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Developmental Differences in the Influence of Distractors on Maintenance in Spatial Working Memory

Anne R. Schutte,

Center for Brain, Biology, and Behavior and the Department of Psychology, University of Nebraska-Lincoln

Brian A. Keiser, and

Children, Youth, and Family Studies, University of Nebraska-Lincoln

Heidi L. Beattie

Department of Psychology, Troy University, Troy, AL.

Abstract

This study examined whether attention to a location plays a role in the maintenance of locations in spatial working memory in young children as it does in adults. This study was the first to investigate whether distractors presented during the delay of a spatial working memory task influenced young children's memory responses. Across two experiments, 3- and 6-year-olds completed a spatial working memory task featuring a static target location and distractor location. Results indicated a change between 3 and 6 years of age in how distractors influenced memory. Six-year-olds' memory responses were biased away from a distractor that was close to the target location and on the outside of the target location relative to the center of the monitor. Distractors that were far from the target or that were toward the center of the monitor relative to the target location had no effect. Three-year-olds' responses were biased toward a distractor when the distractor was on the outside of the target location and farther from the target. Distractors that were near the target location or toward the center of the monitor had no effect. These biases provide evidence that young children's maintenance of a location in memory is influenced by attention.

Executive functions (EF) are higher-level cognitive processes that allow for adaptive, goal-directed behaviors that can override more automatic responses. Miyake and colleagues (2000) examined the structure of executive functions in adults and found three separable, but related, EF components: shifting, inhibition, and information updating and monitoring, which has been interpreted as working memory. The focus of this study is on the working memory component of executive function. Working memory temporarily maintains information in memory that is necessary for the completion of a variety of different types of tasks. It is an important skill for children to develop in order to be successful in school and in life. For example, working memory skills in typically developing school age children predict inattentive, off-task behavior in their everyday environment (Lui & Tannock, 2007). Understanding the relationship between attention and working memory and how the

relationship changes over development is critical for understanding the development of executive function.

Attention has been characterized as being made up of three networks: alerting, orienting, and executive control (Peterson & Posner, 2012; Posner & Peterson, 1990). The executive control network exerts top-down control over cognitive processes and is related to EF. Studies of EF in adults suggest that although components of EF are separable, there is a common factor influencing all three components (Miyake et al., 2000). Executive attention has been proposed to be the common factor influencing all components of EF (Baddeley, 1986; Norman & Shallice, 1986; Shallice, 1988), because executive attention has been found to be related to the components of EF (e.g., Kane, Bleckley, Conway, A., & Engle, 2001). In addition, several models of the development of executive function propose that the development of attentional control underlies the development of EF (Posner & Rothbart, 1998; Garon, Bryson, & Smith, 2008). For example, Garon, Bryson, and Smith (2008) proposed that the development of the attention system and the development of the connections between the attention system and the areas of the brain involved in EF are what lead to the development of EF in preschool. In support of this proposal, Reck and Hund (2011) found that sustained attention predicted inhibitory control in preschoolers. In addition, work in adults suggests that attention is directly related to working memory (Awh & Jonides, 2001; Engle, Kane, & Tuholski, 1999).

There is a large body of behavioral and neuroimaging evidence indicating that in adults there is a strong link between spatial attention and spatial working memory. Spatial working memory involves the maintenance of one or more spatial locations in working memory. In adults, attention influences both perceptual encoding in spatial working memory and the maintenance of locations in spatial working memory (see Awh, Vogel, & Oh, 2006, for a review). A person uses attention to select a location in space in order to process stimuli at that location. This type of attention is called spatial selective attention. Attention is driven by either a bottom-up, stimulus-driven process, which has been labeled exogenous attention, or a top-down process, which has been termed endogenous attention. In stimulus-driven selection, attention is oriented to a stimulus due to a particularly salient property of the stimulus that grabs attention (e.g., an abrupt onset of a target in the visual field). In top-down selection, spatial attention is oriented to a location based on the person's goals and intentions. Spatial selective attention is an endogenous form of attention.

In addition to the role spatial selective attention plays in the encoding of a location in spatial working memory, Smyth and Scholey (1994) proposed that covert shifts of spatial selective attention act as a rehearsal mechanism in spatial working memory similar to the way covert articulation acts as a rehearsal mechanism in verbal working memory. This proposal has been expanded by Awh and colleagues (Awh et al., 1999; Awh, Jonides, & Reuter-Lorenz, 1998; Awh & Jonides, 2001), and has been supported by various studies. For example, adults have trouble maintaining spatial information in memory when required to shift their attention to locations unrelated to the to-be-retained location (Awh et al., 1998). Furthermore, adults increase intentional directed attention to the to-be-retained location when warned ahead of time that distractors will be presented during the memory delay (Awh, Matsukura, & Serences, 2003).

Neuroimaging studies also point to a relationship between maintenance in spatial working memory and spatial selective attention. These studies have found a great deal of overlap in the brain areas activated by spatial attention and those activated by spatial working memory (Awh et al., 1999; Postle, Awh, Jonides, Smith, & D'Esposito, 2004). Specifically, both spatial selective attention and spatial working memory involve a fronto-parietal network (Awh & Jonides, 1998). In addition, Jha (2002) found that ERPs to irrelevant probes presented either early or late during the maintenance interval of a spatial working memory task showed greater amplitudes when they were presented at the location being stored in working memory. This result suggests that attention was engaged at the target location throughout the delay interval.

Additional behavioral research has examined how the abrupt onset of a distractor during the memory delay influences the location of the memory responses. Van der Stigchel, Merten, Meeter and Theeuwes (2007) found that responses to a memorized target location were biased toward the distractor location if the distractor was near the target location. Herwig, Beisert, and Schneider (2010) found the same pattern of results using eye saccades: saccades toward locations being maintained in spatial working memory were biased toward a distractor if the distractor was sufficiently close to the target location.

Despite the relationship between spatial selective attention and spatial working memory maintenance in adults, there has been very little research examining the relationship over development. There is some evidence suggesting spatial working memory and attention are related in children. For example, children clinically diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) also show deficits in spatial working memory on some tasks (Karatekin & Asarnow, 1998), and working memory skills in typically developing school age children predict inattentive, off-task behavior in their everyday environment (Gathercole, Durling, Evans, Jeffcock, & Stone, 2008; Lui & Tannock, 2007). Vicari and colleagues (2004) examined the relationship between spatial memory and attention in a group of preschoolers born full-term and a group born preterm, and, therefore, at higher risk for developing ADHD. The preterm group showed deficits in both the spatial working memory task and the attention task; however, the deficit in attention did not account for the deficit in spatial working memory, suggesting that in children born preterm the deficit in attention was separable from the deficit in spatial working memory.

How spatial working memory and spatial selective attention are related in young children is not clear. Spatial selective attention most certainly plays a role in what items are encoded into spatial working memory and attention may also influence general on-task behavior. However, whether spatial selective attention plays a role in the maintenance of locations in spatial working memory in children is unknown. Although there is evidence of selective attention in children as young as 3 years of age (Sanders, Stevens, Coch, & Neville, 2006), it continues to develop beyond 8 years of age, perhaps even into adulthood (Coch, Sanders, & Neville, 2005). In addition, selective attention involves frontal and parietal areas—areas that show protracted development [see Stevens & Bavelier (2012) for a review]. Given these developmental differences, selective attention may function differently in young children than in adults. Specifically, selective attention may not be developed enough in early childhood to act as a rehearsal mechanism in spatial working memory in the same way as it

does in adults. Rather, in children the executive control of spatial selective attention may be weak, and as a result, their attention to the to-be-retained location in spatial working memory may be shifted more easily by other stimuli in the environment.

The goal of the current study was to examine whether spatial selective attention influences the maintenance of locations in spatial working memory in young children by testing whether distractors affect their memory responses in the same manner as adults. Specifically, we hypothesized that if children use shifts of spatial selective attention to the target location as a rehearsal mechanism, a distractor that is presented during the delay would systematically bias memory responses. If they do not use spatial selective attention to help maintain a location in memory, their responses should not be affected in a systematic manner by the distractor. To test this hypothesis, we adapted a simple spatial working memory task developed by Schutte and Spencer (2002). The task involved remembering the location of a target on a large, otherwise blank, monitor. Specifically, a target appeared for 2000 ms, followed by a memory delay. At the end of the delay the computer said “go” and the child touched the monitor where he/she remembered the target (see Figure 1). To test the relationship between attention and maintenance in spatial working memory, we modified the task by adding a distractor during the delay. If spatial attention and spatial working memory are linked in young children, distractors should bias their memory responses.

Experiment 1a

We tested 3- and 6-year-olds in the spatial working memory task described above. During the delay, we taxed their attention to the memorized location by presenting a distractor, a yellow dot, somewhere on the screen. The distractor was either far from or near the target location (see Figure 2) and appeared for either 1 s or 3 s. We varied the length of time the distractor was present in order to test whether having the distractor present longer would increase the effect of the distractor.

We tested 3- and 6-year-olds, because previous research documented a developmental change in spatial working memory biases in early childhood (e.g., Huttenlocher, Newcombe, & Sandberg, 1994; Schutte & Spencer, 2002, 2009; Spencer & Hund, 2002). When remembering a location in a homogeneous space (such as on a blank computer monitor), the memory responses of young children were biased toward the center of the space while the responses of older children and adults were biased away from the center of the space. These biases have been called “geometric biases,” because they are related to the geometry of the space. The transition in geometric biases occurred between about 3 and 6 years of age, although exactly when depended on the size of the task space (Huttenlocher et al., 1994) and the locations of the targets (Schutte, Simmering, & Ortmann, 2011; Schutte & Spencer, 2009). Based on this developmental difference in geometric biases, we predicted that distractors would result in different biases for the two age groups.

Method

Participants.—Thirty-four 3- and 6-year-olds participated. There were 17 3-year-olds (10 males, 7 females; $M = 3;5.6$, $SD = 2.8$ months), and 17 6-year-olds (10 males, 7 females; $M = 6;3.8$, $SD = 4.0$ months). Participants were recruited by flyers, word-of-mouth and from

previous studies. Participants came from several communities surrounding the local university and were from primarily middle-class families. Participants received a toy of their choice and the participant's parent(s) received \$15 for participating in the study. All parents provided informed consent, and children provided verbal assent. Two additional 3-year-olds participated, but did not complete both tasks so their data were omitted from the analyses. An additional six participants (four 3-year-olds and two 6-year-olds) completed the study, but were not included in the analyses due to a computer error that resulted in their data not being recorded correctly.

Materials/apparatus.—Two flashcards were used for a warm up game. One flashcard had a picture of the distractor, a yellow dot, and the other flashcard had a picture of the target: a spaceship, treasure chest, or bubble. The flashcards corresponded to the game that was played on the computer (see below).

The computerized tasks took place on a large 32 in $\times$ 18 in (82.16 cm $\times$ 46.28 cm) liquid crystal display (LCD) computer monitor (Sharp, Inc.) that was surrounded by black curtains to block the view of any landmarks. The monitor was tilted up 15 degrees from horizontal. The LCD monitor had a resolution of 1024 $\times$ 768 pixels, and a Smartboard touchscreen overlay (SMART Technologies) that responded to the touch of a stylus.

Task and procedure.—A background questionnaire was completed over the phone prior to arrival in the laboratory. The questionnaire asked about birthdate, gender, and handedness. The questionnaire also asked about serious medical conditions including fetal alcohol syndrome, intraventricular or brain hemorrhage/disorder, autistic spectrum disorder, mental retardation, and any non-corrected vision problems. Children with any of these conditions were excluded from the study due to the condition interfering with either their cognitive, visual, or motor ability.

When a participant arrived at the laboratory with his or her parent(s), the informed consent form was explained to the parent(s) while the child played with toys. After the parent signed the consent form, the child was asked if they would like to play a game consisting of “hunting for treasure,” “bursting a bubble,” or “looking for a spaceship.” The three spatial working memory tasks were identical in design, but differed in their “cover story.” Specifically, in the “hunting for treasure” task, the target was a small circle with a treasure chest inside it, and children were told they had to remember the location of the treasure chest. In the “bursting a bubble” task the target was a small white circle that children were told was a bubble. Children had to remember the location of the bubble so they could “pop” it. In the “spaceship” task the target was a small blue triangle that children were told was a lost spaceship. They had to remember the location of the spaceship so that they could find it when the computer said “go.” In order to keep children interested in the spatial memory task, each child completed two spatial working memory tasks using two different cover stories. The cover stories were counter-balanced across participants such that the same number of participants completed each version of the task.

The experimenter gave the child a stylus to use when selecting the target. The experimenter went through a warm-up game where they showed the child two flash cards. The

experimenter told the child to ignore the yellow dot and remember which flashcard had the picture of the target. Both flashcards were placed face down and the experimenter explained that they had to wait for the command “Go, Go, Go,” before pointing to the target card with the stylus. The child had to find the target on two warm-up trials before moving on to the actual game.

After completion of two successful warm-up trials, the child and experimenter moved to the monitor. Each game started with a demonstration trial that was performed by the experimenter in order to familiarize the child with the game. Generally, the experimenter completed only one demonstration trial, but if needed the experimenter could administer more.

The demonstration trials were exactly the same as the practice and test trials. When the experimenter finished the demonstration trial, the participant completed 26 trials that consisted of 2 practice trials and 24 test trials. The sequence of events that occurred during a trial were, first, the computer gave an audio prompt (e.g., “Let’s look for a spaceship”, “Let’s find the treasure”, or “let’s burst a bubble”). Second, the target appeared for 2000 ms. Third, there was a delay of 0, 1, or 10 s. During two-thirds of the 10 s delay trials, a distractor appeared at a designated location. On half of the distractor trials a yellow distractor dot (1 cm in diameter) was illuminated for 1 s, and on the other half it was illuminated for 3 s. At the end of the delay, the computer gave the command “Go, Go, Go.” After the child responded, the target was re-illuminated to provide the child with feedback about how close she/he was to the target location (see Figure 1 for the sequence of events). Lastly, the computer gave verbal and visual feedback based on whether the child found the target (the distance between the response and target was less than 3 cm), was close to the target (the response-target distance was between 3 cm and 5 cm), or was not close (the response-target distance was greater than 5 cm). Verbal feedback and a picture of a burst bubble, treasure chest, or Buzz Lightyear was displayed on the screen when the participant “found” the target or was close to the target. When the response-target distance was greater than 5 cm, the participant received only verbal feedback, such as “Good try,” “Argh, you almost found the treasure,” or “You almost burst the bubble.” The participant completed a second, different game after a 10 minute break. The procedure for the second game was identical to the first game except it had a different “cover story.”

Experimental design.—Children were randomly assigned to play two of the three games. Children responded to two target locations. The two target locations were 40° to the right of midline and –20° to the left of midline (see Figure 2). The angles were computed from a point 15 cm from the bottom edge of the monitor. These locations were the same absolute distance from the bottom center of the monitor as the –20° and 40° locations used by Schutte and Spencer (2009). There were three memory delays: 0 s (8 total trials across both games), 1 s (16 total trials), and 10 s (24 total trials). For the 0 s delay trials the target stayed on until the child responded. On two-thirds (16 trials) of the 10 s delay trials a distractor appeared during the delays. The distractors appeared at a location near or far from the target. The near (outer) distractor appeared away from midline relative to the target location (see Figure 2) and the far (inner) distractor appeared at a location in the same direction as midline, i.e. on the opposite side of the monitor as the target (see Figure 2). When the

distractor appeared, it remained on for 1 s or 3 s. Each distractor appeared at the far and near locations on eight trials—four trials per location for each distractor duration. The offset time for both distractor durations was the same, 1500 ms prior to the go signal. The near distractor was 20° from the targets and the far distractor was 80° from the targets. Therefore, for the -20° target, the near distractor appeared at -40° and the far distractor appeared at 60°. For the 40° target, the near distractor appeared at 60° and the far distractor appeared at -40°.

Method of analysis.—When responding, children occasionally touched the monitor with one hand while pointing with the stylus with the other hand, touched the monitor twice with the stylus, or touched the monitor with the stylus and then slid the stylus over to the remembered location. To control for this, E-prime recorded two responses, and we analyzed the response that was closest to the target location. In addition, some children touched the bottom of the monitor while reaching with the stylus with the other hand. Any response that was within 1 cm of the bottom edge of the monitor was removed from the analyses. If both responses recorded by the computer were within 1 cm of the bottom edge, e.g., the child touched the bottom of the monitor twice with the left hand while reaching with the stylus with the right hand, that trial was removed from any further analyses. This resulted in the removal of 72 trials, 4.5% of the total number of trials.

Inspection of the data revealed some outliers. In the majority of cases, the outliers were in the direction of the other target (i.e., on the opposite side of midline) resulting in a skewed distribution. Inspection of histograms of errors to each target revealed that the majority of errors that were not in the direction of the other target were within 45° of the target. Therefore, for the 3-year-olds, any trial with an error greater than 45° was removed from the analyses. This resulted in the removal of 80 trials (10% of the total number of trials for the 3-year-olds). Inspection of histograms for the 6-year-olds, revealed that the majority of their errors were normally distributed between -30° and 30° from the target. There were only a few trials with errors greater than 30°. These trials were removed from the analyses (7 trials, 0.8% of the total trials for the 6-year-olds).

We analyzed children's constant directional errors (Schutte & Spencer, 2002). Constant directional errors toward midline were coded as negative, and constant directional errors away from midline were coded as positive (see Figure 2). Only errors following the 10 s delay were analyzed. The purpose of the 1 s delay trials was to keep children interested in the task (i.e., they “found” some targets), and to confirm during the data collection session that they understood the task and were responding to the target location. Constant directional errors on individual trials were examined using a linear mixed model. This model is used to analyze mixed model and repeated measures by structured covariance models. This procedure allows you to model the means of your data, and the variances and covariances as well (SAS Institute Inc., 2011). For these analyses, a compound symmetry covariance structure was utilized where all variances and covariances are equal. Restricted Maximum Likelihood (REML) was used in reporting model parameters and to assess the significance of random effects; degrees of freedom were estimated using the Between Within method. The variables that were used in these analyses included main effects of age, distractor location, target, and all possible interactions. Trial was entered as a control variable in all

analyses. An analysis of distractor duration did not find any significant effects of duration, so the data were collapsed across distractor duration in the final model. Effect size was computed using pseudo- R^2 statistics (Singer & Willett, 2003) that reflect the change in each of the relevant variance components after including the effect of interest.

Results

To test whether spatial attention and spatial working memory are linked in 3- and 6-year-olds we analyzed spatial working memory errors. The first analysis examined whether distractors significantly influenced constant directional error by comparing distractor trials to no distractor trials; therefore, constant directional error was the dependent variable and age (3 years, 6 years), target location (-20° , 40°), and distractor (no distractor, near distractor, far distractor) were independent variables. All main effects and possible interactions were examined. There was a main effect of age, $F(1,32) = 4.18$, $p = .049$. Three-year-olds made errors toward midline ($M = -1.33$, $SE = 1.41$), while 6-year-olds made errors away from midline ($M = 2.68$, $SE = 1.36$). There was also an Age $\times$ Distractor interaction, $F(2,64) = 8.36$, $p < .001$. Three-year-olds made errors toward midline both when there was no distractor and when there was a far (inner) distractor. When the distractor was the near (outer) distractor, 3-year-olds made small errors away from midline. Six-year-olds responses were biased away from midline at all distractor locations, but were less biased when the distractor was the near (outer) distractor (see Figure 3).

In order to determine which distractor effects were significant, a follow-up analysis was completed for each age group separately examining the main effects of trial, target and distractor. There was a significant distractor effect for the 6-year-olds, $F(2,32) = 8.10$, $p = .001$. Effect size was computed using pseudo- R^2 statistics (Singer & Willett, 2003) that reflect the change in the relevant variance components, in this case the residual variance, before and after including the effects of distractor. Adding distractor to the 6-year-old model accounted for an additional 3.7% of the residual variance. No significant distractor effects were found for the 3-year-olds, $F(2,32) = 2.38$, $p = .109$.

Discussion

As predicted, the distractor influenced the responses of the 6-year-olds. Specifically, when there was no distractor, 6-year-olds' memory responses were biased away from the midline of the monitor. In contrast, when the distractor was the outer distractor, 6-year-olds' responses were not significantly biased. This result suggests that the distractor repelled their memories back toward the center of the monitor. This change in bias suggests that by 6 years of age, attention is beginning to play a role in the maintenance of locations in spatial working memory. Interestingly, only the distractor near the target location influenced the responses of the 6-year-olds. This finding corresponds to studies with adults that found that only distractors near the target location influenced memory responses (Herwig et al., 2010; Van der Stigchel et al., 2007). The direction of errors shown by the 6-year-olds, however, did not match the errors adults make. Previous research found that adult responses were biased toward distractors (Van der Stigchel et al., 2007). In contrast, the 6-year-olds responses were repelled from the outer distractor.

The outer distractor was also the distractor that was closest to the target location. One question that remains is whether the distance from the target is what matters, or whether the location relative to midline is what matters. In Experiment 2 we moved the locations of the distractors in order to determine whether distance, location relative to midline, or both determine whether or not a distractor influences 6-year-olds' memory responses. Specifically, we tested the hypothesis that an outer distractor that is far from the target location will not influence the memory responses of 6-year-olds. We also tested the hypothesis that an inner distractor that is closer to the target location will "push" 6-year-olds' memory responses even further from midline than when there is no distractor.

In contrast to the 6-year-olds, distractors did not significantly influence the responses of 3-year-olds. There are two possible reasons for this result. First, attention may not be developed enough to influence the maintenance of a location in spatial working memory. This conclusion corresponds with research on the development of executive functions that suggest a large developmental change in attention and inhibitory control between 3 and 6 years of age (Simpson & Riggs, 2005; Steele, Karmiloff-Smith, Cornish, & Scerif, 2012). Prior to this developmental change 3-year-olds may not have enough endogenous control over spatial selective attention to use it as a rehearsal mechanism for spatial memory, and, therefore, shifts of spatial attention during the delay do not significantly influence maintenance of locations in spatial memory; however, there are other possible explanations.

Second, it is possible that the distractors were in locations that did not influence 3-year-olds' memory responses. Three-year-olds' memory responses are biased toward midline, due to geometric biases (Schutte & Spencer, 2009). Thus, if the distractor "pushed" their memory away in the same manner as the 6-year-olds, their biases on the outer distractor trials would be in the same direction as their biases on the no distractor trials. Examination of Figure 3, however, suggests that this was not the case. On trials with an outer, near distractor 3-year-olds were more accurate, suggesting that the distractor actually "pulled" their memory toward it. Although a tantalizing possibility, this effect was not statistically significant. Therefore, based on the results of this experiment, we cannot conclude that distractors do or do not influence maintenance in spatial working memory for 3-year-olds.

The third possibility is that due to the variability of 3-year-olds' performance, we did not have enough power to detect a systematic influence of distractors. The effect of distractor was marginal for the 3-year-olds ($p = .109$). Three-year-olds are more variable than older children which could result in non-significant results, but it may be possible to reduce variability by adjusting the task. Specifically, 3-year-olds are not as experienced with holding writing implements, therefore, using the stylus may have been more challenging for them than for the 6-year-olds and resulted in more variable responding. In Experiment 1b we tested 3-year-olds in the same paradigm, but had them point and touch the screen rather than touch the screen with a stylus.

Experiment 1b

Method

Participants.—Seventeen 3-year-olds (6 males, 11 females; $M = 3;8.3$, $SD = 4.9$ months) participated in this experiment. Recruitment and compensation details were the same as Experiment 1a. All parents provided informed consent. Two additional 3-year-olds participated (1 male, 1 female), but were not included in the analyses due to not completing the data collection session.

Materials/apparatus.—The materials used were the same as Experiment 1a, except the stylus was not used.

Task and procedure.—The task and procedure were the same as Experiment 1a, except children pointed and touched the screen with their finger instead of with a stylus.

Experimental design.—The design was the same as Experiment 1a.

Method of analysis.—The method of analysis was the same as Experiment 1a. A total of 60 trials (8.2%) were removed from the analyses due to touching within 1 cm of the bottom of the monitor. As in Experiment 1, any trial with an error greater than 45° was removed from the analysis. This resulted in the removal of 95 trials (13.0% of the trials). As in Experiment 1a, constant directional error was analyzed using linear mixed models. The first model analyzed errors in Experiment 1b only, and the second model analyzed 3-year-old data from Experiments 1a and 1b in order to examine whether use of a stylus influenced performance. The final model collapsed across experiment to test whether there was a significant effect of distractor with a greater sample size. As in Experiment 1a, an analysis of distractor duration did not find any significant effects, so the data were collapsed across distractor duration.

Results

The first analysis examined whether distractors significantly influenced constant directional error by comparing distractor and no distractor trials. Constant directional error was the dependent variable and target location (-20° , 40°) and distractor (no distractor, near distractor, far distractor) were independent variables. There were no significant main effects or interactions. The second model tested whether or not performance without the use of a stylus differed from performance with a stylus. This analysis included 3-year-old data from Experiment 1a, and experiment (1a, 1b) was added as an independent variable. There was not a significant main effect of experiment, $F(1,32) = 0.39$, $p = .538$, or any interactions with experiment, all p s $> .35$. Thus, the performance of 3-year-olds was the same with and without a stylus. The third model collapsed across experiment and included target location (-20° , 40°) and distractor (no distractor, near distractor, far distractor) as independent variables. There were no significant main effects or interactions, all p s $> .10$.

Discussion

Results from Experiment 1a and 1b suggest that use of the stylus did not influence memory responses of the 3-year-olds. Increasing power by increasing sample size also did not influence the results. Therefore, two possibilities for the lack of influence of distractors remain: either attention is not developed enough in 3-year-olds to influence performance in this spatial memory task, or the distractors were not in locations that influenced 3-year-old's memory responses. Therefore, Experiment 2 tested the hypothesis that changing the location of the distractors will lead to distractors influencing the memory responses of 3-year-olds.

Experiment 2

Experiment 2 tested whether changing the location of the distractors relative to the target location would influence the memory responses of 3- and 6-year-olds. In Experiment 1, the memory responses of the 3-year-olds were not significantly biased by the distractor. If 3-year-olds' responses are influenced by a distractor that may occur if the distractor is toward the midline of the monitor relative to the target location, because the responses of 3-year-olds are biased toward midline. Thus, in this experiment the inner distractor was near the target location in the direction of the midline of the monitor (inner, near distractor), and the outer distractor was far from the target location in the direction of the outer edge of the monitor (outer, far distractor).

Experiment 2 also tested the hypothesis that the distractor has to be near the target location in order to repel the memory of the 6-year-olds, a distractor that is far from the target location, about twice as far as the outer distractor in Experiment 1, should not influence their memory responses. Thus, we predicted that, unlike Experiment 1, the memory responses of the 6-year-olds would not be systematically biased by the distractors in this experiment.

We made two other changes to the design. First, because the amount of time the distractor was present did not influence errors in Experiment 1, we simplified the design by having all distractors remain on the screen for 1 s. Second, we included two memory delays, 4 s and 9 s, to examine whether the length of the delay affected errors. Spencer and Hund (2003) found that bias increased as delay increased. This increase in bias over delay may result in distractor only having a significant effect at longer delays.

Method

Participants.—Three- and 6-year-olds participated. There were 21 3-year-olds (13 males, 8 females; $M = 3;5.7$, $SD = 3.5$ months) and 17 6-year-olds (8 males, 9 females; $M = 6;5.3$, $SD = 3.7$ months). Recruitment and compensation details were the same as Experiment 1. All parents provided informed consent. An additional 3-year-old participated, but was not included in the analyses due to not completing the data collection session.

Materials/apparatus.—The materials used were the same as Experiment 1.

Task and procedure.—The task and procedure were the same as Experiment 1.

Experimental design.—The design was similar to Experiment 1, but had three differences. The first difference was in the delays. Children responded after no delay (target remained present until response) and delays of 100 ms, 4000 ms, and 9000 ms. On half of the 4000 ms and 9000 ms delay trials a distractor appeared during the delays. The second difference was that all distractors remained on for 1000 ms. The third difference was that the distractors were in different locations than in Experiment 1. As in Experiment 1, the near distractor was 20° from the targets, but it was toward the center of the monitor. The far distractor was 40° from the targets, because a larger separation would have put it too close to the bottom edge of the monitor. Therefore, for the –20° target, the near distractor appeared at 0° and the far distractor appeared at –60°. For the 40° target, the near distractor appeared at 20° degrees and the far distractor appeared at 80° degrees.

Method of analysis.—The method of analysis was the same as Experiment 1. As in Experiment 1, if both responses recorded by E-prime were within 1 cm of the bottom edge of the monitor, that trial was removed from any further analyses. A total of 59 trials (3.6%) were removed from the analyses. Inspection of the data once again revealed several outliers with distribution similar to those in Experiment 1. Therefore, as in Experiment 1 for the 3-year-olds, any trial with an error greater than 45° was removed from the mean error analysis. This resulted in the removal of 83 trials (13.7% of the trials for the 3-year-olds). For the 6-year-olds, any trial with an error greater than 30° was removed from the analyses (8 trials, 1.5%).

Results

The same method as in Experiment 1 was used to test the hypothesis that a distractor would influence the memory responses of 3-year-olds if the distractor was toward the midline of the monitor relative to the target location. A preliminary analysis found no significant main effect of or interactions with delay, so delay was removed from the model. In the first analysis constant directional error was the dependent variable and age (3 years, 6 years), target location (–20°, 40°), and distractor [no distractor, near (inner) distractor, far (outer) distractor] were independent variables. As in Experiment 1, negative errors indicated errors toward midline; positive errors indicated errors away from midline. All main effects and possible interactions were examined in this analysis. A main effect of age was found $F(1,35) = 8.69, p = .006$. The 3-year-olds made errors toward midline ($M = -2.44, SE = 1.13$), while the six-year-olds made errors away from midline ($M = 2.42, SE = 1.19$). There was also a main effect of distractor, $F(2,70) = 7.10, p = .002$. Children made small errors toward midline when there was no distractor present ($M = -.32, SE = .91$), or when there was a near, inner distractor ($M = -2.08, SE = 1.08$). When there was a far (outer) distractor children made errors away from midline ($M = 2.39, SE = 1.10$). Lastly, there was a significant Age $\times$ Distractor interaction, $F(2,70) = 7.55, p = .001$ (see Figure 4).

In order to determine which distractor effects were significant, a follow-up analysis was completed for each age group separately examining the main effects of target and distractor. There was a significant distractor effect for 3-year-olds, $F(2,38) = 8.65, p < .001$. As in Experiment 1, effect size was computed using pseudo- R^2 statistics (Singer & Willett, 2003). Adding distractor to the 3-year-old model accounted for an additional 3.0% of the residual

variance. As can be seen in Figure 4, 3-year-olds made errors toward midline when there was no distractor, or when there was a near, inner distractor. When there was a far, outer distractor 3-year-olds made errors away from midline. There were no significant effects in the analysis of the data from the 6-year-olds.

Discussion

The distractors in this experiment influenced the responses of the 3-year-olds, but not the 6-year-olds. Specifically, memory responses of the 3-year-olds were biased toward the distractor when it was the outer, far distractor. When there was no distractor or an inner distractor, their responses were biased toward the center of the monitor. Interestingly, this result contrasts with Experiment 1. In Experiment 1 the responses of the 3-year-olds were not significantly biased toward the outer distractor when it was only 20° from the target location.

As hypothesized, the far, outer, distractor did not influence the responses of the 6-year-olds. Additionally, the near, inner, distractor also did not influence the memory responses of the 6-year-olds. Thus, the hypothesis that a distractor toward the center of the monitor would significantly increase their bias away from the center was not supported. The bias away from midline may already be so great that an added “push” from a distractor does not increase that bias. Taken together with the results from the 6-year-olds in Experiment 1, this finding suggests that by at least 6 years of age the distance and direction of the distractor from the target location influences whether or not the distractor affects maintenance in spatial working memory. Specifically, the distractor needs to be near the target location and in the direction of their memory bias, i.e., away from the midline of the space, in order to influence the maintenance of the location in spatial working memory. This result requires replication, however, with distractors closer to the target than 20°. A distractor that is toward midline may influence their memory of the location if it is closer to the target location.

The effect of the distractor did not interact with the length of the delay. In fact, the results of Experiment 2 did not replicate previous research showing that response bias increased as delay increased (Schutte & Spencer, 2002; Spencer & Hund, 2003). Previous research that found a significant effect of delay used more than two delays. For example, Schutte and Spencer (2002) included a 0 s delay in their analyses, and Spencer and Hund (2003) included 5 s, 10 s, 15 s, and 20 s delays. Thus, the lack of an effect of delay may have been due to having only two delays with a difference between them of only 5 s.

General Discussion

The goal of the current study was to examine whether spatial selective attention influences the maintenance of locations in spatial working memory in young children. Across two experiments we tested the proposal that spatial selective attention and spatial working memory are linked in young children by examining whether distractors presented during the delay influenced their memory responses. Results of Experiment 1 suggested that by 6 years of age, there is a clear link between spatial selective attention and maintenance in spatial working memory. When a distractor was presented near the target location, memory responses were biased away from the distractor. The memory response of the 3-year-olds in

Experiment 1, however, did not show a significant effect of distractor. Experiment 1b ruled out difficulty with using a stylus or power as the reason for distractors not influencing the responses of the 3-year-olds.

In Experiment 2 we moved the distractor locations to further test whether the location and distance of the distractor from the target location would influence the memory responses of 3- and 6-year-olds. Specifically, the outer distractor was farther from the target and the inner distractor was closer to the target. Thus, we were able to examine whether only distance from the target influenced whether or not a distractor affected responses or if direction from the target also mattered. The memory responses of the 3-year-olds in Experiment 2 were biased toward the outer, far distractor. Therefore, attention plays a role in the maintenance of a location in spatial working memory for 3-year-olds, but only significantly so when the distractor is relatively far from the target location. It is possible that their “spotlight” of attention is rather large, and, therefore, a distractor near the target does not cause them to move their attention. When the distractor is farther away, but not as far as the far distractor in Experiment 1, they move their attention to it during the delay, and as a result they are biased toward it. In contrast, the memory response of 6-year-olds were not influenced by the outer distractor when it was far from the target; thus their “spotlight” of attention may be more focused than the 3-year-olds.

When taken together with the biases shown by adults in previous research, the pattern of biases over development is interesting: 3-year-olds are biased toward some distractors, 6-year-olds are biased away from some distractors, and adults are biased toward distractors (Herwig et al., 2010; Van der Stigchel et al., 2007). Schutte and Spencer (2009) found that between 3 and 6 years of age there is a transition from being biased toward the midline of the space to be biased away from the midline of the space. The same appears to be true for the influence of distractors. But why is there a difference between 6-year-olds and adults in the direction of bias?

There were several differences between the method used here and those used in previous research with adults that may have resulted in differences in the direction of bias. One key difference was the amount of time the distractor remained present. In past research with adults, distractors were presented for brief amounts of time, e.g., 400 ms (Herwig et al., 2010) or 100 ms (Van der Stigchel et al., 2007). Varying the amount of time the distractor was presented in Experiment 1 did not influence errors, but the shortest distractor was presented for 1000 ms, which is significantly longer than the distractor times used in the adult studies. The longer amount of time may have resulted in children treating the distractor like a landmark. Research with adults found that spatial memory responses are biased away from landmarks (Schmidt, Werner, & Diedrichsen, 2003). Why children would have treated the distractor like a landmark is not clear, however, because the distractor and target were never presented simultaneously. Perhaps, having the distractor presented longer resulted in children “anchoring” their memory of the target location to the distractor location in the same manner as they would to a landmark, and, as a result, their memory of the target location was repelled from the distractor location. Future research should test children and adults with short and long duration distractors.

Another possibility is that the distractors in our study were not close enough to the targets to cause the 6-year-olds' memory for the target to move toward them. According to the competitive integration model (Godijn & Theeuwes, 2002), both target and distractor locations activate neuronal populations in a pre-oculomotor system. The activation associated with the distractor attracts the activation associated with the target when the distractor is close enough to the target that the neuronal populations overlap (Van der Stigchel et al., 2007). In this study the target and distractor may not have been close enough for the neuronal populations to overlap. It is not clear, however, whether repulsion would occur in the competitive integration model. This model also does not address developmental changes in spatial working memory. Thus, it is unknown whether the model would predict that attraction would occur earlier in development. Spencer and colleagues (Schutte, Spencer, & Schöner, 2003; Schutte & Spencer, 2009; Spencer, Simmering, Schutte, & Schöner, 2007) proposed a similar type of model, Dynamic Field Theory (DFT), a dynamic neural field model of spatial memory, which they have used to model the changes in spatial memory biases over development.

According to DFT, targets activate neuronal populations in spatial working memory (Schutte & Spencer, 2002, 2009; Spencer et al., 2007). Activity is maintained in spatial working memory through recurrent excitatory and inhibitory connections. Input into spatial working memory during the maintenance period, such as input from a distractor, can result in either attraction or repulsion, depending on where the input is located in the neural field. If the input is near the target (i.e., neuronal populations overlap), local excitatory connections result in the memory activity being attracted toward the input. If the input is farther from the location in memory, the activation in memory will be repelled from the input due to inhibitory mechanisms. If the input is very far from the activation in memory, the input will not affect the activity in memory. Thus, according to this model, repulsion of the memory response from the distractor may occur if the distractor is an intermediate distance from the target.

Spencer and colleagues (Schutte & Spencer, 2002, 2009) have proposed that early in development, the neuronal population activated by the target is broad and the activation is not very stable. Thus, distractors that are quite far from the target may attract the activation associated with the target location. The results from the 3-year-olds in Experiment 2 support this proposal. According to Spencer and colleagues, over development neural activation becomes more precise (narrower) and more stable. Thus, over development, memory responses should go from being biased toward distractors to being biased away from them due to the inhibition associated with the distractors. The results from the 6-year-olds in Experiment 1 support this proposal. This proposal, however, cannot explain why the memory responses of adults are attracted toward distractors unless the distractors are significantly closer to the target locations than those used in these experiments. Future research should compare adults and children in the same task to determine exactly how the biases change over development.

This study is the first study we know of to examine the influence of distractors on the maintenance of a location in spatial working memory in young children. Significantly, distractors biased spatial memory rather than just resulting in larger random error. In

addition, the influence of the distractor depended on the direction and distance of the distractor from the target location as well as the age of the child. Thus, the experiments presented here provide support for spatial selective attention being involved in the maintenance of a location in spatial working memory in young children. Executive function develops rapidly between 3 and 6 years of age. Development in children's visuo-spatial selective attention may underlie developmental changes in spatial working memory. Future research is needed to examine the effects in more detail in order to determine why there are differences across development and examine the relationship between attention and spatial working memory across development. Understanding this relationship will be key to determining why children with attention deficits also display deficits in spatial working memory. Understanding the relationship between attention and working memory is also key for understanding why children with poor working memory also display more off-task behavior in their everyday environment (Lui & Tannock, 2007).

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References

- Awh E, Jonides J, & Reuter-Lorenz PA (1998). Rehearsal in spatial working memory. *Journal of Experimental Psychology: Human Perception and Performance*, 24(3), 780–790. [PubMed: 9627416]
- Awh E, Jonides J, Smith EE, Buxton RB, Frank LR, Love T, ... Gmeindl L (1999). Rehearsal in spatial working memory: Evidence from neuroimaging. *Psychological Science*, 10, 433–437.
- Awh E, & Jonides J (1998). Spatial working memory and spatial selective attention In *The attentive brain* (pp. 353–380). Cambridge, MA, US: The MIT Press.
- Awh E, & Jonides J (2001). Overlapping mechanisms of attention and spatial working memory. *Trends in Cognitive Sciences*, 5(3), 119–126. doi:10.1016/S1364-6613(00)01593-X [PubMed: 11239812]
- Awh E, Matsukura M, & Serences JT (2003). Top-down control over biased competition during covert spatial orienting. *Journal of Experimental Psychology: Human Perception and Performance*, 29(1), 52–63. doi:10.1037/0096-1523.29.1.52 [PubMed: 12669747]
- Awh E, Vogel EK, & Oh S-H (2006). Interactions between attention and working memory. *Neuroscience*, 139(1), 201–208. doi:10.1016/j.neuroscience.2005.08.023 [PubMed: 16324792]
- Baddeley A (1986). *Working memory*. Oxford, England: Oxford University Press.
- Coch D, Sanders LD, & Neville HJ (2005). An event-related potential study of selective auditory attention in children and adults. *Journal of cognitive neuroscience*, 17(4), 605–622. doi: 10.1162/0898929053467631 [PubMed: 15829081]
- Engle R, Kane M, & Tuholski S (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex In Miyake A & Shah P (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 102–134). Cambridge, England: Cambridge University Press.
- Garon N, Bryson SE, & Smith IM (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, 134, 31–60. doi: 10.1037/0033-2909.134.1.31 [PubMed: 18193994]
- Gathercole SE, Durling E, Evans M, Jeffcock S, & Stone S (2008). Working memory abilities and children's performance in laboratory analogues of classroom activities. *Applied Cognitive Psychology*, 22, 1019–1037.

- Godijn R, & Theeuwes J (2002). Programming of endogenous and exogenous saccades: evidence for a competitive integration model. *Journal of experimental psychology. Human perception and performance*, 28(5), 1039–1054. [PubMed: 12421054]
- Herwig A, Beisert M, & Schneider WX (2010). On the spatial interaction of visual working memory and attention: Evidence for a global effect from memory-guided saccades. *Journal of Vision*, 10(5). doi:10.1167/10.5.8
- Huttenlocher J, Newcombe NS, & Sandberg EH (1994). The coding of spatial location in young children. *Cognitive Psychology*, 27, 115–147. [PubMed: 7956105]
- Jha AP (2002). Tracking the time-course of attentional involvement in spatial working memory: an event-related potential investigation. *Cognitive Brain Research*, 15(1), 61–69. doi:10.1016/S0926-6410(02)00216-1 [PubMed: 12506934]
- Kane M, Bleckley M, Conway A, & Engle R (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General*, 130, 169–183. [PubMed: 11409097]
- Karatekin C, & Asarnow RF (1998). Working memory in childhood-onset schizophrenia and attention-deficit/hyperactivity disorder. *Psychiatry research*, 80(2), 165–176. [PubMed: 9754696]
- Lui M, & Tannock R (2007). Working memory and inattentive behaviour in a community sample of children. *Behavioral and Brain Functions*, 3(1), 12. doi:10.1186/1744-9081-3-12 [PubMed: 17319951]
- Miyake A, Friedman N, Emerson M, Witzki A, Howerter A, & Wager TD (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*, 41, 49–100. [PubMed: 10945922]
- Norman D, & Shallice T (1986). Attention to action: Willed and automatic control of behaviour In Davidson R, Schwartz G, & Shapiro D (Eds.), *Consciousness and Self-regulation* (Vol. 4, pp. 1–18). New York: Plenum Press.
- Peterson SE, & Posner ML (2012). The attention system of the human brain: 20 years after. *Annual Reviews of Neuroscience*, 35, 73–89. doi:10.1146/annurev-neuro-062111-150525
- Posner MI, & Petersen SE (1990). The attention system of the human brain. *Annual Review of Neuroscience*, 13, 25–42.
- Posner M, & Rothbart M (1998). Attention, self-regulation and consciousness. *Philosophical Transactions of the Royal Society of London, Series B*, 353, 1915–1927. doi: 10.1098/rstb.1998.0344 [PubMed: 9854264]
- Postle BR, Awh E, Jonides J, Smith EE, & D’Esposito M (2004). The where and how of attention-based rehearsal in spatial working memory. *Brain research*, 20(2), 194–205. doi:10.1016/j.cogbrainres.2004.02.008 [PubMed: 15183391]
- Reck SG & Hund AM (2011). Sustained attention and age predict inhibitory control during early childhood. *Journal of Experimental Child Psychology*, 108, 504–512. doi:10.1016/j.jecp.2010.07.010 [PubMed: 20801457]
- Sanders LD, Stevens C, Coch D, & Neville HJ (2006). Selective auditory attention in 3- to 5-year-old children: An event-related potential study. *Neuropsychologia*, 44(11), 2126–2138. doi:10.1016/j.neuropsychologia.2005.10.007 [PubMed: 16289144]
- SAS Institute Inc. (2011). SAS (V. 9.3) [Software]. Available from <http://support.sas.com/rnd/app/da/glimmix.html>.
- Schmidt T, Werner S, & Diedrichsen J (2003). Spatial distortions induced by multiple visual landmarks: How local distortions combine to produce complex distortion patterns. *Perception & Psychophysics*, 65(6), 861–873. doi:10.3758/BF03194820 [PubMed: 14528896]
- Schutte AR, Simmering VR, & Ortmann MR (2011). Keeping Behavior in Context: A Dynamic Systems Account of a Transition in Spatial Recall Biases. *Spatial Cognition & Computation*, 11(4), 313–342. doi:10.1080/13875868.2011.579212
- Schutte AR, & Spencer JP (2002). Generalizing the dynamic field theory of the A-not-B error beyond infancy: Three-year-olds’ delay- and experience-dependent location memory biases. *Child Development*, 73(2), 377–404. doi:10.1111/1467-8624.00413 [PubMed: 11949898]
- Schutte AR, & Spencer JP (2009). Tests of the dynamic field theory and the spatial precision hypothesis: Capturing a qualitative developmental transition in spatial working memory. *Journal of*

- Experimental Psychology: Human Perception and Performance, 35(6), 1698–1725. doi:10.1037/a0015794 [PubMed: 19968430]
- Schutte AR, Spencer JP, & Schöner G (2003). Testing the Dynamic Field Theory: Working Memory for Locations Becomes More Spatially Precise Over Development. *Child Development*, 74(5), 1393–1417. doi:10.1111/1467-8624.00614 [PubMed: 14552405]
- Shallice T (1988). *From neuropsychology to mental structure*. Cambridge, England: Cambridge University Press.
- Simpson A, & Riggs KJ (2005). Inhibitory and working memory demands of the day-night task in children. *British Journal of Developmental Psychology*, 23(3), 471–486. doi: 10.1348/026151005X28712
- Singer JD, & Willett JB (2003). *Applied Longitudinal Data Analysis: Modeling Change and Event Occurrence*. New York: Oxford University Press.
- Smyth MM, & Scholey KA (1994). Interference in immediate spatial memory. *Memory & Cognition*, 22, 1–13. [PubMed: 8035679]
- Spencer JP, & Hund AM (2002). Prototypes and particulars: Geometric and experience-dependent spatial categories. *Journal of Experimental Psychology: General*, 131(1), 16–37. doi: 10.1037/0096-3445.131.1.16 [PubMed: 11900101]
- Spencer JP, & Hund AM (2003). Developmental continuity in the processes that underlie spatial recall. *Cognitive Psychology*, 47(4), 432–480. doi:10.1016/S0010-0285(03)00099-9 [PubMed: 14642291]
- Spencer JP, Simmering VR, Schutte AR, & Schöner G (2007). What does theoretical neuroscience have to offer the study of behavioral development? Insights from a dynamic field theory of spatial cognition In Plumert JM & Spencer JP (Eds.), *The emerging spatial mind*. (pp. 320–361). New York, NY US: Oxford University Press.
- Steele A, Karmiloff-Smith A, Cornish K, & Scerif G (2012). The multiple subfunctions of attention: Differential developmental gateways to literacy and numeracy. *Child Development*, 83(6), 2028–2041. doi:10.1111/j.1467-8624.2012.01809.x [PubMed: 22804751]
- Stevens C, & Bavelier D (2012). The role of selective attention on academic foundations: A cognitive neuroscience perspective. *Developmental Cognitive Neuroscience*, 2(Suppl 1), S30–S48. doi: 10.1016/j.dcn.2011.11.001 [PubMed: 22682909]
- Van der Stigchel S, Merten H, Meeter M, & Theeuwes J (2007). The effects of a task-irrelevant visual event on spatial working memory. *Psychonomic Bulletin & Review*, 14(6), 1066–1071. [PubMed: 18229476]
- Vicari S, Caravale B, Carlesimo GA, Casadei AM, & Allemand F (2004). Spatial working memory deficits in children at ages 3–4 who were low birth weight, preterm infants. *Neuropsychology*, 18(4), 673–678. doi:10.1037/0894-4105.18.4.673 [PubMed: 15506835]

Figure 1.

Schematic of one trial of the spatial working memory task. The start of the trial is at the back of the figure and time runs toward the front.

Figure 2.

Diagrams of the screen for the spatial working memory task showing the target locations (white triangles) for the (a) -20° target and the (b) 36° target. Gray dots mark the possible distractor locations for each target location.

Figure 3.
Mean constant directional error in Experiment 1a for each age and each distractor type.
Error bars are standard error of the mean.

Figure 4.

Mean constant directional error in Experiment 2 for each age and each distractor type. Error bars are standard error of the mean.