The Effects of Working Memory in Children's Learning of Spatial Skills from a Virtual Reality Game

By

ALLYSON L. SNYDER
THESIS

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF SCIENCE

in

Child Development

in the

OFFICE OF GRADUATE STUDIES

of the

UNIVERSITY OF CALIFORNIA

DAVIS

Approved:

____

Drew P. Cingel, Chair

____

Amanda E. Guyer

____

Kali H. Trzesniewski

Committee in Charge

2024

Abstract

While children can and do learn STEM (science, technology, engineering, and math) skills from interactive media, like smartphone and tablet applications, it is not clear why digital interactivity might benefit children's learning. As new interactive technologies, like virtual reality, become more popular, it is important to understand the mechanisms behind learning from these media to best design them for learning. Some research demonstrates that interactive media may not produce greater learning than non-interactive media (such as watching a video), and these findings come in contrast to social theories of learning. Another theory that is untested in this area of research is the Limited Capacity for Motivated Media Message Processing which would suggest that working memory demands could hinder children's learning from interactive media. The current study was an experiment (N = 188, children ages 7-12) in which children completed both puzzles in virtual reality and physical puzzles to demonstrate learning spatial skills. Working memory demands were manipulated through working memory precues that were predictive (children saw a picture of a completed puzzle for 3s) or neutral (children saw a picture of a blank square or rectangle for 3s). Findings demonstrate that the working memory precue manipulation did not relate to number of physical puzzles completed after using virtual reality, but there was a main effect of age such that older children completed more physical puzzles than younger children. Theoretical and practical implications are discussed.

Keywords: virtual reality, STEM learning, middle childhood, interactivity, working memory

The Role of Working Memory in Children's Learning of Spatial Skills from a Virtual Reality Game

Children's cognitive development can be affected by environmental influences, such as parents, schools, and the resources available to them. Interactive media like smartphones, tablets, and emergent technologies such as virtual reality headsets have become prominent in children's lives (Rideout & Robb, 2020). Though digital media can affect children's cognitive development both positively and negatively, one particular area of importance is how technologies might be used to support children's learning. One such emergent technology is the virtual reality (VR) headset, a head-mounted device used to simulate an immersive experience in a virtual world. Though some researchers have examined how VR headsets can be used to support classroom learning (e.g., Oigara, 2018; Pilgrim & Pilgrim, 2016; Schweitzer & Rizzo, 2022), no study to date has examined the specific mechanisms by which children might learn from these devices nor how this learning might develop with age as children gain new cognitive capabilities. Though this literature demonstrates that children can and do learn from interactive games (for a review, see Griffith et al., 2020), little is known about why digital interactivity (i.e., features that respond to user input) may or may not support learning. Researchers have hypothesized that the experience of doing a task (rather than watching someone else do a task) should improve learning from interactive media because feedback is unique and immediate (Aladé et al., 2016; Schroeder & Kirkorian, 2016). However, findings do not consistently support these claims, prompting researchers to consider alternative explanations as to why children sometimes learn better from interactive media and sometimes learn better from passively watching others' use of these media. One of these proposed explanations is that interactive media burdens children's working memory. While this work has primarily focused on children's learning from tablet applications (apps), new technologies, such as virtual reality, have emerged and are used by children[1] (Rideout & Robb, 2020). These digital spaces are three-dimensional, and potentially more naturalistic, which could help children learn from them more readily. However, it is also possible that this immersive quality increases the demands on children's cognitive resources (i.e., working memory), which could hinder learning. Further, little is known about how children learn from these technologies during middle childhood (ages 7-12), a time when children's cognitive skills develop rapidly, allowing them to learn more efficiently (Best & Miller, 2010; Gathercole et al., 2004). To test if working memory affects how much children learn from interactive media, I conducted an experimental study to test a manipulation of working memory (either reducing working memory demands or not) before children (ages 7-12) interacted with the game *Cubism* (see Figure 1) in a virtual reality headset. The current study contributes to the literature by directly testing unaddressed hypotheses about the role of working memory in children's learning from interactive media.

Children and Interactive Media

Research on children's learning from interactive media has primarily focused on what is called *transfer*, or children's ability to take what they have learned in a digital context and apply it in novel, physical contexts. Transfer is typically measured through near, medium, and far transfer tasks to see if and where difficulty with applying information to novel contexts occurs. Near transfer tasks change context but not content of learned material. For example, if a child learns to count buttons on a tablet, they then must count buttons from a picture screenshot of the same game on the tablet. In contrast, far transfer tasks change both content and context. Thus, the child counting buttons would then be asked to count a novel object, like rubber ducks, that are

[1] Just over 10% of children of children in the United States had a virtual reality headset in the home in 2019 (Rideout & Robb, 2020).

laid out in front of them, rather than on a tablet or on paper. By measuring different levels of transfer, researchers have been able to identify when children struggle to learn. When looking at non-interactive media (such as videos), researchers have found that very young children (under 30 months) struggle to transfer learning from digital media (Anderson & Pempek, 2005; Barr, 2010), and thus researchers have wondered if adding interactive elements to media might help children overcome this deficit (Kirkorian, 2018). Some scholars suggest that contingency (Kirkorian, 2018), or responses that are in sync with user behavior, might drive learning from interactive media, as has been demonstrated with television (e.g., Krcmar & Cingel, 2019). Other scholars (Aladé et al., 2016) turn to theories of experiential learning (Kolb, 2014; Kolb & Fry, 1974), suggesting that children will learn more from interactive media simply by being more hands-on and allowing children to engage in activities and reflect on their actions. Findings do not consistently demonstrate support for these hypotheses, however.

Research on children's learning from interactive media has primarily focused on preschoolers (ages 3-6). This age group has been of interest due to a national focus on promoting STEM (science, technology, math, and engineering) skills in the United States to fill a gap of STEM jobs (The White House, 2022). Further, the interest in this age group emerged from the findings of young children's (under the age of 30 months) struggle to transfer learning from video media to other contexts. While preschool children are slightly older than 30 months, they are more capable of using interactive technology due to advanced fine motor and cognitive skills (CDC, 2023). The same framework of assessing transfer, however, has been applied to the context of children's learning from interactive media. The current study focuses on older children (ages 7-12) for both practical and theoretical reasons. First, children under the age of seven are less likely to be able to use virtual reality headsets because they do not fit properly on their smaller heads (Bartholomeusz et al., 2002). Second, by the age of six, the basic modular structure of children's working memory has developed, meaning that children of this age can readily engage in more complex tasks requiring working memory (Gathercole et al., 2004). Because the basic structure is developed, children during this age range (7-12) should be able to engage with tasks that require some working memory skills, but deeper examination can be conducted because working memory continues to rapidly development during this age range (Gathercole et al., 2004). Therefore, manipulating working memory demands should have stronger effects for children at the younger end of this spectrum who are still developing working memory, and this comparison can be made because there is a broad spectrum of working memory ability across the age range. As noted above, extant research on children's learning from interactive media has primarily focused on young children. Though there are notable exceptions (e.g., Liu et al., 2011; Yelland, 1995), these studies have not specifically addressed the mechanisms by which children learn from interactive media.

Here I review the findings of two studies on children's learning from interactive media. Each focused on a preschool (ages 3-6) sample and their ability to learn STEM skills from interactive media, such is the interest of the current study. Additionally, the authors of both of these studies allude to the potential effects of working memory on children's learning from interactive media in their discussion sections, and as such their findings demonstrate the need for a shift in how children's learning from interactive media is studied.

First, Aladé and colleagues (2016) conducted a study to see if children learned better from an interactive game on a tablet or from watching the gameplay of someone else. They hypothesized that children who interacted with the game would be able to demonstrate their learning in novel contexts better than children who passively watched the gameplay of someone else. This hypothesis was rooted in theories of experiential learning (Kolb, 2014; Kolb & Fry, 1974) and theories of embodiment, which suggest that humans' physical bodies are important for processing information and learning (Clark, 2008; Varela et al., 1992). Children (ages 3-6) participated in one of three conditions: interactive, non-interactive, and control. In the interactive condition, children played with the app Measuring with Murray on a touchscreen tablet. They used novel objects to measure animals at the direction of the character Murray, a muppet. The children in the non-interactive condition watched gameplay on the same touchscreen tablet, but they could not manipulate the characters nor objects. They watched a video of someone else's gameplay. Children in the control condition played a game called "Murray Cleans Up" that did not involve measuring but also featured the muppet Murray. Children then engaged in three knowledge transfer tasks in which they used novel objects to measure pictures of animals, as they did in the game, as well as an image of a robot. Findings varied by level of transfer. For near transfer, the task closest to the game, children in the interactive condition performed better than children in the control condition. For medium transfer, both children in the interactive and non-interactive conditions performed better than children in the control condition, but only children in the non-interactive condition outperformed children in the control condition for the far transfer task. Thus, the authors suggested that interactivity may burden young children's cognitive capabilities, especially when the child must transfer their learning to new situations. Children in the interactive condition may have spent more of their cognitive resources manipulating the screen rather than attending to the general concept of measuring. These findings, however, have not yet been replicated with older children who have more developed working memory capabilities (Luciana & Nelson, 1998).

The second study, conducted by Schroeder and Kirkorian (2016) also examined how preschoolers (ages 3-6) learned from either playing a tablet game or watching gameplay of the same game. These authors suggest that interactive media might be beneficial to children's learning as it provides a more scaffolded experience. However, these authors also acknowledge that humans have a limited capacity for working memory, and thus interactivity might overburden children and hinder their learning. The authors also consider character familiarity as part of this study to see if working memory requirements might be eased by familiarity of characters and context (i.e., familiarity with the television show upon which the tablet game is based). Preschoolers experienced two tablet games during a laboratory experiment. Both were based on the show *Dinosaur Train.* Children were randomly assigned to a condition and then played one game and watched gameplay for the other. One game related to numerical cognition and the other to the biological concept of growth. Pre- and post-tests were conducted for each game, and children also engaged in near- and far-transfer tasks. Familiarity with characters and the show was not associated with any of the outcome variables. For older children (ages 4.5-5.5), the numerical cognition game had a ceiling effect, and post-test scores did not significantly differ from pre-test scores for older preschoolers. For young children (ages 3.5-4.5), they could only learn from the numerical cognition game when they were watching rather than playing. Learning was measured by asking children to answer the same questions they did in the game but on a printed screenshot of the game. This learned knowledge, however, did not generalize to near- and far-transfer tasks. The growth game was more appropriate for older children but too difficult for younger children. For older children, post-test scores were significantly greater than pre-test scores in both the watch and play conditions. This learning also generalized to near-transfer tasks for both conditions, but only to far-transfer for children in the watching condition. Thus, children might learn better from reduced burdens on working memory, but it is possible for them to learn from more interactive media.

Limitations of Extant Research

The major limitations of these studies are novelty effects, unbalanced designs, and transfer task measures.

Novelty Effects

In both studies, children did not receive a trial round or training to learn how to play the games before they started engaging in actual trials of each game. Thus, children in the watching conditions were at an advantage in that they did not also need to learn how to use the media devices in addition to the educational content. Having standardized, thorough training to teach children to play can help reduce novelty effects, and, in turn, reduce any tax on working memory. If children still struggle to transfer knowledge after eliminating novelty effects, we can identify if there are issues with interactivity itself. One study comparing children's learning from an interactive smartphone application (app) to learning from a physical puzzle demonstrates that once novelty is overcome, children using an app can learn just as well as children in the more familiar (physical puzzle) condition (Eisen & Lillard, 2020). Further, past interactive media experience has been demonstrated to help children learn from other video-based tasks (Kirkorian & Choi, 2017; Troseth et al., 2007). By training individuals to use media, we can eliminate novelty effects and reduce working memory tax to see if interactive media can be beneficial once the novelty is removed, especially when compared to non-interactive media. When tasks are practiced, they become more automatic and draw on fewer working memory resources (Shiffrin & Schneider, 1977).

Comparison

Further, in the extant studies on children's learning from varying levels of interactivity in media, children in the watching (non-interactive) conditions viewed the error-free gameplay of adults, rather than the actual gameplay of other children. Thus, all children in the watching condition engaged with the interactive media for the same amount of time while other children had a variety of engagement time. Additionally, children in the watching condition saw no errors during gameplay while children in the interactive condition made a variety of errors, which differ from child to child. In Schroeder and Kirkorian's (2016) study, children who made more errors performed worse on learning and transfer tasks, and children in the watching condition did not see these errors. In order to address this design issue, some researchers have attempted modified yoked designs with adults to ensure equal distribution of time and errors across conditions, but these designs still have sources of random error (Church, 1989), making it difficult to make inferences about the role of working memory specifically.

Research comparing the experience of watching someone's behaviors with interactive media as compared to engaging with interactive media has mixed findings, as detailed above. Social theories of learning (Bandura, 1971; Kolb, 2014; Kolb & Fry, 1974), which suggest that more learning will occur when working with more knowledgeable social partners, and theories of embodiment, which suggest that physically embodying actions supports learning, would predict that engaging with interactive media produces more learning than watching another person's behavior. Because findings are mixed, it is important to assess potential mechanisms as to why children may be learning more from watching rather than doing. While many developmental processes (such as greater motor and cognitive skills) may help children learn better from both passive and interactive media as they advance in developmental stage, working memory is a cognitive capability that is not only helpful but necessary for learning from interactive media. To use interactive media, one must master the controls to use the medium. Working memory is used to access information about these controls, but, as noted above, when interactive media is novel, users do not have mastery of control, and thus their working memory is burdened with learning this information (Aladé et al., 2016; Lang, 2000). Thus, when children are expected to learn both the controls of a digital game and the educational content in that game, their working memories may be overburdened, and thus they learn less than if they watched someone else's gameplay instead. Comparison between watching and doing then is not equivalent as some children are required to learn more information than others. As noted above, it is difficult to create an equivalent comparison of watching and doing with the same media, and thus to test hypotheses of working memory (which could explain the mixed findings of why watching is sometimes better for learning even though theory would suggest greater learning from doing; Bandura, 1971; Kolb, 2014; Kolb & Fry, 1974), alternative methods must be used, such as manipulating working memory demands, as detailed below.

Transfer Task Measures

Studies have also used study-specific measures to understand transfer task performance. For example, in Aladé and colleagues' (2016) study of *Measuring with Murray*, children's performance on transfer tasks (measuring pictures of animals or a robot using novel objects) was measured through four dichotomous variables: attempt to measure (i.e., did children place measuring objects in a straight line?), correct measurement direction, correct placement, and correct counting of objects used to measure. Reliability was not reported for these measures. While this assessment may have been appropriate to the study, it is difficult to bring these results in conversation to those from other studies of children's learning from interactive media (e.g., Kirkorian & Choi, 2017; Schroeder & Kirkorian, 2016; Yelland, 1995). Because media evolves and changes with technological developments, it is important that our understanding of the mechanisms driving children's learning from new interactive media can be in conversation with past work. Further, employing measures that can be used across studies can put into conversation, research on children's learning with research on adults' learning, providing a clearer view on developmental patterns across the literature.

One such measure that is appropriate for the current study is task completion, rather than a measure of strategy or errors made while completing a task. The current study uses spatial rotation tasks done to completion (i.e., participants must rotate puzzle pieces and put them together to complete a puzzle), which are discussed in the method section of this manuscript. Past research demonstrates that the ability to complete puzzles is related to better spatial rotation skills (VanMeerten et al., 2019), and thus completing puzzles is an appropriate task to assess spatial learning from virtual reality. Though past research on children's learning from interactive media sometimes employs measures of strategy in completing a task (Aladé et al., 2016; Schroeder & Kirkorian, 2016), there is a risk of not capturing internal thought processes, thus simplifying the outcome measure (i.e., completion) can account for individual differences in employing internal versus external strategies.

Working Memory

Working memory consists of the information processing system that temporarily holds and manipulates information in the brain to use for cognitive tasks. Working memory is a critical part of higher-level cognitive processes, such as decision-making and problem-solving. Further, it is necessary to acquire and retain new information. Working memory supports children's development across domains such as reading (Borella & De Ribaupierre, 2014), math (Cragg et al., 2017), and self-regulation (Ilkowska & Engle, 2010). Throughout childhood and early adulthood, working memory develops in a generally linear trajectory (Best & Miller, 2010) and working memory task performance matures by age 14 or 15 (Gathercole et al., 2004), but performance can continue to improve through early adulthood (Luciana & Nelson, 1998). Children under 14 do have working memory capacity, but increasingly complex tasks tax this working memory, and they may struggle with task performance.

Working memory allows humans to process and retain information, making it a critical component for learning. Working memory also helps people make connections between concepts and apply past knowledge to new knowledge and situations (Joh & Plakans, 2017). While problem-solving, individuals need a high capacity of working memory in order to track and manipulate many different pieces of information (Davidson & Sternberg, 2003). One situation in which children must use working memory is when they are engaging with media. In particular, interactive media, such as smartphone or tablet apps, require users to hold many pieces of information in their working memory while also making decisions, solving problems, and navigating virtual environments. The brain's processing system has a limited capacity, however, and thus working memory can be overwhelmed by media (Fisher et al., 2018; Lang, 2017).

Limited Capacity Model of Motivated Media Message Processing

The Limited Capacity Model of Motivated Media Message Processing (LC4MP; Fisher et al., 2018; Lang, 2000) is one such model to understand how humans' limited capacity to process information affects response to media. The LC4MP considers four types of cognitive resources involved in processing media: cognitive resources allocated to a task, cognitive resources not allocated to a task, resources required to process media messages, and available resources (resources required to do the task subtracted from resources allocated to the task). In this way, thoroughness of information processing is constrained by available resources (Lang, 2017). Past research using the LC4MP has produced surprising results, however (Fisher et al., 2018). For example, cognitive processing theories would suggest that measures of resource availability (such as secondary-task response times or neuroimaging measures) should exhibit a U-shaped pattern as perceptual cognitive load increases, meaning that people use more cognitive resources when tasks are too simple or too complex, but use fewer cognitive resources for messages that are at an appropriate level for processing. Research demonstrates that this pattern is actually shaped like an inverted-U: tasks that are too simple or too complex use fewer cognitive resources than tasks that are at an appropriate level (e.g., Fox et al., 2007; Huskey et al., 2018). The current explanation for these results is that cognitive resources are allocated away from the message when effort and reward are mismatched, thus when tasks are too easy or too difficult, people shift their cognitive resources away from that task (Fisher et al., 2018). In this way, when cognitive resources are overtaxed, humans cognitively offload these resources to secondary, unrelated tasks, and they should learn less from media. Easing the tax on working memory resources should thus help improve learning from media. One way to manipulate working memory resource allocation is through the use of working memory cues.

Working Memory Cues

To best assess the role of working memory in children's learning from interactive media, the current study employed the use of working memory precues. A working memory precue (typically an image) was presented before exposure to stimulus in a working memory task. When this type of cue is predictive, it directs the attention of working memory toward the most salient information that will be probed (Myers et al., 2017). Thus, when viewing the stimulus, items can be prioritized if they are expected to be necessary. A neutral version of this cue does not provide relevant information, and thus does not help in prioritizing information. Predictive working memory cues have been shown to produce quicker and more accurate responses (Heuer & Rolfs, 2022; Oberauer & Hein, 2012). Further, predictive precues have been shown to have greater benefit on task performance than predictive retrocues, as these types of cues come after the stimulus has been viewed (Heuer & Rolfs, 2022). By employing the use of precues in the current study, we can reduce the tax on participants' working memory and better assess the role of working memory, alongside interactivity, in children's learning from media.

Current Study

The current study sought to fill the gaps in the literature on children's learning from interactive media through an experimental manipulation of working memory precues before exposure to the virtual reality game *Cubism*. The main research question of this study was whether predictive working memory precues reduce working memory requirements in a virtual reality (VR) environment such that children who receive predictive precues perform transfer tasks faster than those who receive neutral precues. Based on past research with working memory precues, I predicted that:

H1: There will be a main effect of condition such that children who see predictive precues will complete more (a) near, (b) medium, and (c) far transfer tasks successfully.

Finally, I considered how age will influence the relation between experimental condition and completion of transfer tasks, as has been demonstrated in past research (Aladé et al., 2016; Kirkorian, 2018; Schroeder & Kirkorian, 2016). As children develop, they improve their cognitive and motor skills, making it easier for them to learn from interactive media. Thus, I hypothesized that older children would complete more transfer tasks than younger children:

H2: There will be a main effect of age (treated continuously) such that age will have a significant positive relation to the number of successfully completed (a) near, (b) medium, and (c) far transfer tasks.

Because working memory develops throughout middle childhood (ages 7-12), it is possible that younger children (as compared to older children) will benefit more from receiving working memory precues as they do not have as developed working memories as their older peers. Thus, I predicted

H3: There will be an interaction between age and condition such that age will moderate the relation between working memory precue condition and successful completion of (a) near, (b) medium, and (c) far transfer tasks such that younger children will benefit more from predictive working memory cues than older children.

The current study took a new approach to studying children's learning from interactive media by addressing methodological limitations of past work (such as novelty effects and unbalanced comparisons). Further, the current study focused on how working memory demands affect children's learning from interactive media and across a wide age span of middle childhood, a hypothesis that has been posed in existing literature but has not yet been tested.

Method

Procedure

The current study was an experiment with two conditions that was conducted at a local science museum (admission prices at the time of data collection were $14.95 for children and $17.95 for adults). This project was part of a lab initiative to do science in our local community, and thus the experiment was conducted openly on the museum floor such that patrons could see the experiment while it was happening. Participants played the game *Cubism* in virtual reality (see Figure 1). *Cubism* is a spatial rotation game with block-like puzzle pieces that fit together in empty frames to form squares or rectangles. After completing consent and assent, participants were helped into a virtual reality headset so that they could see clearly. The Oculus Quest 2 headsets have hand tracking such that children did not need to use controllers to play the game. Instead, they saw outlines of their actual hands, which they could use to pick up and move pieces. Parents filled out a survey containing demographics. Participants were told they could use their fingers to pinch and let go of the puzzle pieces. Then participants started the first training puzzle, which included all shapes that participants will see during the study. Each shape has an outline to which it needed to be dragged and dropped. Once participants completed this puzzle, they did the second training puzzle. This puzzle was similar to the first, but participants needed to rotate the shapes to fit them into the puzzle. The third puzzle included just two shapes but an empty frame that requires the two shapes to be combined into a larger shape. These training puzzles were intended to eliminate novelty effects and ensure that all participants could complete the required movements to play the game. Participants in both conditions completed these training puzzles. Once the training session was done, the experimenter asked the child to take off the headset so that the first working memory precue could be shown. From this point forward, the study differed based on condition.

Participants were randomly assigned (stratified by gender and age) to either see predictive or neutral working memory cues (see Figure 2). The predictive cues included an image of the completed puzzle, emphasizing the goal of completing the puzzle, while children in the neutral condition saw an image of an empty puzzle frame. Immediately after each VR puzzle, children completed a 3-D printed physical version of the puzzle outside of virtual reality (near transfer; see Figure 3). Over five trials, children saw the assigned precue, completed the puzzle themselves in virtual reality, and then completed the same puzzle with a 3-D printed version that is identical to the puzzle they just saw. After these five trials, children completed four more physical puzzles that they had not yet completed to test medium and far transfer. Two puzzles contained four pieces like both the physical and virtual puzzles completed before (medium transfer), and two puzzles contained six pieces (far transfer).

Participants

Children were recruited at the Museum of Science and Curiosity in Sacramento, CA. In total, 213 children participated in the study, randomly assigned (stratified by age and gender to be represented equally across conditions) to either the predictive precue condition or to the neutral precue condition. Children were given a sticker for their participation in the study. Participants were dropped due to experimenter errors (n = 13) or not being able to complete the study/follow directions (n = 12). Thus, the final sample included 188 children (M_{age} = 9.33 years; SD_{age} = 1.63; 37.77% girls; 57.98% boys). The sample was 18.62% Asian (n = 35), 5.85% Black (n = 11), 42.02% White (n = 79), 12.23% Hispanic (n = 23), and 0.53% American Indian or Alaska Native (n = 1). Another 15.96% of parents reported two or more race options for their child (n = 30), and 4.79% declined to answer (n = 9). The median household income bracket of the sample was $125,000-$149,000, and the median level of parental education was some post-graduate study.

Measures

Transfer Tasks

The main outcome variable in this study was the number of physical puzzles children were able to complete (i.e., transfer of learning from virtual reality to physical space). Children could take as long as they liked to complete puzzles, but after three minutes (or after the child looked visibly upset, whichever was earlier), the experimenter asked if the child would like to move on to a new puzzle. Sums of near, medium, and far transfer tasks were taken independently. Completion is considered successful when the child puts all of the pieces into the outline such that they fit and that this task was done independently (see Table 1 for coding scheme). Six (6) trained research assistants coded each video for completion, and 20% of these videos were used for reliability ($n = 43$; ICC = 0.98).

Near Transfer. Children completed five puzzles immediately after seeing each puzzle in VR. Physical puzzle pieces were placed identically to their locations in VR, and there was an outline of an empty box for children to place them in. Successful completion of these puzzles were summed to create a near transfer score ($M = 4.93$; $SD = 0.27$).

Medium Transfer. After the child completed all of the VR puzzle trials, they attempted two novel puzzles with four pieces each. This task was more difficult than the near transfer tasks because the puzzles are novel, but each of these puzzles included four pieces, like all of the puzzles in VR. Successful completion of these puzzles was summed to create a near medium score ($M = 1.87$; $SD = 0.37$).

Far Transfer. The last two puzzles the children saw were six-piece, novel puzzles. This task was more difficult than near and medium tasks because the puzzles were not only novel, but they also contained more pieces. Successful completion of these puzzles was summed to create a far transfer score ($M = 1.71$; $SD = 0.60$).

Potential Covariates and Demographics

Because condition was randomly assigned, potential covariates are not included in the main analyses, but they are included in the correlation table (Table 2). Demographic variables included parent age, child age, parent race, child race, parent gender, child gender, household income, and parent education. Parents were also asked if there was a VR headset in their home. Children were asked if they had used virtual reality before, and children also responded to questions about if they had played video games on different platforms (phone, tablet, computer/laptop, television, virtual reality headset, augmented reality). Responses were coded as 1 – yes and 0 – no. These responses were summed to create an experience with video games score, potential scores ranged from 0 (no video game experience) to 6 (video game experience with the six different platforms listed above; $M = 4.11$, $SD = 1.36$).

Results

A series of two-way ANOVAs were run to assess the main effects of condition (H1) and age (H2) as well as the interaction between the variables (H3) on completion of near, medium, and far transfer tasks. Assumptions of normality and equal variance were tested before analyses were run. The assumption of normality was violated due to a ceiling effect (which will be discussed later in this manuscript), but ANOVA is robust against assumption of normality with large sample sizes (Blanca Mena et al., 2017). As such, analyses were conducted as planned.

Near Transfer

For completion of near transfer tasks, the main effect of condition on children's task completion was not significant ($F(1,184) = .04$, $p = .84$, $\eta_p^2 < .001$), not supporting H1a. The main effect of age on children's near transfer task completion was significant ($F(1,184) = .42$, $p = .02$, $\eta_p^2 = .03$), such that older children completed more puzzles, supporting H2a. The interaction between these variables (ConditionXAge) on children's completion of near transfer tasks was not significant ($F(1,184) = .02$, $p = .89$, $\eta_p^2 < .001$), not supporting H3a.

Medium Transfer

For medium transfer tasks, the main effect of condition on children's task completion was not significant ($F(1,184) = .25$, $p = .62$, $\eta_p^2 < .001$), not supporting H1b. The main effect of age on children's medium transfer tasks completion was significant ($F(1,184) = 10.64$, $p = .001$, $\eta_p^2 = .05$), supporting H2b. The interaction between these variables (ConditionXAge) on children's medium transfer task completion was not significant ($F(1,184) = .01$, $p = .92$, $\eta_p^2 < .001$), not supporting H3b.

Far Transfer

For far transfer tasks, the main effect of condition on children's task completion was not significant ($F(1,184) = .23$, $p = .63$, $\eta_p^2 < .001$), not supporting H1c. The main effect of age on children's far transfer task completion was significant ($F(1,184) = 12.25$, $p < .001$, $\eta_p^2 = .06$), supporting H2c. The interaction between these variables (Condition X Age) on children's far transfer task completion was not significant ($F(1,184) = .04$, $p = .85$, $\eta_p^2 < .001$), not supporting H3c.

Because the interactions were not significant, post-hoc analyses were not conducted.

Discussion

The current study aimed to address the role of children's developing (ages 7-12) working memory in learning from virtual reality by manipulating working memory demands before children engaged with virtual reality STEM media. Results demonstrated that manipulating working memory through precues shown before tasks meant to assess learning did not have a significant effect on task completion outside of virtual reality. Age, however, was significantly and positively related to task performance on near, medium, and far transfer tasks that were physical puzzles (see Figures 4-6). The current study addresses limitations of past work by eliminating novelty effects and testing a hypothesis about working memory as a specific mechanism by which children may learn (or not) from VR interactive media. Findings from the current study contribute to our understanding of children's development, the LC4MP, and the design of interactive media. In this section I discuss the theoretical and practical implications of these findings as well as the limitations of this study and future directions for research.

Implications

Theoretical

The current study contributes to literature on the development of working memory during middle childhood, literature on the role of working memory in learning from media, and literature on young children's learning from STEM media. Because children are still developing their working memory capacity, it is important to consider how this development affects their ability to learn from media. All humans have a limited capacity for processing and learning from media (Lang, 2000). Humans can learn from media, but the thoroughness of this learning (as operationalized through transfer tasks) can vary based on unique susceptibilities, such as development of cognitive capabilities (Valkenburg & Peter, 2013). Thus, manipulating the demands required for learning from media can potentially influence the ability to transfer this learning to new contexts, especially for children who are still developing their working memory capabilities (Best & Miller, 2010). The manipulation of working memory in this study was not significantly related to learning outcomes (near, medium, and far transfer tasks), but children did complete more of these tasks as they got older. Children develop physically and cognitively throughout middle childhood and early adolescence (the developmental stages this study focused on), and so while the development of working memory may contribute to the significant findings of age and task performance, it is possible that the combination of a variety of physical and cognitive factors contribute to this increase in performance with age. Working memory precues were used in this study to manipulate cognitive demands (Heuer & Rolfs, 2022; Myers et al., 2017; Oberauer & Hein, 2012), either directing children toward the most salient information (the learning outcome of the completed puzzle) or not. For this study, I elected to show the cues for three seconds to give children time to process the cues. Typically these cues are shown for 200-500ms (Heuer & Rolfs, 2022; Schmidt et al., 2002). The tasks completed after these shorter cues are simpler (such as selecting a specific shape out of a series of shapes), but the working memory precues do show effects on task performance (Heuer & Rolfs, 2022; Oberauer & Hein, 2012). Because these precues in the current study did not have an effect on task performance, it is likely that the ceiling effect witnessed for near, medium, and far transfer tasks may have suppressed any effect of the working memory precues. It also is possible that working memory is not the developmental mechanism driving children's ability to learn from interactive media, but researchers should continue to explore the possibility of a connection between working memory and learning from media, as has been demonstrated and theorized about with adults (Fisher et al., 2018; Lang, 2017). Directions for future research are detailed in the next section.

Practical

As for practical implications, the results of this study can better inform parents, educators, and media makers about what types of media will best support children's learning. Older children learned more from this interactive media (virtual reality) than their younger peers in order to complete physical puzzles (near, medium, and far transfer tasks). This finding is consistent with past research (Aladé et al., 2016; Schroeder & Kirkorian, 2016), but it is still unclear why younger children struggle more to transfer what they have learned from VR media to real life than their older peers. For the near transfer tasks in particular, children completed the same puzzle in real life that they did in virtual reality, just as the older children did. Thus, it is interesting that age had a significant, positive relationship with near transfer tasks. Considering these findings, media makers should be thoughtful about the desired outcomes and target audience of their products. As children get older, they might be more capable of learning from virtual reality, and thus educational games can be developed effectively for this age group. For younger children, virtual reality might be better suited for entertainment if they are less able to transfer skills to novel contexts. Parents should also be mindful consumers. Many interactive technologies are marketed as benefiting children's learning, but this learning may not be as pronounced for younger children, particularly with cognitively demanding technologies like virtual reality. Educators should exert the same caution as virtual reality devices become present in schools. It is possible that virtual reality can provide unique learning opportunities, but more research is needed to understand what content and what audience works best with virtual reality. Virtual reality headsets are expensive in comparison to tablets and smartphones, and thus understanding for whom these headsets work best can guide parents, educators, and media makers to make thoughtful decisions on media use for educational purposes.

Limitations

Though this study addresses major limitations of past work, it also has novel limitations which should be considered alongside the findings. First and foremost, this study was conducted on a museum floor during the day, making time a key limitation. Families volunteered to take time out of their day at the museum to participate in this study, and thus the study occurred within a short timeframe to respect the needs and interests of families (no more than 40 minutes from start to finish). Other measures and repeated trials would provide more extensive information, but time constraints hindered the ability to employ these measures. A longitudinal version of this study (such as one over the course of 10 weeks or one year) could incorporate more standardized developmental measures, such as other spatial rotation tasks (e.g., Peters et al., 1995; Peters & Battista, 2008; Yoon, 2011) and be able to determine if virtual reality games can benefit children's broader skill development rather than learning closely related to the experimental stimuli. The second major limitation of this study was the inability to program working memory cues into the VR headset. While the puzzles in the study were custom made (both the puzzles in virtual reality and the physical puzzles), there was not a way to program the working memory precues into the headset. Cues were shown on paper before children put on the headset. Though past research would suggest that these precues should work even in the presence of a short time delay (Myers et al., 2017), this setup was still different from other working memory precue studies that had the precues on the same screen as the other stimuli. Because H1 was not supported, it is possible that this intervention was too subtle to detect differences in performance that might be driven by working memory demands. Considering these limitations, I suggest directions for future research.

Future Directions

Future research on children's learning from interactive media should continue to search for the underlying developmental mechanisms that support children's learning from this type of media. Further, researchers should attempt to compare different mediums to one another (such as interactive tablet games vs. watching gameplay).

Working Memory

As discussed in the literature review, research on children's learning from interactive media has lacked theoretical direction. While many hypotheses (such as arousal and scaffolding) have been tested, findings are mixed. The current study employed understanding of children's working memory development as well as theory on adults' ability to learn from media to explore another potential mechanism, working memory. Though interactive media is popular among younger children (Rideout et al., 2021; Rideout & Robb, 2020), they learn less from it than their older peers. Understanding how to best scaffold learning for younger children using interactive media can help promote positive developmental outcomes, such as numeracy, literacy, and spatial skills. Future research should continue to explore the idea of working memory but use a less subtle intervention than the one used in the current study. For example, researchers have developed modifiable video games (e.g., Huskey et al., 2018) that can be programmed with distractors or varying numbers of tasks to be completed, either increasing or reducing demands on working memory. As such, working memory demands are manipulated within the game itself, and researchers could use these types of games to assess the role of working memory in a different way.

Types of Media

The issue of children's learning from interactive media stems from a debate on whether children should play with or watch media (Kirkorian, 2018; Schroeder & Kirkorian, 2016). As noted in the literature review, it is difficult to make a fair and direct comparison of watching vs. doing, but education theory would suggest that doing should better support learning (Clark, 2008; Kolb, 2014; Kolb & Fry, 1974; Varela et al., 1992). Researchers should continue to attempt these comparisons. For example, a study might include an interactive condition and two passive conditions: one where children watch the recorded gameplay of an adult (such as in past research; Kirkorian, 2018; Schroeder & Kirkorian, 2016) and another with a yoked design where children watch the recorded gameplay of other children. In this manner, researchers can compare their results to past findings while also addressing the limitation of children in one group having a variety of experiences with the stimuli while the other has a static experience. Many children watch video game play from online streamers (Rideout et al., 2021), and thus understanding how this type of media experience compares to playing a game can help parents direct their children to media that is the most beneficial for their development.

Additionally, researchers should compare the same media on different platforms. Interactive media has expanded beyond computers and smartphones to include tablets and virtual/augmented reality headsets as well as other, emerging technologies. Young children are still developing their cognitive skills, and interactive media has been posed as a way to scaffold children's learning from media, but past research has suggested that learning to use this type of media while also trying to learn educational content may overwhelm children (Aladé et al., 2016; Kirkorian, 2018; Schroeder & Kirkorian, 2016). Emerging technologies, such as virtual reality headsets, provide a more naturalistic experience where children see objects in three dimensions and can use their hands to grab things as they would in real life, but these technologies can also be overwhelming as objects have no physical feedback and gestures must be specific to manipulate the virtual space. Non-immersive interactive technologies like smartphones and tablets also require knowledge of manipulating digital space, but the space is limited to the size of the screen, rather than a potential unlimited realm as in virtual reality. There are clear advantages to learning from both types of media, but to understand which best support children's learning might, researchers must compare these platforms. It can be difficult to choose a stimulus that is appropriate for both of these platforms as they have different affordances, but researchers should attempt to compare them to better understand children's learning from interactive media. Further, results from this type of study can inform parents and media makers on who the best audience is for their educational media.

Conclusion

In summary, little attention has been paid to the conditions under which children learn best from interactive media. The current study addresses this gap by examining the role of working memory in this learning. Working memory precues (predictive or neutral) did not have a significant effect on children's completion of transfer task puzzles, but older children performed more of these tasks successfully. As children gain increasing access to virtual reality, it is important to consider how to best leverage this technology to support their development.

References

Aladé, F., Lauricella, A. R., Beaudoin-Ryan, L., & Wartella, E. (2016). Measuring with Murray: Touchscreen technology and preschoolers' STEM learning. *Computers in Human Behavior*, *62*, 433–441. https://doi.org/10.1016/j.chb.2016.03.080

Anderson, D. R., & Pempek, T. A. (2005). Television and very young children. *American Behavioral Scientist*, *48*(5), 505–522.

Bandura, A. (1971). *Social Learning Theory* (Vol. 1). Prentice Hall.

Barr, R. (2010). Transfer of learning between 2D and 3D sources during infancy: Informing theory and practice. *Developmental Review*, *30*(2), 128–154. https://doi.org/10.1016/j.dr.2010.03.001

Bartholomeusz, H., Courchesne, E., & Karns, C. (2002). Relationship between head circumference and brain volume in healthy normal toddlers, children, and adults. *Neuropediatrics*, *33*(05), 239–241.

Best, J. R., & Miller, P. H. (2010). A Developmental Perspective on Executive Function: Development of Executive Functions. *Child Development*, *81*(6), 1641–1660. https://doi.org/10.1111/j.1467-8624.2010.01499.x

Blanca Mena, M. J., Alarcón Postigo, R., Arnau Gras, J., Bono Cabré, R., & Bendayan, R. (2017). Non-normal data: Is ANOVA still a valid option? *Articles Publicats En Revistes (Psicologia Social i Psicologia Quantitativa)*. https://diposit.ub.edu/dspace/handle/2445/122126

Borella, E., & De Ribaupierre, A. (2014). The role of working memory, inhibition, and processing speed in text comprehension in children. *Learning and Individual Differences*, *34*, 86–92.

CDC. (2023, July 21). *What developmental milestones is your 30-month-old reaching?* Centers for Disease Control and Prevention. https://www.cdc.gov/ncbddd/actearly/milestones/milestones-30mo.html

Church, R. M. (1989). The yoked control design. *Aversion, Avoidance, and Anxiety: Perspectives on Aversively Motivated Behavior*, 403–415.

Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. OUP USA.

Cragg, L., Keeble, S., Richardson, S., Roome, H. E., & Gilmore, C. (2017). Direct and indirect influences of executive functions on mathematics achievement. *Cognition*, *162*, 12–26.

Davidson, J. E., & Sternberg, R. J. (2003). *The Psychology of Problem Solving*. Cambridge University Press.

Eisen, S., & Lillard, A. S. (2020). Learning from Apps and Objects: The Human Touch. *Mind, Brain, and Education*, *14*(1), 16–23. https://doi.org/10.1111/mbe.12224

Fisher, J. T., Huskey, R., Keene, J. R., & Weber, R. (2018). The limited capacity model of motivated mediated message processing: Looking to the future. *Annals of the International Communication Association*, *42*(4), 291–315. https://doi.org/10.1080/23808985.2018.1534551

Fox, J. R., Koloen, G., & Sahin, V. (2007). No joke: A comparison of substance in The Daily Show with presidential election campaign. *Journal of Broadcasting & Electronic Media*, *51*(2), 213–227.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The Structure of Working Memory From 4 to 15 Years of Age. *Developmental Psychology*, *40*(2), 177–190. https://doi.org/10.1037/0012-1649.40.2.177

Griffith, S. F., Hagan, M. B., Heymann, P., Heflin, B. H., & Bagner, D. M. (2020). Apps As Learning Tools: A Systematic Review. *Pediatrics*, *145*(1), e20191579. https://doi.org/10.1542/peds.2019-1579

Heuer, A., & Rolfs, M. (2022). A direct comparison of attentional orienting to spatial and temporal positions in visual working memory. *Psychonomic Bulletin & Review*, *29*(1), 182–190. https://doi.org/10.3758/s13423-021-01972-3

Huskey, R., Craighead, B., Miller, M. B., & Weber, R. (2018). Does intrinsic reward motivate cognitive control? A naturalistic-fMRI study based on the synchronization theory of flow. *Cognitive, Affective, & Behavioral Neuroscience*, *18*(5), 902–924. https://doi.org/10.3758/s13415-018-0612-6

Ilkowska, M., & Engle, R. W. (2010). *Working memory capacity and self-regulation.*

Joh, J., & Plakans, L. (2017). Working memory in L2 reading comprehension: The influence of prior knowledge. *System*, *70*, 107–120. https://doi.org/10.1016/j.system.2017.07.007

Kirkorian, H. L. (2018). When and How Do Interactive Digital Media Help Children Connect What They See On and Off the Screen? *Child Development Perspectives*, *12*(3), 210–214. https://doi.org/10.1111/cdep.12290

Kirkorian, H. L., & Choi, K. (2017). Associations between toddlers' naturalistic media experience and observed learning from screens. *Infancy : The Official Journal of the International Society on Infant Studies*, *22*(2), 271–277.

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*. FT press.

Kolb, D. A., & Fry, R. E. (1974). *Toward an applied theory of experiential learning*. MIT Alfred P. Sloan School of Management.

Krcmar, M., & Cingel, D. P. (2019). Do Young Children Really Learn Best From the use of Direct Address in Children's Television? *Media Psychology*, *22*(1), 152–171. https://doi.org/10.1080/15213269.2017.1361841

Lang, A. (2000). The limited capacity model of mediated message processing. *Journal of Communication*, *50*(1), 46–70.

Lang, A. (2017). Limited Capacity Model of Motivated Mediated Message Processing (LC4MP). In P. Rössler, C. A. Hoffner, & L. Zoonen (Eds.), *The International Encyclopedia of Media Effects* (1st ed., pp. 1–9). Wiley. https://doi.org/10.1002/9781118783764.wbieme0077

Liu, M., Horton, L., Olmanson, J., & Toprac, P. (2011). A study of learning and motivation in a new media enriched environment for middle school science. *Educational Technology Research and Development*, *59*, 249–265.

Luciana, M., & Nelson, C. A. (1998). The functional emergence of prefrontally-guided working memory systems in four- to eight-year-old children. *Neuropsychologia*, *36*(3), 273–293. https://doi.org/10.1016/S0028-3932(97)00109-7

Myers, N. E., Stokes, M. G., & Nobre, A. C. (2017). Prioritizing Information during Working Memory: Beyond Sustained Internal Attention. *Trends in Cognitive Sciences*, *21*(6), 449–461. https://doi.org/10.1016/j.tics.2017.03.010

Oberauer, K., & Hein, L. (2012). Attention to information in working memory. *Current Directions in Psychological Science*, *21*(3), 164–169.

Oigara, J. N. (2018). Integrating virtual reality tools into classroom instruction. In *Handbook of research on mobile technology, constructivism, and meaningful learning* (pp. 147–159). IGI Global.

Peters, M., & Battista, C. (2008). Applications of mental rotation figures of the Shepard and Metzler type and description of a mental rotation stimulus library. *Brain and Cognition*, *66*(3), 260–264.

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A Redrawn Vandenburg and Kuse Mental Rotations Test: Different Versions and Factors That Affect Performance. *Brain and Cognition*, *28*, 39–58.

Pilgrim, J. M., & Pilgrim, J. (2016). The use of virtual reality tools in the reading-language arts classroom. *Texas Journal of Literacy Education*, *4*(2), 90–97.

Rideout, V., Peebles, A., Mann, S., & Robb, M. B. (2021). *The Common Sense Census: Media Use by Tweens and Teens, 2021*. Common Sense.

Rideout, V., & Robb, M. B. (2020). *The Common Sense census: Media use by kids age zero to eight*. Common Sense Media.

Schmidt, B. K., Vogel, E. K., Woodman, G. F., & Luck, S. J. (2002). Voluntary and automatic attentional control of visual working memory. *Perception & Psychophysics*, *64*(5), 754–763. https://doi.org/10.3758/BF03194742

Schroeder, E. L., & Kirkorian, H. L. (2016). When Seeing Is Better than Doing: Preschoolers' Transfer of STEM Skills Using Touchscreen Games. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.01377

Schweitzer, J. B., & Rizzo, A. "Skip." (2022). Virtual Reality and ADHD: Clinical assessment and treatment in the metaverse. *The ADHD Report*, *30*(3), 1–9.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, *84*(2), 127.

The White House. (2022, January 21). *FACT SHEET: Biden-Harris Administration Actions to Attract STEM Talent and Strengthen our Economy and Competitiveness*. The White House. https://www.whitehouse.gov/briefing-room/statements-releases/2022/01/21/fact-sheet-biden-harris-administration-actions-to-attract-stem-talent-and-strengthen-our-economy-and-competitiveness/

Troseth, G. L., Casey, A. M., Lawver, K. A., Walker, J. M., & Cole, D. A. (2007). Naturalistic experience and the early use of symbolic artifacts. *Journal of Cognition and Development*, *8*(3), 309–331.

Valkenburg, P. M., & Peter, J. (2013). The Differential Susceptibility to Media Effects Model. *Journal of Communication*, 23.

VanMeerten, N., Varma, K., Gravelle, M., Miller, N., Kraikul, E., & Fatemi, F. (2019). Evidence of a Relationship Between Mental Rotation Skills and Performance in a 3D Puzzle Game. *Frontiers in Education*, *4*. https://doi.org/10.3389/feduc.2019.00082

Varela, F. J., Thompson, E. T., & Rosch, E. (1992). *The embodied mind: Cognitive science and human experience. New Edition*. Cambridge, MA: The MIT Press.

Yelland, N. J. (1995). Encouraging Young Children's Thinking Skills with Logo. *Childhood Education*, *71*(3), 152–155. https://doi.org/10.1080/00094056.1995.10521831

Yoon, S. Y. (2011). *Psychometric properties of the revised purdue spatial visualization tests: Visualization of rotations (The Revised PSVT: R)*. Purdue University.

Figure 1

Image of a Puzzle in Cubism

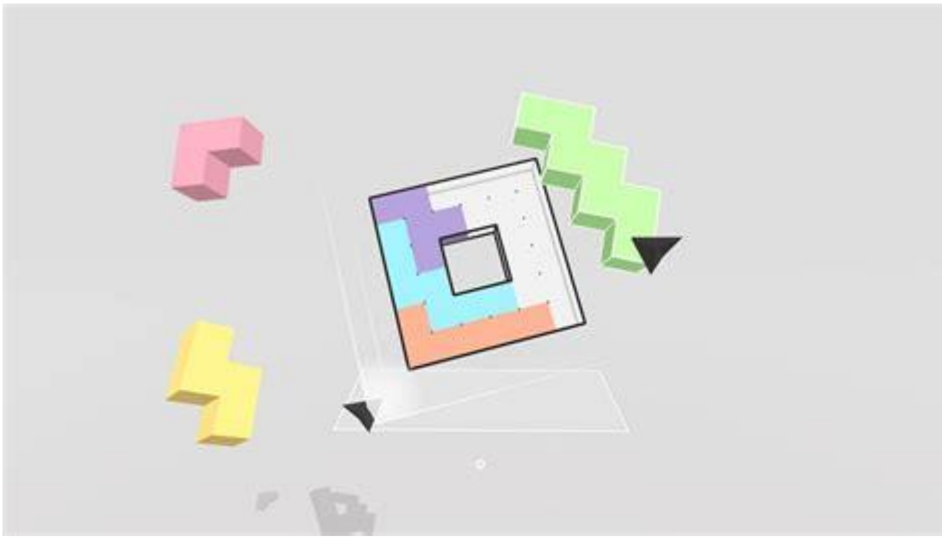


Figure 2

Working Memory Precues: Predictive (left), Neutral (right)

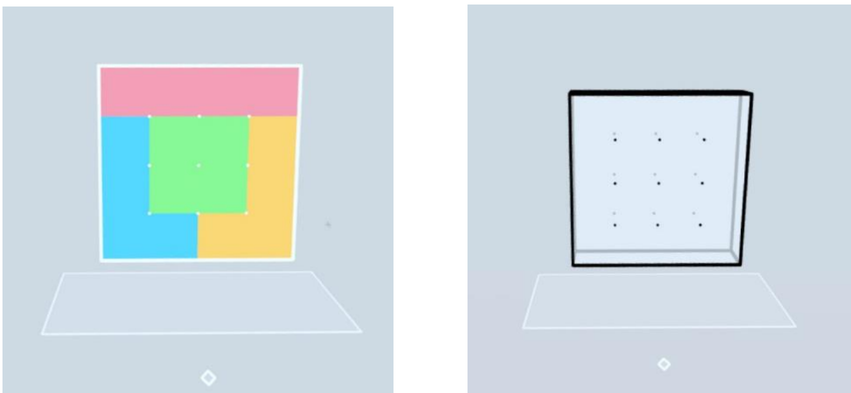


Figure 3

Physical Puzzles

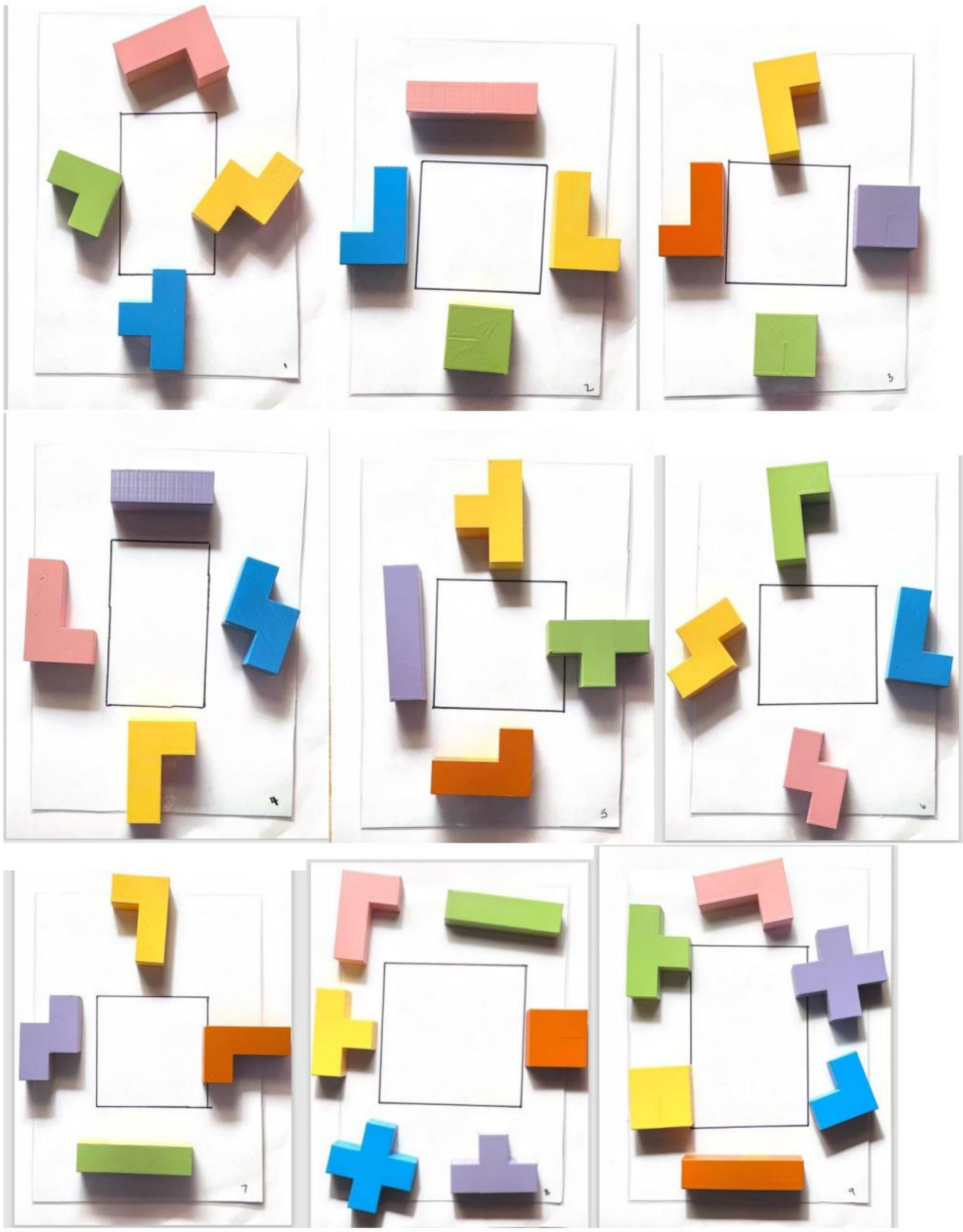
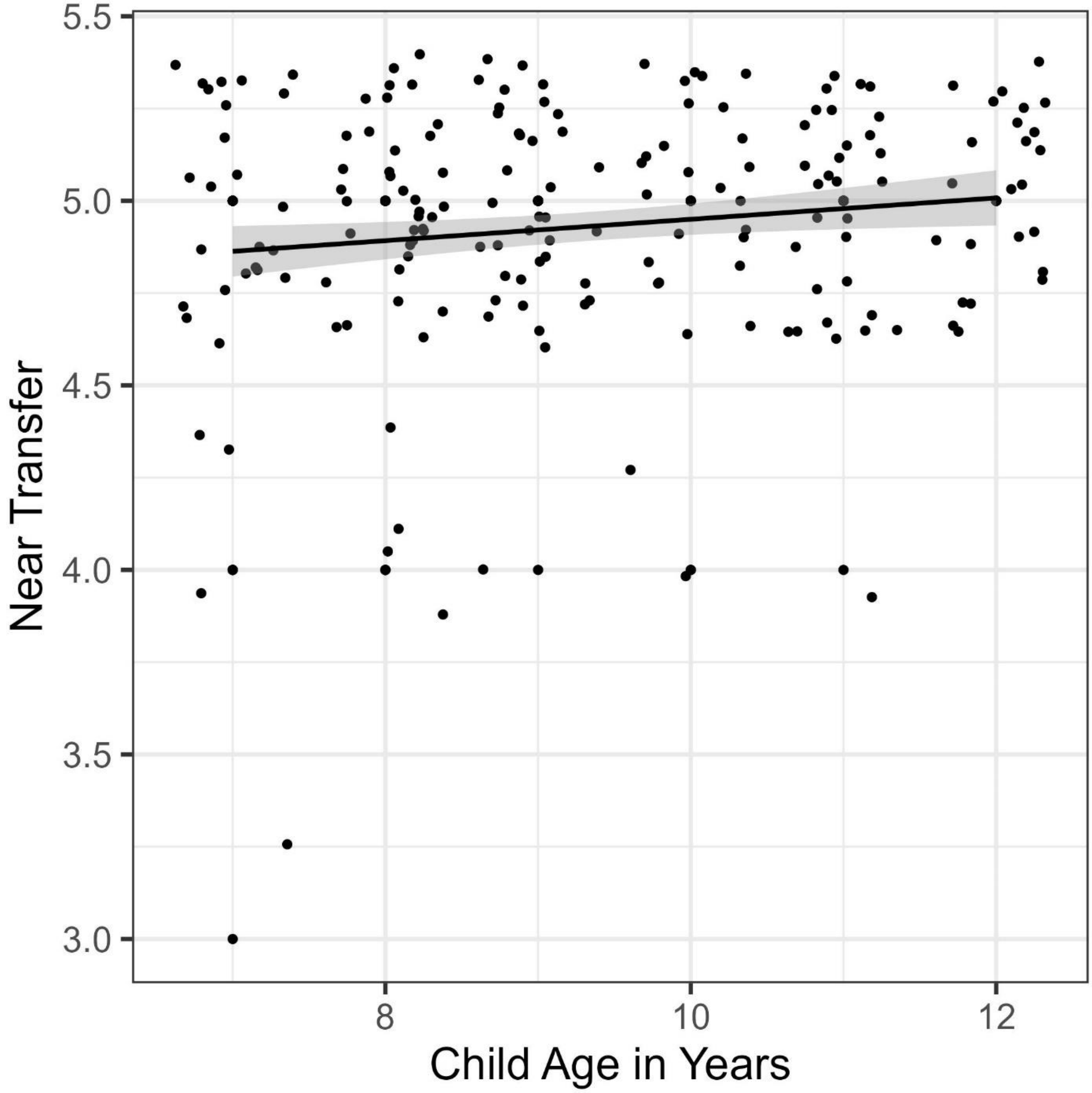


Figure 4

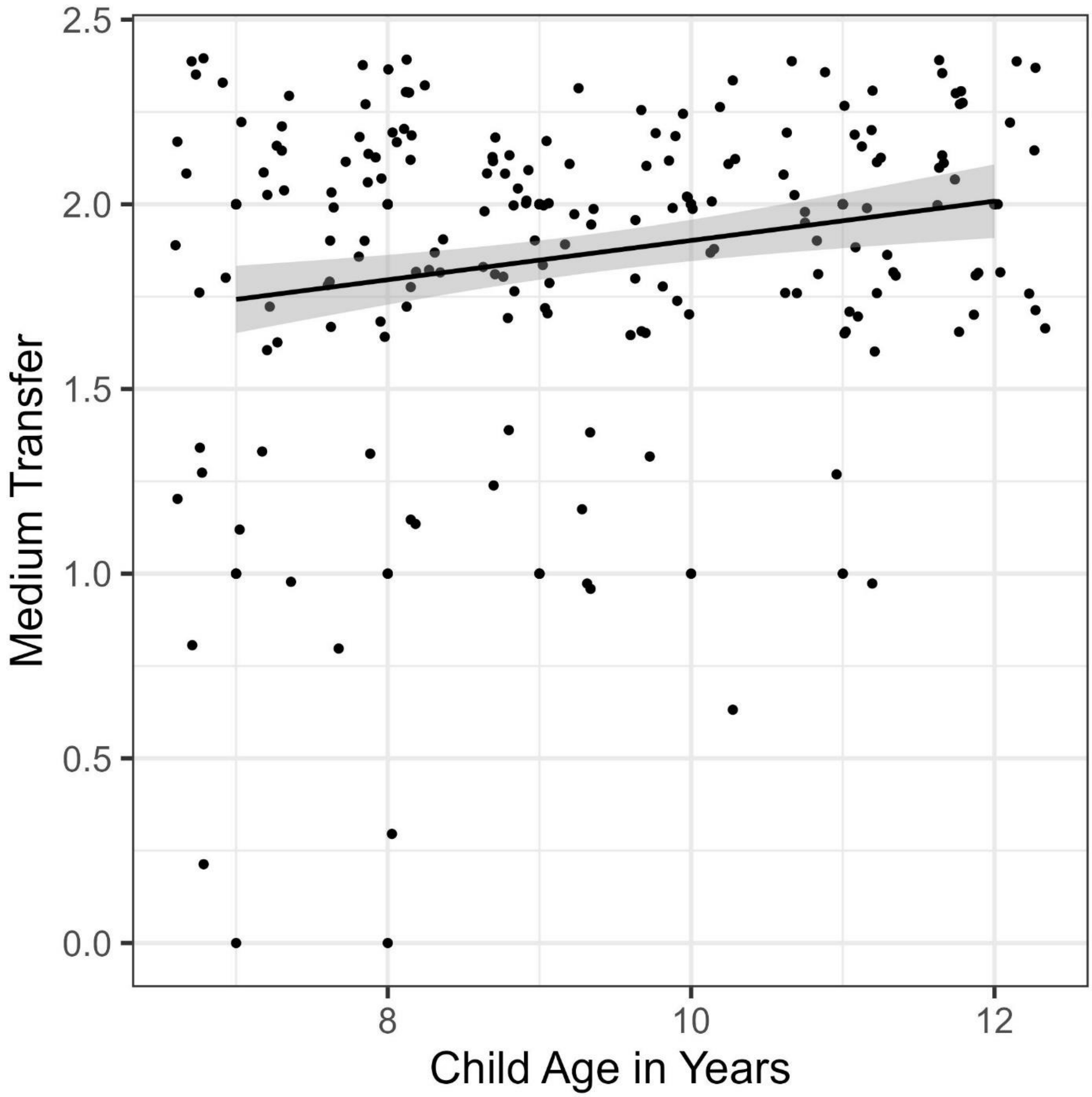
Near Transfer Task Performance and Age



Note. Data points are jittered for viewing density. Though it appears that datapoints reach over the maximum score (5), these points are the maximum score, but they are spread out so the reader can more clearly see how many children scored at each level. $N = 188$

Figure 5

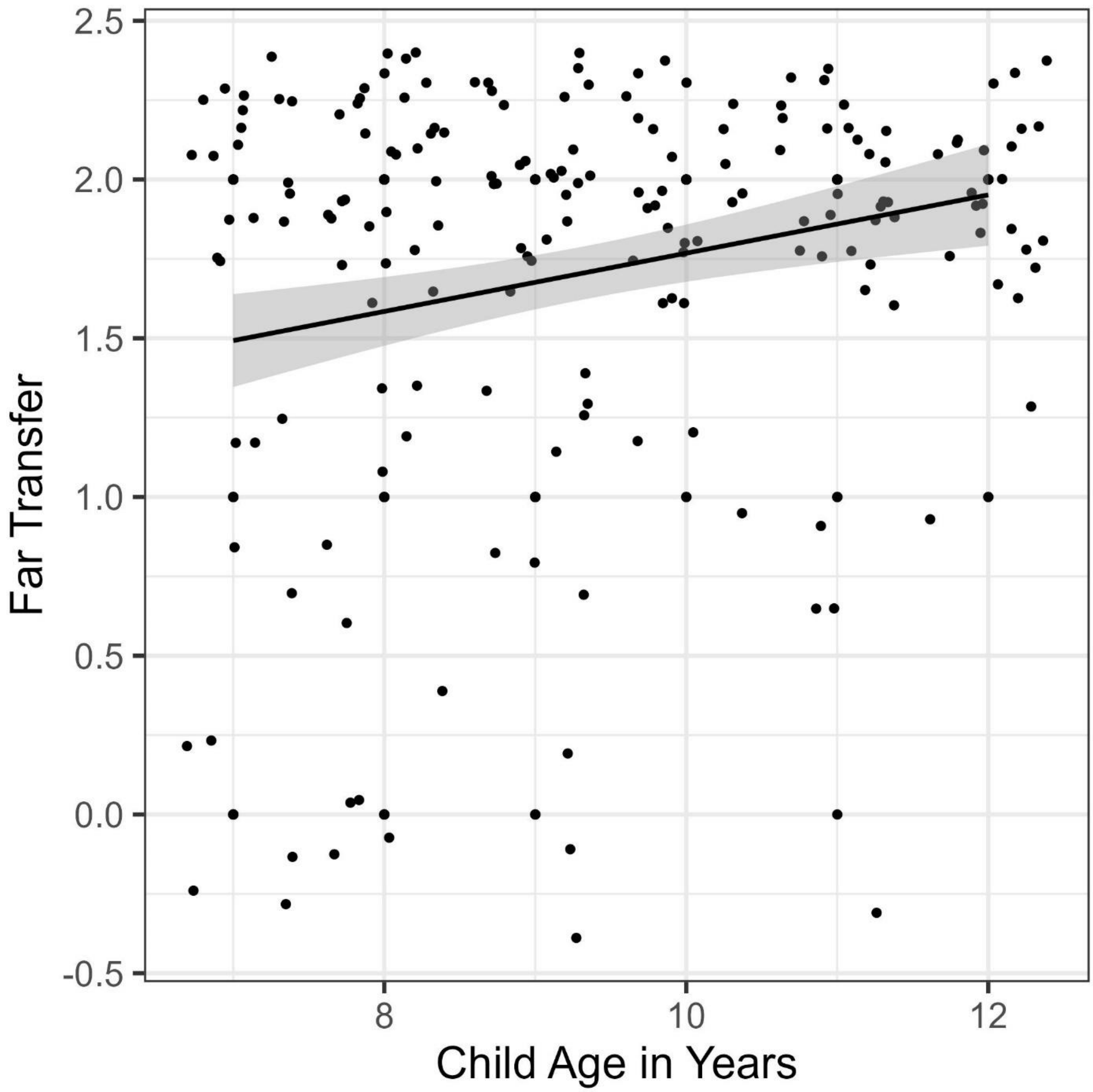
Medium Transfer Task Performance and Age



Note. Data points are jittered for viewing density. Though it appears that datapoints reach over the maximum score (2), these points are the maximum score, but they are spread out so the reader can more clearly see how many children scored at each level. $N = 188$

Figure 6

Far Transfer Task Performance and Age



Note. Data points are jittered for viewing density. Though it appears that datapoints reach over the maximum score (5), these points are the maximum score, but they are spread out so the reader can more clearly see how many children scored at each level. $N = 188$

Table 1

Puzzle Completion Coding Scheme

Category	Description
Finished (1)	The child independently finished the puzzle by putting all of the pieces together such that they fit into the box drawn on the page. The experimenter did not suggest puzzle placement to the child (experimenter error, even if the child asked for help).
Did Not Finish (0)	The child did not finish the puzzle or claimed to finish the puzzle, but the pieces did not fit together in the box. The experimenter took the incomplete puzzle away. If the child came back to the puzzle later and completed it (experimenter error), it still considered incomplete as this puzzle came outside of the order of the experiment. If the experimenter gave the child a hint (experimenter error), the puzzle is considered incomplete.
NA	The puzzle was not given to the child or the experiment ended before the child got to this puzzle.

Table 2

Correlations

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Condition													
2. Child Age	.03												
3. Child Race	.14	-.07											
4. Child Gender	.04	.02	-.01										
5. Parent Age	-.06	.08	-.12	.11									
6. Parent Race	.19*	-.05	.93**	.01	-.09								
7. Parent Gender	-.03	-.08	-.12	.06	-.13	-.15*							
8. Parent Education	.13	-.10	.03	-.03	.09	.10	-.03						
9. Household Income	.08	-.03	-.12	-.10	.08	-.13	-.21**	.35**					
10. Used VR Before	.08	-.26**	.14	.10	-.09	.16*	.06	.06	-.03				
11. Video Gaming Experience	-.01	.29**	-.05	-.11	.03	-.06	-.11	-.06	.13	-.39**			
12. Near Transfer	.02	.17*	.09	-.16*	-.00	.10	-.03	.04	.16*	.00	.05		
13. Medium Transfer	.04	.23**	.13	.02	.09	.11	-.05	.12	.18*	-.08	.09	.49**	
14. Far Transfer	.04	.25**	.10	-.04	.01	.11	-.16*	.09	.24**	.04	.02	.40**	.52**

Note. Condition was coded a 0 – neutral cues 1 – predictive cues. Parent and child gender was coded 1 – boys/men 2 – girls/women. Parent and child race was coded as 1 – White 2 – Hispanic/Latino, Black/African American, Asian, American Indian and Alaska Native, and two or more races.