp. 259-278). New York: Springer Science and Business Media.

Marmor, G. S. (1975). Development of kinetic images: When does the child first represent movement in mental images? *Cognitive Psychology*, *7*(4), 548–559. doi:10.1016/0010-0285(75)90022-5.

Mast, F. W., & Kosslyn, S. M. (2002). Visual mental images can be ambiguous: Insights from individual differences in spatial transformation abilities. *Cognition, 86*, 57-70. doi:10.1016/S0010-0277(02)00137-3.

Möhring, W., Newcombe, N. S., & Frick, A. (2014). Zooming in on spatial scaling: preschool children and adults use transformations to scale spaces. *Developmental Psychology, 50*, 1614-1619.

Perner, J., Kloo, D., & Rohwer, M. (2010). Retro- and prospection for mental time travel: Emergence of episodic remembering and mental rotation in 5- to 8-year-old children. *Consciousness and Cognition*, *19*, 802-815. doi: 10.1016/j.concog.2010.06.022

Peterson, M. A., Kihlstrom, J. F., Rose, P. M., & Glisky, M. L. (1992). Mental images can be ambiguous: Reconstruals and reference-frame reversals. *Memory & Cognition*, *20,* 107-123. doi:10.3758/BF03197159.

Pinker, S. & Kosslyn, S. M. (1978). The representation and manipulation of three-dimensional space in mental images. *Journal of Mental Imagery*, *2*, 69-84.

Plumert, J. M., & Spencer, J. P. (2007). *The Emerging Spatial Mind.* New York, US: Oxford University Press.

Pylyshyn, Z. W. (1981). The imagery debate: Analogue media versus tacit knowledge. *Psychological Review, 88*, 16-45. doi:10.1037/0033-295X.88.1.16

Pylyshyn, Z. W. (2002). Mental imagery: In search for a theory. *Behavioral and Brain Sciences*, *25,* 157-237. doi: 10.1017/S0140525X02000043

Pylyshyn, Z. W. (2003). Mental imagery: In search of a theory. *Behavioral and Brain Sciences*, *25,* 157-238. doi:10.1017/S0140525X02000043

Richman, C. L., Mitchell, D. B., & Reznick, J. S. (1979). Mental travel: Some reservations. *Journal of Experimental Psychology: Human Perception and Performance*, *5*, 13-18. doi:10.1037/0096-1523.5.1.13

Riggs, K. J., McTaggart, J., Simpson, A., & Freeman, R. P. J. (2006). Changes in the capacity of visual working memory in 5- to 10-year-olds. *Journal of Experimental Child Psychology*, *95*, 18-26. doi:10.1016/j.jecp.2006.03.009

Schneider, W. (1986). The role of conceptual knowledge and metamemory in the development of organizational processes in memory. *Journal of Experimental Child Psychology*, *42*, 218-236. doi:10.1016/0022-0965(86)90024-X

Shepard, R. N., & Cooper, L. A. (1982). *Mental images and their transformations.* Cambridge, MA: The MIT Press.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science, 171,* 701-703.

Smits-Engelsman, B. C. M., & Wilson, P. H. (2013). Age-related changes in motor imagery from early childhood to adulthood: Probing the internal reprsentation of speed-accuracy trade-offs. *Human Movement Science, 32*, 1151-1162. doi: 10.1016/j.humov.2012.06.006

Wimmer, M. C., & Doherty, M. J. (2011). The development of ambiguous figure perception. *Monographs of the Society for Research in Child Development, 76(1),* 1-130.