Toddlers' Learning from Touch Screens: The Role of Working Memory

By

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Abstract

Toddlers exhibit difficulty transferring information from video to real-world events (Anderson & Kirkorian, 2015). The goal of these three studies was to examine the role of working memory and cognitive load in toddlers' learning from screens. In Study 1, a battery of working memory tasks was used to identify an age-appropriate task for toddlers (27-34.5 months, N = 62). Study 2 examined the role of working memory in transfer of learning and the effects of contextual differences in the transfer. A subsample of toddlers from Study 1(N= 42) watched a hiding event on a tablet computer and then found the hidden object either on a felt board (between-context transfer) or another tablet (within-context transfer). Results from Study 2 indicated that working memory was a significant predictor of search performance regardless of the contextual change. In addition, the within-context group performed better than the between-context group during earlier trials, but this effect was reversed in later trials. Study 3 examined whether the facilitative impact of interactivity on toddlers' learning varies as a function of working memory capacity. The remaining toddlers from Study 1 (N = 20) were randomly assigned to an interactive condition in which children touched the screen to view hiding events before searching for the hidden object on the felt board. These toddlers were compared to the noninteracitve, between-context transfer condition in Study 2. Results from Study 3 revealed that making video interactive increases toddlers' performance regardless of their working memory skills. Together, these findings suggest that transferring information from screens is cognitively demanding for toddlers, as indicated by better performance as working memory skills increase. Also, toddlers have more difficulty transferring from screens when task demands are high either by increasing the perceptual differences between hiding and retrieval contexts or by increasing

competition between multiple representations across learning trials. However, while interactive media may require more cognitive effort, it nonetheless enhanced transfer of educational content even for toddlers with low working memory skills, suggesting that carefully designed interactive media may have the potential to be particularly effective tools for early learning.

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Chapter I: Literature Review

Introduction

Recent years have seen a rapid increase in young children's use of interactive mobile digital devices such as smartphones, iPods, and iPad-style tablets (Rideout, 2013). This parallels the growing production of interactive media such as mobile apps and games, targeting toddlers and preschoolers (Shuler, 2012). Regarding traditional media, more than decades of research demonstrated that toddlers exhibit difficulty in transferring information from video to real-world events, a phenomenon labeled as a *video deficit* (Anderson & Kirkorian, 2015; Anderson & Pempek, 2005). However, recent research on interactive media has shown that interactivity can support toddlers' learning (Choi & Kirkorian, 2016; Lauricella, Pempek, Barr, & Calvert, 2010; Kirkorian, Choi, & Pempek, 2016). Despite the promising evidence supporting the benefit of interactive media, the questions of how and for whom interactive media can be beneficial have yet to be examined. To better understand the nature of media effects, it is important to investigate contextual influences and individual differences that moderate media effects (Valkenburg & Peter, 2013).

Information processing theories posit that young children have limited working memory capacity and they would learn more when cognitive load is lessened (Baddeley, 1986). Also, researchers who study the video deficit have proposed several mechanisms that might increase or decrease cognitive load in working memory (e.g., Barr 2010). Working memory has been studied in relation to various cognitive activities and learning outcomes (Im-Bolter, Johnson, & Pascual-Leone, 2006; Blair & Razza, 2007; Bull & Scerif, 2001). Thus, toddlers' working memory may be an important factor to explain the difficulty of learning from traditional media and the facilitative effect of interactive media. However, the role of individual differences in working memory has not been studied in details with toddlers' screen-based learning.

The purpose of this dissertation is to understand the role of working memory and cognitive load in screen-based learning. This literature review begins with a summary of information processing theories as a theoretical framework of proposed studies. It includes a review of the development of working memory skills in very young children. It moves to what is currently known about young children's screen-based learning and then a summary of relevant theoretical accounts regarding the video deficit. This chapter concludes with a list of research questions.

Theoretical Framework

The theoretical framework for this dissertation is based on information processing theories, which are a collection of theories and models that define human thinking as the processing of information. Historically, information processing approaches emerged in the 1950s with the Cognitive Revolution as a movement that was opposed to Behaviorism (Baddeley, 1993) and attempted to identify how human minds actually function. Information processing approaches cover broad topics such as memory, strategies, problem solving, and intelligence (Miller, 2010) and have generated a wide range of theories such as neo-Piagetian, connectionist, and production-systems theories (see Munakata, 2006; Siegler & Alibali, 2005). The most important commonality of these wide ranges of information processing theories is that that human information processing is limited in terms of capacity and speed of processing, which requires flexibility in our thinking to adapt to environments (Klahr & MacWhinney, 1998).

Information processing theories divide human thinking into specific structures, such as attention and memory (Sigler & Alibali, 2005). Memory can be further classified as sensory memory, working memory, and long-term memory. Sensory memory is a capacity for retaining information from environments for a relatively short period of time, whereas long-term memory

is a place for experiences and facts about the world with no limitation on the amount or the length of information to be stored. Working memory is the place where individuals combine information coming into sensory memory with information stored in long-term memory. Working memory, in particular, is considered to be an important structure for various problem-solving activities due to the fact that it is the place to hold and manipulate information.

In addition to the cognitive structures, information processing approaches emphasize cognitive processes, such as encoding, storage, and retrieval used to actively manipulate information in sensory, working, and long-term memory (Sigler & Alibali, 2005). For example, young children often fail to encode important features of objects and events because sometimes they do not know how to encode them efficiently (Franchak, Heeger, Hasson, & Adolph, 2015; Frank, Vul, & Johnson, 2009; Kirkorian, Anderson, & Keen, 2012). Also, young children might have information stored in long-term memory but be unable to retrieve that memory in order to solve a problem at a later time (Barr, 2010). For successful learning, it is essential to selectively attend to and encode important elements in the environments and to store and retrieve them appropriately. Failure during any of these processes can limit the effective processing of information.

Cognitive growth in information processing theories is conceptualized in terms of age-related or experience-related changes in capacity and efficiency (Towse & Hitch, 2007). In information processing theories, structural and procedural features of the cognitive system are maintained throughout development. That is, these features are universal; all children have the same basic cognitive organization as adults. However, while the structures are intact throughout the lifespan, changes occur in how the system functions. For example, information processing theories assume that young children have limited capacity to hold and manipulate information in

mind. With increasing age, children can hold longer strings of items or do more manipulations of information such as reproducing a sequence in reverse.

Developmental changes are often assumed to be maturational and based on the development of the brain such as myelination (Case, 1995). However, developmental increases in capacity may also reflect children's improved efficiency in using a constant amount of capacity (Case, 1995; Dempster, 1981). For example, when cognitive skills are practiced, children become faster at processing, and thus they can deal with more information at a given time. Likewise, children can further utilize a given amount of capacity as they become more skilled at processing. Also, increased knowledge may help children to select the most critical information because they can utilize their preexisting categories or structures, allowing more efficient processing as children develop.

The specificity of the information processing theories offers a useful framework for the precise analysis of performance and change that can be tested in experimental settings (Sigler & Alibali, 2005). Error analysis and microgenetic designs are especially powerful methods for developmental research on how children learn. Especially, a trial-by-trial analysis method can facilitate understanding of how children acquire information over the course of an experiment session. As an example, researchers who conducted object-retrieval studies not only analyzed correct responses in the task but also considered the types of errors that children made across multiple trials, enabling researchers to speculate underlying mechanisms of incorrect answers (Schmidt et al., 2007; Schmitt & Anderson, 2002; Troseth, 2010).

An additional strength of the information processing approach is its utility in identifying underlying mechanisms of cognitive activities by exploring the role of individual differences (e.g., executive function). While there are several studies exploring group differences in specific

processes related to the video deficit (e.g., attention, memory) (Kirkorian et al., 2012; Barr & Hayne, 1999), research examining individual variations in learning is still sparse (Valkenburg & Peter, 2013). Understanding the link between cognitive skills and screen-based learning would provide an important groundwork for future studies on examining the impact of media on children's development.

The information processing approach can be used not only to inform basic research on young children's learning but also to provide specific guidelines to inform the effective design and use of educational media. One example is Fisch's (2000) capacity model, which is rooted in information processing theories and shows how effective learning from television is possible through the efficient use of working memory resources. Specifically, an educationally effective program requires a balance between educational messages and narratives of the program to make them fall within children's working memory capacity limit. For example, utilizing familiar characters (Lauricella, Gola, & Calvert, 2011) or repetition (Barr, Muentener, Garcia, Fujimoto, & Chavez, 2007) can reduce the demands on cognitive resources and allow more efficient processing of narrative and educational content. As an extension of his capacity model, Fisch (2004) later proposed that the extent to which children transfer information from media to the real world would depend, at least in part, on the extent to which the surface features of the television program (e.g., animation versus live action) match those in the real world. According to this account, children will be more likely to retrieve information from long-term memory if the perceptual differences between television and reality are reduced. These models provide information about the effective design and use of educational media and also posit individual differences that moderate learning, such as working memory capacity.

As applied to this study, information processing theories emphasize the cognitive mechanisms (e.g., working memory) involved in children's learning from screens, as well as the degree to which task demands influence learning (e.g., by increasing cognitive load). Information processing theories also call attention to individual differences in how children process information on screens, for instance as a function of working memory capacity. This dissertation aims the practical application of information processing theories to the topic of toddlers' learning from non-interactive and interactive screen media.

Development of Working Memory

Of particular importance to this dissertation is working memory, the essential structure in which active thinking processes take place (Sieger & Alibali, 2005). Working memory is defined as a limited-capacity store of temporary memory which forms the basis of information processing systems. The specific focus of the current dissertation is on visual-spatial working memory, which is suggested as a component separated from verbal working memory (Baddeley, 1986; Baddeley, Lewis, & Vallar, 1984). An important characteristic of working memory is its limited capacity. Given the limited availability in working memory, humans need to exert cognitive processes to adapt to their environment (Baddeley, 1993). For example, one can control the amount information that enters into memory by selectively paying attention to limited items. These attentional control aspects of working memory have gained much attention in recent years.

Working memory supports the capacity for complex cognitive activities (Baddeley & Hitch, 1974). Working memory entails the ability to maintain and update information in the mind for future actions, making it an important aspect of cognitive control or executive functioning that helps guide thoughts and behaviors in a goal-directed manner (Morasch, Raj, & Bell, 2013;

Carlson, Zelazo, & Faja, 2013). Thus, early development of working memory has shown to be predictive of various cognitive activities and learning outcomes including language development (Im-Bolter, Johnson, & Pascual-Leone, 2006), mathematical skills (Bull, Espy, & Wiebe, 2008; Bull & Scerif, 2001; Clark, Pritchard, & Woodward, 2010), and cognitive and academic outcomes (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Blair & Razza, 2007; Diamond, Barnett, Thomas, & Munro, 2007).

Working memory can be distinguished from short-term memory, which refers to the ability to hold information in the mind. However, the distinction between short-term and working memory is not always clear; therefore, the terms "simple" and "complex" working memory have been proposed (Garon, Bryson, & Smith, 2008). The simple form of working memory exists early in life. The delayed-response task is the most commonly used paradigm to measure how long and how many representations can be retained. Infants around 6 months of age can hold a representation for a few seconds and this increases up to ten seconds near their first birthday (Diamond & Doar, 1989). Pelphrey et al. (2004) found that 12-month-olds could find an object in four possible hiding locations, suggesting that they can hold four items in their mind. The number of items that can be held in the mind increases between the ages of three and five years (Hongwanishkul, Happaney, Lee, & Zelazo, 2005), and it continues to improve during the preschool period (Gathercole, 1998).

The complex form of working memory, the ability to not only hold information in the mind but also update and manipulate information for actions, appears to improve later in development. Stationary and scrambled pot tasks are designed to assess complex working memory in young children; in these tasks, an experimenter hides objects under cups and asks a child to find them after either leaving the cups stationary (simple) or scrambling them (complex).

Using these tasks, Diamond et al. (1997) showed developmental improvements in both simple and complex working memory between 15 and 30 months.

Despite increasing attempts to develop behavioral assessments of working memory in young children (Blair, 2002; Carlson & Moses, 2001; Hughes, 1998), difficulties still exist in finding developmentally appropriate measurement tools. Compared to infancy and early childhood, much less is known regarding developmental changes associated with working memory skills during toddlerhood (12-36 months; Diamond, 2002; 2006). Despite the rapid development in language and cognition from infancy to childhood, there is a lack of research examining the development of working memory in toddlerhood.

Given the importance of working memory skills in a diverse range of cognitive abilities, the role of working memory in toddler's learning from screens has also been speculated (Barr, 2010; Fisch, 2000; Schmidt et al., 2007; Suddendorf, 2003). Nevertheless, only a few studies have examined the role of working memory in young children's learning from screens. In the following section, the development of screen-based learning and the potential role of working memory skills are described.

Toddlers' Learning from Screens and Accounts for a Video Deficit

The presence of interactive mobile media in children's daily lives has rapidly increased in recent years. According to a series of nationally representative surveys conducted in the United States, the percentage of children aged 0-8 years who have ever been exposed to interactive mobile devices has nearly doubled in just a two-year period from 38% in 2011 to 72% in 2013, including 38% of children under 2 years and 80% of children 2 to 4 years (Rideout, 2011; 2013). Furthermore, the Joan Ganz Cooney Center at Sesame Workshop reported that toddlers and preschoolers are the target audience of the majority (58%) of the apps in the educational category

on the iTunes App Stores (Shuler, 2012). With the rise of touch screens loaded with interactive features, the question has been raised as to whether these new interactive media provide any additional educational benefit above and beyond what has already accrued by traditional media.

Screen-based Learning in Toddlerhood

The cumulative evidence provides a strong contrast to the belief that television viewing is an effortless activity. Numerous studies have documented that learning from videos requires a set of cognitive skills, including attention, comprehension, and memory, which develops over time and improves with biological maturation and experience (for review, see Anderson & Hanson, 2010). Thus, the design of effective educational programs such as *Sesame Street* or *Blue's Clues* owes a great deal to extensive research on the development of cognitive skills (Anderson et al., 2000; Fisch & Truglio, 2001). These programs are meticulously designed to deliver educational messages to preschoolers with the consideration of their limited cognitive processing capacities (Fisch et al., 2005).

Despite the effectiveness of some educational television programs for preschoolers, learning from a video is a cognitively demanding task, particularly for children younger than 3 years of age; these young children find it more difficult to use information from screens than equivalent in-person experience to solve real-world problems. It is important to note that infants and toddlers can gain some information from video but their learning from video is poorer compared to learning from real-life experience. This difficulty has been labeled the *video deficit*, the observation that children younger than 3 years of age show a relative difficulty in learning from screens compared to real-life experiences (Anderson & Pempek, 2005; Anderson & Kirkorian, 2015). The video deficit has been documented across different domains of development such as imitation, language, and object retrieval, which are described in turn.

Imitation tasks are often used to study learning among infants and young children. In imitation studies, children are asked to watch an actor demonstrating actions and then to execute the observed actions. Barr and Hayne (1999) examined whether 12-, 15-, and 18-month-old infants could imitate three-step actions (e.g., remove a puppet's mitten, shake the mitten to hear a bell inside, and remove the bell from the mitten). Results indicated that infants as young as 12 months demonstrated better imitation of unmediated, in-person models than video models. Hayne, Herbert, and Simcock (2003) found that the performance of the video group was still inferior to that of the live demonstration group even at 2 and 2.5 years of age. Similar results have been consistently reported in studies of children between 12 and 30 months (Hayne et al., 2003; Strouse & Troseth, 2008). These studies using simple imitation procedures provide evidence to support that the video deficit peaks between 15 and 30 months of age (Barr, 2010), although the video deficit may persist until at least 42 months of age when using more complex imitation tasks that are designed for older children (e.g., Dickerson et al., 2013).

Another area in which the video deficit is visible is language learning. Evidence from research on more fundamental language skills such as phonemic awareness suggests that infants exhibit the video deficit before they reach their first birthday. For instance, a group of 9- and 10-month-olds exposed to a live Mandarin speaker were able to maintain perception of Mandarin phonemes three months later, but another group of infants exposed to the same speaker on video did not retain this ability (Kuhl, Tsao, & Liu, 2003). Other studies demonstrate that a video deficit in the ability to learn words from video begins as early as 13 months of age for nouns (Krcmar, 2010) and lasts until at least 42 months of age for verbs (Roseberry, Hirsh-Pasek, Parish-Morris, & Golinkoff, 2009).

Evidence also comes from studies using object-retrieval tasks. In such tasks, children are asked to watch an experimenter hiding an object (either in person or on video) and to remember the location in order to search for the hidden object in the real display. The original object-retrieval study was designed to explore children's ability to use symbolic objects, such as scale models and pictures (DeLoache, 1987; DeLoache, 1991; DeLoache & Burns, 1994). Using the object-retrieval task, researchers have found that the ability to learn from video develops between 24 to 36 months of age (Troseth & DeLoache, 1998; Schmitt & Anderson, 2002; Schmidt, Crawley-Davis, & Anderson, 2007). These studies demonstrated that it is the use of video specifically, rather than the difficulty of the task more generally, that impedes performance by young children.

In sum, experimental studies show that the difference between the video and live conditions peaks around 15 months of age, continues until about 30 months of age, and generally decreases around 36 months of age (Barr & Hayne, 1999; Hayne et al., 2003; Kuhl, Tsao, & Liu, 2003; Schmitt & Anderson, 2002; Troseth, 2003; Troseth & DeLoache, 1998). The results are relatively consistent for children around 24 months of age, but the specific age range varies depending on the type and difficulty of the tasks (McGuigan, Whiten, Flynn, & Horner, 2007; Roseberry et al., 2009). Therefore, the video deficit is considered as a domain-general phenomenon, but the exact developmental time course of experiencing the difficulty appears to be a moving window influenced by the specific characteristics of each task.

Several theoretical accounts have been proposed to explain why the video deficit exists. Although these accounts are not mutually exclusive, a fully-fledged account of the phenomenon has not yet been developed. The following sections describe two different theoretical accounts of the video deficit that are grounded in the information processing framework: (a) representational

flexibility and (b) graded representations in working memory. The evaluation of each account and the possibility of combining these two accounts are discussed in the following sections.

Representational Flexibility Account of the Video Deficit

Recently, the video deficit has been referred to as a transfer deficit (Barr, 2013), emphasizing that the deficit is due to the difficulty of transfer across contexts generally (e.g., 2D to 3D or vice-versa), rather than transfer from video specifically. This argument is based on the representational flexibility account, which emphasizes the difficulty of equating a two-dimensional video image and a real-life object. Representational flexibility refers to the ability to retrieve memories regardless of changes in cues, which allows the generalization of learning to new circumstances (Eichenbaum, 1997). As children get older, they are more likely to tolerate perceptual differences between the encoding and the retrieval contexts because of the increase in working memory capacity. Given that research examining the video deficit requires children to transfer what they saw on the screen to objects in real life, representational flexibility is an essential feature of tasks examining the video deficit (Barr, 2010). While there is no universally accepted explanation for the video deficit, the representational flexibility account is promising to address the mismatch between screens and real objects, which increases the processing load. Furthermore, the representational flexibility account is consistent with age-related improvement in children's ability, insofar as working-memory capacity increases with age.

Based on this account, reducing working memory demands would improve transfer (Barr, 2010). Prior research has attempted to reduce cognitive processing load either by allowing repeated exposure to video images, reducing the complexity of tasks (e.g., number of steps required to solve a problem) or eliminating the competition between mental representations (e.g., between current learning trials and previous ones). The results of these manipulations are mixed.

Some studies found that lowering working memory demands ameliorated the video deficit (e.g., Barr & Hayne, 1999, Exp. 2; Huang & Charman, 2005; Meltzoff, 1988). For example, Barr and Hayne (1999) used a simplified imitation task and showed that 15-month-olds' performance in the video group was as good as the in-person group. However, lowering the working memory load does not always enhance children's learning from screens (Flynn & Whiten, 2008; Gerhardstein et al., 2009; Hayne et al., 2003), perhaps due to relative differences in task difficulty across studies (Barr et al., 2010).

The representational flexibility account assumes that the mismatch between encoding and retrieval is a particularly important source of transfer difficulty. Therefore, according to this account, lowering the contextual differences between encoding and retrieval should improve transfer. Consistent with this hypothesis, Zack et al. (2009) found that 15-month-olds were able to imitate target actions when the transfer between dimensions was not required. For example, if 15-month-olds watched an action on the screen (e.g., pressing a button on a touch screen) and were tested on the same screen, then their performance was as good as that of children who watched and were tested with a real object (e.g., pressing a button on a real toy). Contrarily, the transfer groups were not as successful as the no-transfer groups regardless of the direction of transfer (i.e., real object to screen, screen to real object). This study suggests that young children may learn from screens as well as from real-life demonstrations but they are less likely to transfer between real objects and screens.

The findings of Zack et al. (2009) provided important insights regarding the video deficit by highlighting the role of the mismatch between encoding and retrieval contexts in the video deficit. In this study, however, the role of working memory has not been directly tested. Research that directly assesses individual differences in working memory would enable

researchers to control for, or directly explore, the role of working memory capacity. However, the direct relation between children's working memory and their ability to learn from screens has not yet been investigated.

Furthermore, the representational flexibility account has been supported by studies using the imitation paradigm, but it has not been directly tested using object-retrieval tasks, which allows testing performance over multiple trials. In object retrieval tasks, prior research revealed that 2-year-olds were able to apply information acquired from video to their search on the first trial but not for subsequent trials. When errors were made, 2-year-olds often perseverated by looking at the outdated hiding location, where they found the toy in the previous trial. This phenomenon suggests that toddlers are able to learn from video when memory demands are low, but they have particular difficulty updating memory in the face of outdated (but salient) memory from previous search trials (Schmitt & Anderson, 2002; Schmidt et al., 2007; Suddendorf, 2003). Toddlers' superior performance in the first trial and frequent perseverative errors in subsequent trials cannot be explained by the representational flexibility account alone because the contextual differences between encoding and retrieval contexts are the same on the first trial as on subsequent trials. Thus, another account is required to explain this phenomenon.

Graded Representations Account of the Video Deficit

The graded representations in working memory account, when combined with representational flexibility, may account for the full pattern of results reported in previous literature. Children's superior performance on the first trial and their perseverative errors in later trials can be linked to an explanation based on graded representations in working memory. Munakata and Yerys (2001) argued that children's knowledge is graded in nature and that stronger representations are required to solve tasks that involve conflicting information.

According to this account, age-related differences in perseverative behaviors reflect increasing working memory capacity, which enables children to maintain active representations of new information and to flexibly update prior representations (Munakata, 2001).

Based on the graded representations account, two-year-olds are unable to update their representations of the location of an object from the second trial because the new information from the video (i.e., the current hiding event) conflicts with information from real-world experience (i.e., the previous search event). If children's representation of the new location (information from screen) is not strong enough, it conflicts with the representation of the previous location (where they actually searched) in their working memory. At the time of updating their existing representation, children may fail to actively maintain the new information about the location change in working memory because they need to disregard conflicting information of the object's prior location. That is, the memory of the last hiding spot from the real-world search event still interfere with the new target representation from video because the new representation is not salient enough. Because of the lacking ability in selecting the most relevant information from multiple representations, 2-year-olds make perseverative errors by choosing the one that is the most salient in memory (Schmidt et al., 2007). It is only on the first trial, where there is no conflict inherent in the task, that children can succeed even with weak representations of the new information.

The graded representations account is consistent with several studies documenting high rates of perseveration among young children, particularly in learning from video (Choi & Kirkorian, 2016; Kirkorian, Lavigne, et al., 2016; Schmidt et al., 2007; Schmitt & Anderson, 2002). Further evidence to support this account can be found in a study that eliminated the need for memory updating during an object-retrieval task. Instead of having 24-month-olds search in

one space four times, Suddendorf (2003) had toddlers search one time in each of four different rooms. This procedure eliminated competition between representations of different events in the same space, thus ruling out the possibility of perseverative errors and increasing performance in subsequent trials.

Moreover, the graded representations account is consistent with Troseth's (2003; 2010) interpretation of perseverative errors during an object retrieval task. Troseth (2010) developed a symbolic understanding account for object-retrieval tasks including those using video and interpreted toddlers' perseverative errors as a failure to mentally represent both the event on TV and the real event it stands for under the condition of competing representations. While this account places an emphasis on the weak understanding of symbolic functions as the main reason for the video deficit, it also acknowledges the difficulty in updating the mental representation of the current event using information from video, rather than relying on an outdated memory during an object-retrieval task.

Both the representational flexibility and graded representations accounts would predict the association between working memory and toddlers' learning from screens. However, these accounts differ in their predictions regarding the perceptual differences between encoding and retrieval contexts and children's performance across multiple trials. When Zack et al. (2009) initially pitted the representational flexibility hypothesis against other hypotheses using an imitation task, the possibility of conflict between a new and an old representation was not under consideration, given that there was only one imitation trial. Object-retrieval tasks, however, allow researchers to test the representational flexibility account with the consideration of competition between old and new representations. According to the representation flexibility account, reducing the contextual differences would increase transfer across trials. Conversely,

according to the graded representations accounts, reducing the perceptual differences may create two representations that are similar in strength and, therefore, result in greater perseverations and lower overall performance. Therefore, these two accounts make different predictions about children's performance in an object-retrieval task that varies perceptual differences between contexts and that includes multiple search trials.

Learning from Interactive Media

The vast majority of existing research explores toddlers' learning from noninteractive video. However, technological innovations have altered the ways in which children experience media. Advances in both software and hardware allow users to actively engage while viewing. Although interactive media may be more cognitively demanding (insofar as children must plan and organize a physical response), this new type of media may also create additional opportunities to facilitate children's learning from screens. For instance, interactive media may help children learn by drawing attention to important information on the screen or by increasing overall arousal and engagement (Kuhl, 2007).

Closed-circuit video or video chatting is one form of new technology that provides a platform for socially contingent interactions. Social contingency is one of the areas that have been shown to reduce the video deficit. This view of social contingency posits that socially contingent interactions should be accurate in content (Bornstein, Tamis-LeMonda, Hahn, & Haynes, 2008) and intensity (Gergely & Watson, 1996). In the few studies examining the role of social contingency in screen-based learning, researchers defined a socially contingent interaction as a two-way exchange in which the adult on video established herself as relevant and interactive by referring to the child by name and by asking child-specific questions about their siblings and pets. In all cases, toddlers learned better from socially contingent experiences than from

noncontingent videos (Nielsen et al., 2008; Roseberry et al., 2014; Troseth et al., 2006).

While socially relevant interactions via content and intensity are inevitably important aspects of learning, timing and synchrony of interactions are also major features of interactive media such as mobile apps and games in the absence of a socially contingent partner (Roseberry et al., 2014). A few existing studies address the question whether interactivity alone, without adding social factors, would enhance young children's learning from screens. For instance, Lauricella et al. (2010) found that 30- and 36-month-old children who played an interactive computer game and those who observed a live demonstration performed significantly better on an object-retrieval task than children who observed a non-interactive video. Further, the impact of different types of interactivity on toddlers' learning has been recently investigated using touch-screen tablet devices (Choi & Kirkorian, 2016; Kirkorian, Choi, Pempek, 2016). These findings suggest that even interactivity itself, in the absence of socially relevant information from a real-time social partner, can enhance children's learning.

Together, increasing evidence suggests that children's learning from screens can be improved through interactive experiences with media, despite the increased cognitive load created by active responses (versus passively viewing); this renders the role of working memory unclear. Interactive features may decrease processing demands by scaffolding attention to the most important information on screens and therefore support limited cognitive capacity (Choi & Kirkorian, 2016; Kirkorian, Choi, & Pempek, 2016). Eye-tracking studies showed that younger children experience difficulty identifying the most important information on the screen when they watch traditional, non-interactive video (Franchak et al., 2015; Frank et al., 2009; Kirkorian et al., 2012). Therefore, by helping children ignore irrelevant content and focus on important information, interactive media may support children with low working memory to perform as

well as toddlers with high working memory.

On the other hand, given that manipulating screens could be cognitively demanding (Strommen,1993), physical interactions with media may actually hinder learning for toddlers with low working memory abilities. Therefore, adding additional interactive features may increase children's cognitive load, thereby only making toddlers who already possesses sufficient working memory benefit from interactivity.

A third possibility is that interactivity may facilitate toddlers' learning regardless of working-memory skills. In that case, children with both low and high working memory would equally benefit from interactive experience with media perhaps due to mechanisms that are not related to working memory. For example, if toddlers find interacting with screens is more engaging than traditional media, their increased excitement may help them ignore distractions, thereby making more cognitive resources available to solve the task regardless of working memory (Richards & Anderson, 2004).

Taken together, toddlers have difficulty learning from screens, and theoretical accounts suggest that toddlers' working memory capacity as well as the cognitive demands created by the task would moderate what they can learn. However, to date research has not directly assessed working memory in toddlers as it relates to screen-based learning. Also, only few studies simultaneously explored the impact of different sources of cognitive load (such as perceptual similarity across multiple trials or active responses during interactive media). Therefore, considerable research is needed to establish whether, how, and for whom different media experiences can be educationally valuable in order to maximize the impact of educational media.

Overview of the Current Study

This dissertation consists of three studies that were designed to examine the role of working memory and cognitive load in toddlers' learning from screens. The purpose of Study 1 was to identify an appropriate task for assessing working memory in toddlers to reflect variability above and beyond the effects of age and vocabulary. Toddlers (27-34.5 months, N = 62) completed three working memory tasks, which have been reported to have at least some utility for toddlers between 24-36 months and a receptive vocabulary test. This study is presented in Chapter II.

The purpose of Study 2 was (a) to examine the role of working memory in transfer of learning from screens and (b) to examine the effects of contextual differences in transfer. According to the representational flexibility account, reducing the contextual differences would support children's learning by lessening the cognitive demands of transfer (Barr 2010; Zack et al., 2009). However, the graded representations account suggests that contextual similarity may lead to more proactive interference (and therefore decreased performance) when learning is assessed across multiple trials using the same stimuli (Troseth, 2010). A randomly selected subsample of toddlers from Study 1 (27-34.5 months, N = 42) was assigned to transfer between contexts (screen to felt board) or transfer within a context (screen to screen) over four trials. Then the moderating effect of toddler's working memory and the performance over trials were examined. This study is presented in Chapter III.

The purpose of Study 3 was to examine whether the facilitative impact of interactivity on learning varies as a function of toddlers' working-memory capacity. The remaining toddlers from Study 1 (27-34.5 months, N = 20) were randomly assigned to an interactive video condition. These children were compared to the noninteractive, between-context condition in

Study 2 in order to assess the impact of interactivity on learning. Toddlers' working memory was examined as a moderator of the relation between the interactive experience with media and screen-based learning. This study is presented in Chapter IV.

The final chapter presents a general discussion. Findings across the studies were summarized in light of information-processing theories generally and two accounts of the video deficit specifically (representational flexibility and graded representations). It includes several directions for future research and the practical significance of the findings for the development and use of educational media for young children.

Chapter II. Study 1: Selection of Working Memory Tasks

Working memory provides the essential capacity for complex cognitive activities (Baddeley & Hitch, 1974); however, there have been challenges in identifying age-appropriate measurements in young children (Carlson, 2005; Garon et al., 2008). Measuring individual differences in working memory for toddlers is particularly challenging, creating a gap in the understanding of its development. Most working memory tasks for preschoolers and beyond rely on language abilities, which continue to develop throughout the third year of life, making it difficult to isolate toddlers' working memory abilities. Meanwhile, the existing tasks that are commonly used to measure infants' working memory are also limited in their use for toddlers because of a ceiling effect observed once children reach 24 months of age. Therefore, identifying appropriate measures for working memory is an important initial step to understand the role of working memory in toddlers' learning and transfer and to bridge the gap between research with infants and preschoolers.

Despite the difficulties described above, there have been some successful attempts to develop working memory tasks for toddlers, usually by making age-appropriate adjustments to tasks for infants or older children. For instance, the delayed response task is the most commonly used tool to measure simple working memory in infants. In this task, infants are prompted to find a hidden object after a delay. Prior research tested the duration (how long) and capacity (how many) of infants' representations (Diamond & Doar, 1989; Pelphery et al., 2004). Hughes and Ensor (2005) developed a more complicated delayed search task (Spin-the-Pots) to measure complex visual working memory in toddlers by asking children to search for stickers on a rotating display. Thus, this task measures toddlers' ability not only to store but also to update the spatial memory of hidden objects (Garon et al., 2008).

Similarly, while several studies have explored the development of working memory of 3 years of age and older (e.g., Kemps, Rammelaere, & Desmet, 2000), some researchers have adapted these tasks for younger children. For instance, a simplified block-span task can be used to measure toddlers' visual-spatial span (Roid & Barram, 2004). In this task, children are asked to tap a sequence of blocks in the same order as presented by experimenters. Although most of the research using the block-span task is with children over 4 or 5 years of age (Simmering & Perone, 2013), the simplified version of the block-tapping task has been used to measure toddler's performance as young as 2 years of age.

The purpose of this preliminary study was to identify an age-appropriate measure assessing 2-year-olds' individual differences in working memory in order to examine the role of working memory in the video deficit. Based on the literature review of studies on working memory of young children, the three working memory tasks were identified: (a) delayed-response task, (b) block-tapping task, and (c) spin-the-pots task. Of particular interest was which (if any) of these tasks was most likely to capture individual differences among a sample of 2-year-olds.

Method

Participants

Participants for this study included 62 children (32 females) between the ages of 27 and 34.5 months (M = 30.82, SD = 1.80). Eight additional children were recruited but were dropped from the sample due to refusal to complete all tasks (n = 2) or inability to complete the second day of testing (n = 6); however, these children did not differ systematically from study participants on any of the tasks that they did complete. Data were collected from August 2013 through January 2015. Demographic information based on a parent survey is presented below.

Procedure

Two researchers conducted experimental sessions in an empty classroom at a preschool or in a laboratory on the university campus. For preschool participants, the experimenter met with the child in his or her classroom and then ushered him or her into an adjacent room. There were two visits over a one-week period, with each visit lasting approximately 20 minutes. During the first visit, toddlers played an object-retrieval task using a touch screen (described in Chapters 2 and 3) and completed the first two working memory tasks (delayed-response and block-tapping). During the second visit, toddlers completed vocabulary and the last working memory task (spin-the-pots). For lab participants, a child came into the lab with his or her parent, and the child sat on the parent's lap during the lab session. In the lab, all tasks were completed on the same day with a 10-minute break in between. For both preschool and lab participants, the experimenter explained that they would play games together. An assistant noted the children's responses during each task. A video camera, behind the child and looking over the child's shoulder, was used to record the child's behavior.

Measures

Delayed response. This task was adapted from Standford-Binet 5th edition (SB5) Delayed Response (Roid & Barram, 2004). In this task, children found an object hidden under an upside-down cup (Fig 1). The difficulty of the task gradually increased. First, the experimenter hid a toy duck underneath one of 2 cups. Then, the experimenter hid a toy car underneath one of 2 cups and then slid the cups so that they switched places (i.e., the location of the car moved before the child was able to search). Lastly, the experimenter hid the car underneath one of 3 cups for two additional trials (once under the middle and once under the cup to the experimenter's right) and then blocked child's view with an occluder for 3 seconds before the child were asked to search

for the car. The scores ranged from 0-4 based on the number of successful searches.

Figure 1. Each of three individual working memory tasks: (a) delayed response (top left), (b) block-tapping (top right), (c) spin-the-pots (bottom left), and (d) receptive vocabulary (bottom right).

Block Tapping (Corsi-Block Span). There are many versions of Corsi's block span (1971), some of which have been adapted for use with young children. In this study, the block-tapping task was adapted from SB5 edition (Roid & Barram, 2004). In this task, an experimenter demonstrated a block-tapping sequence and asked the child to repeat it. The sequences increased in difficulty over the course of the task. During training, two blocks were arranged in a row on a board and the child was asked to tap the same block that the experimenter tapped (Fig 1). At Level 1, the experimenter tapped one block out of two blocks, and then put the block on the table between the experimenter and the board. Afterward, the child was asked to tap the same block using the block that the experimenter used. If the child did not understand the direction, the experimenter repeated tapping the block and then gently held the child's hand and guided his or her hand to tap the correct block. At Level 2, the experimenter increased the number of blocks up

to four and then tapped out a sequence of two blocks. At Level 3, the experimenter increased the number of blocks up to eight and then tapped out a sequence of two blocks. There were four trials for each of three test levels, and therefore, the total correct responses ranged from 0 to 12.

Spin the pots. This task was adapted from previous studies with 2-year-old participants (Bernier, Carlson, & Whipple, 2010; Hughes & Ensor, 2005). A set of eight visually distinct boxes (e.g., candy tins, jewelry boxes, decorated wooden boxes) was arranged on a round mat (Fig. 1). Eight boxes, six stickers and a scarf were used. For training, all boxes were visible. For training, the experimenter hid a sticker in an opaque box, and the child was asked immediately to retrieve the sticker from where it was hidden. For testing, the experimenter repeated this one more time with a randomly chosen box. For testing, the experimenter hid 6 stickers in 8 different boxes in the child's view, leaving two additional boxes empty. The experimenter covered the boxes with the scarf and rotated the mat 180 degrees. Then the experimenter removed the scarf and asked the child to find the stickers. The child found one sticker at a time. The experimenter covered the boxes and rotated the mat 180 degrees after each search attempt. The child was congratulated and encouraged after each attempt. An observer recorded the chosen box on a score sheet. The task ended when all six stickers were found or after 16 trials, whichever came first. Scores were calculated as 16 minus the number of errors made (i.e., looking in a box in which no sticker had been hidden or in which the child searched on a previous trial). Thus, possible scores ranged from 0 to 16.

Receptive vocabulary. The Receptive One-Word Picture Vocabulary Tests, 4th, Fourth Edition (ROWPVT-4) was used to measure each child's receptive vocabulary (Martin & Brownell, 2010). Each page had four pictures on it. The experimenter showed one page of a flipbook at a time. The experimenter asked the child to point to one of the four pictures that

matched to the word (e.g., “Doll. Which one is the doll?”). The experimenter repeated the request up to three times if the toddler did not immediately respond. The observer recorded whether children produced a correct response by pointing to the corresponding picture. The task continued until the child provided incorrect answers to six out of eight consecutive trials. The total raw score for each child was calculated by counting the number of correct items. Then the vocabulary score was converted to a standardized percentile rank on the basis of the child’s age and gender for comparison across the age range.

Parent survey

Parents were asked to complete an online questionnaire that requested demographic information including parent’s education and child’s race and ethnicity. In order to examine associations between media exposure at home and screen-based learning in the lab (Studies 2 and 3), the survey also requested information about the child’s media use at home. For media use at home, parents reported whether they allow their child to use interactive touch-screen devices and how much time their child spent using different types of media (e.g., television, mobile device) on the previous day.

Results

Parent Survey and Preliminary Analyses

Among the 58.06% of participating families who completed the survey, most (72.22%) identified their child’s race and ethnicity as White. On average, parents had completed 18.5 years of education (*SD* = 2.51, range = 12–23 years) and were in their mid-thirties (M=35.14, *SD* = 3.38, range = 27–47 years). The majority of respondents (83.33%) reported that they allowed their child to use a touch-screen device at home. The children’s total amount of screen time on the previous day averaged 50.61 min (*SD* = 36.49, range = 0–225 min), during which children

spent 40.08 min (*SD* = 42.02, range = 0–180 min) watching television and 9.22 min (*SD* =21.87, range = 0–120 min) using a touch-screen device. These averages are consistent with a recent survey of a large, nationally representative sample of families in the U.S. (Rideout, 2013).

The purpose of Study 1 was to identify which working-memory tasks – if any – would capture individual differences among a sample of 2-year-olds. In particular, we sought a task that resulted in an approximately normal distribution without evidence of a ceiling or floor effect. The tasks were evaluated based on (a) the frequency distribution of scores for each task, (b) the associations between task performance and age, and (c) the associations between individual tasks.

Working Memory Assessments

Frequency Distributions of Scores. The distribution of toddlers' performance in each individual working-memory task is presented in Figure 2, and descriptive statistics are presented in Table 1. For the delayed-response task, the majority of the sample (66.13%) reached the maximum score (4 out of 4), and the distribution was highly negatively skewed (skewness = -1.56, $p < .001$). No child received the minimum score. The distribution suggests a ceiling effect for the delayed-response task.

For the block-tapping task, about one-fifth of subjects (19.35%) received the minimum score (0 out of 12), and the distribution was highly positively skewed (skewness = 0.78, $p < .001$). No child received the maximum score. The distribution suggests a floor effect for the block-tapping task.

For the spin-the-pots task, the range of the performance was between 5 to 16 and the distribution was approximately symmetric. While there was some negative skew (skewness = -0.34, $p < .01$), the distribution for this task more closely approximated a normal distribution than

the distribution for either of the other tasks, insofar as the majority of children received intermediate scores (*M*= 10.38, *SD* = 3.16, *Mdn* = 11). Also, all children found at least 5 of the 6 stickers by the end of the task (16 trials), and only two children received perfect scores.

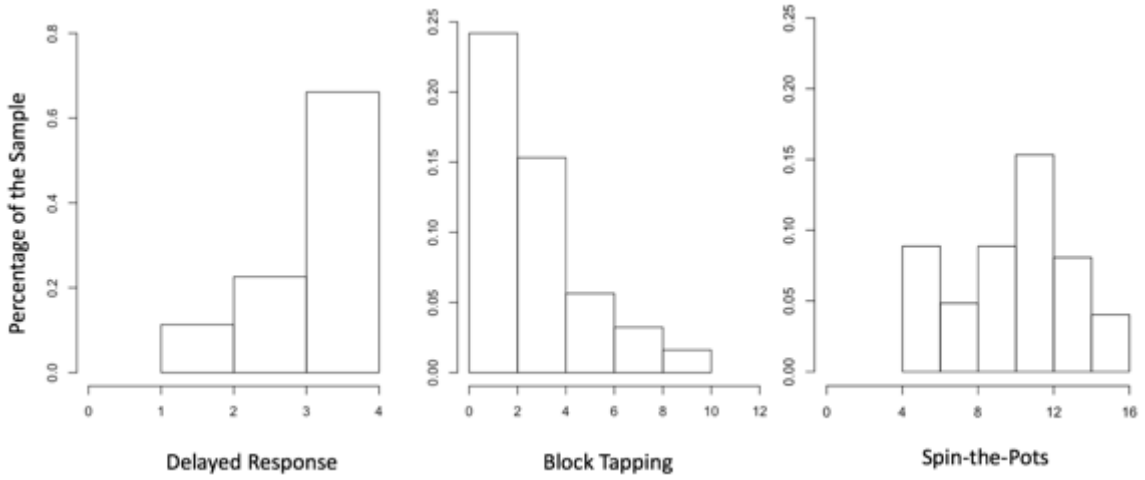

Figure 2. The distribution of performance in each individual working memory task: (a) delayed response (left), (b) block tapping (middle), and (c) spin-the-pots (right) (N = 62).

Table 1. Descriptive Statistics

Task	N	Mean	*SD*	Median	Min	Max	Skewness
1. Delayed Response	62	3.52	0.78	4	1	4	−1.56***
2. Block Tapping	62	3.06	2.45	3	0	10	0.78***
3. Spin-the-Pots	62	10.38	3.16	11	5	16	−0.34**
4. Vocabulary	62	105.95	10.19	105	77	132	−0.11
5. Age	62	30.82	1.80	31	27	34.5	−0.27

**$p < .01$. ***$p < .001$. The possible range for scores were 0-4 for delayed response, 0-12 for block tapping, 0-16 for spin-the-pots, and 55-145 for vocabulary.

Age Trends in Working Memory Performance. Figure 3 plots scores as a function of age for the three working memory tasks. Regression was used to analyze the effect of age for each task. The delayed-response task showed a nonsignificant age effect (β = −0.02, *SE* = 0.06, *t* = −0.36, *p* > .250), block-tapping task showed a significant age effect (β = 0.43, *SE* = 0.17, *t* =2.59, *p* = .012), and spin-the-pots showed a nonsignificant age effect in the group tested (β = 0.09, *SE* = 0.23, *t* =0.39, *p* > .250). The block-tapping task appears to reflect age-related changes, whereas the other tasks reflect individual differences independent of age within the age range of the current sample (27-34.5mos).

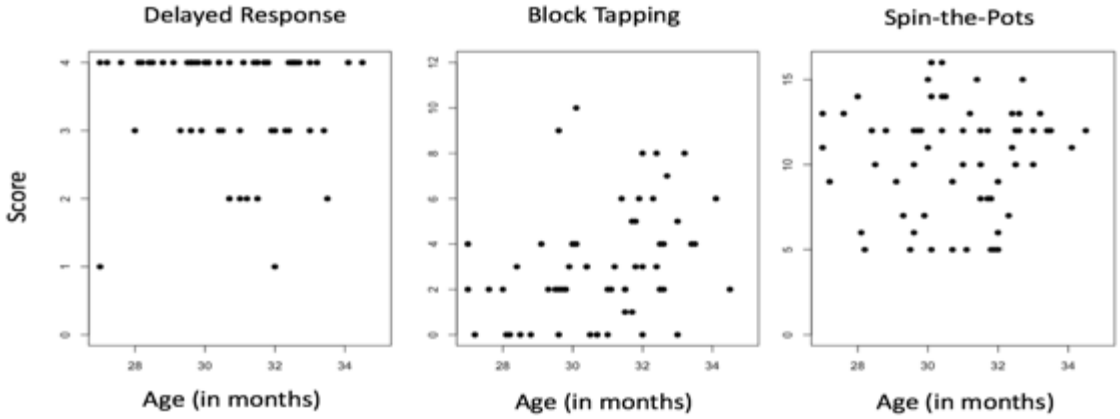

Figure 3. Scatterplots for performance in each individual working memory task as a function of age: (a) delayed response (left), (b) block tapping (middle), and (c) spin-the-pots (right) (N = 62).

Associations Between Tasks. Table 2 presents bivariate correlations and partial correlations after controlling for age for the individual assessments. Neither bivariate nor partial correlations among the three working memory tasks were significant (all *p*s >.250). Moreover, none of the working memory tasks were correlated with normed vocabulary or with age (all *p*s >.250).

Table 2. Correlations Between Assessments and Partial Correlations Controlling for Age

Task	1	2	3	4
1. Delayed Response	_	.18	.15	−.05
2. Block Tapping	.15	_	.08	.14
3. Spin-the-Pots	.14	.09	_	.01
4. Vocabulary	−.05	.18	.01	_

Note. Numbers below the diagonal show correlations while the numbers above the diagonal show partial correlations controlling for age. None of the correlations were significant (all *p*s >.250). N = 64.

Discussion

The purpose of this study was to identify an age-appropriate measure for individual differences in 2-year-olds' working memory capacity. Three working memory tasks were considered: (a) delayed response, (b) block tapping, and (c) spin-the-pots. The correlations between these tasks were low. Moreover, the distributions of scores for the three tasks suggest a ceiling effect for the delayed-response task and a floor effect for the block-tapping task. The distribution for the spin-the-pots task most closely approximated a normal distribution, with the majority of children receiving intermediate scores. In addition, there was no significant relation between this task and chronological age, suggesting that this working memory task is capturing variability above and beyond that of age. Thus, the spin-the-pots task was selected as a working memory assessment for 2-year-olds.

Chapter III. Study 2: The Impact of Contextual Differences on Toddlers' Object Retrieval and the Role of Working Memory

According to information processing theories, young children have limited capacity to hold and manipulate information in memory (Towse & Hitch, 2007), and this capacity is closely related to their cognitive activities such as learning. Thus, to the extent that transferring from screens to real-world situations is cognitively demanding (Anderson & Kirkorian, 2015; Troseth, 2010), children with lower working memory are expected to have difficulty learning from video due to their limited capacity. However, this hypothesis has not been directly tested using individual difference measures of working memory.

Prior research suggests two possible sources of cognitive load existed in transfer from screens: (a) contextual differences between 2D and 3D stimuli and (b) competition between multiple mental representations. Based on the representational flexibility account, it is hypothesized that reducing the contextual differences would support children's learning by lessening the cognitive load due to transfer across contexts (Barr 2010; Zack et al., 2009). Evidence from imitation studies provides support for this account: when learning is assessed in a single trial, infants transfer more easily within one context (e.g., video to video) than across contexts (video to real-world objects or vice-versa; Zack et al., 2009). According to the representational flexibility account, reducing the contextual difference should increase learning equally on all trials.

Regarding children's performance across multiple trials, the graded representations account provides a different prediction that contextual similarity may lead to more proactive interference (and therefore decreased performance) when learning is assessed across multiple trials using the same stimuli (Troseth, 2010). Thus, if perceptual similarity creates more overlap

between representations of the hiding and search event, then it may also increase confusion between representations of separate hiding events, resulting in greater perseveration. Prior research designed to eliminate competition showed improvement in learning, providing evidence to support this account (Suddendorf, 2003). However, one prior study examining the effect of contextual differences (Zack et al., 2009) only included a single trial, and therefore did not directly examine the effect of contextual differences with the presence of the competition between multiple mental representations.

The purpose of this study was two-fold: (a) the first goal was to explore the association between working memory and transfer, and (b) the second goal was to determine whether perceptual similarity (between encoding and retrieval contexts) benefits performance on subsequent trials or results in more perseveration. In this study, an object-retrieval task was used to examine the role of contextual differences across multiple trials. Using a randomly selected subsample from Study 1, toddlers between the ages of 27 to 34.5 months (N = 42) watched hiding events on a tablet computer. To examine the effects of the contextual differences between encoding and retrieval, toddlers were randomly assigned to find a hidden sticker either on a corresponding felt board (between-context transfer) or on another tablet (within-context transfer). The outcome measures were toddlers' errorless retrieval and perseverative errors. In addition, toddlers' receptive vocabulary and visual-spatial working memory (i.e., Spin-the-Pots task) were assessed (see Chapter II).

Both the representational flexibility and graded representations accounts hypothesized that toddlers' working memory would predict toddlers' screen-based object retrieval performance. Moreover, if working memory explains the effects of the source of cognitive load (either contextual differences or competing representations) on learning, working memory was

expected to be particularly important for children in the more cognitively demanding condition. However, the specific task features that create cognitive load differ by each account.

According to the representational flexibility account, increasing perceptual similarity would reduce cognitive load to the same extent across trials (Barr 2010; Zack et al., 2009); thus, performance would be greater in the within-context condition than in the between-context condition in all trials. Moreover, working memory would moderate the effects of contextual differences such that working memory would be particularly important for children in the between-context transfer condition where children are required to transfer between two distinct contexts.

While the representation flexibility account suggests that performance should be better in the within-context condition on all trials, the graded representations account suggests that this might change across trials as competition between representations increases. Specifically, reducing the perceptual differences between the encoding and retrieval events may increase confusions between mental representations (i.e., the competition between the recent, relevant information and the outdated memory); thus, this account would predict that the facilitative effect of the within-context transfer condition would decrease across trials. Moreover, working memory would moderate the effects of contextual differences such that working memory would be particularly important for children in the within-context transfer condition where perceptual similarity may hinder children's ability to distinguish between multiple representations.

Method

Participants and Design

Participants for this study were a randomly selected subsample of Study 1 including 42 children (23 females, 19 males) between the ages of 27 and 34.5 months. Participants were

randomly assigned to one of two conditions: between-context transfer (n = 22, 14 females; mean age = 31.18 months) and within-context transfer (n = 20, 9 females; mean age = 30.35 months).

Stimuli and Apparatus

We used video stimuli and a corresponding felt board adapted from those used in prior studies (Choi & Kirkorian, 2016; Kirkorian, Lavigne, et al., 2016; Schmidt et al., 2007; Fig. 4). The video stimuli were displayed on two touch-screen tablet computers (10.1-in. Galaxy Tab; Samsung America, San Jose, CA) using a mobile application that was developed for this project. The video included images of four hiding locations (a blue gift box, a brown cake, a green balloon, and a red gift box; 4 × 4 cm) and a cartoon teddy bear named Cece (2.5 × 2.7cm). One tablet device was used to display videos about hiding events in both conditions.

Figure 4. The left panel shows the stimuli used in the between-context condition: a touch-screen tablet for hiding events (left) and a felt board for search events (right). The right panel shows the stimuli used in the within-context condition: separate touch-screen tablets used for hiding events (left) and search events (right).

A video camera was located behind the child to record the child's behavior. In the between-context condition, a felt board was used for search events. The felt board had the same dimensions and appearance as the video hiding space. To create the four hiding locations, we printed screenshots of the video images and glued them to white felt, which attached loosely to the surface of the blue felt board. The cartoon character was printed on sticker paper and was

used as the object for which children searched on the felt board. A child lifted the felt objects to see what was underneath.

In the within-context condition, a second tablet device was used to present videos related to search events. The experimenter asked the child to touch an object on the screen to search for the bear, which triggered an animation of the object moving up to reveal what was underneath. See Figure 5 for a full script and procedure during training and test.

Training	General Instructions 	• Cece: "Hi! I'm Cece! I'm going to play a hide-and-seek game with you and your friend. Your friend and I have the same boards. Do you see your friend's board that looks just like this one?" • Experimenter (revealing felt board): "See this?" • Cece: "I will show you where I'm going to hide, and then you can find me on your friend's board! First, let's practice! Watch the screen to see where I might hide!"
	Correspondence Training 	• Cece (moving beneath Location 1; object begins to wiggle): "Sometimes I'll hide here. Do you see this place on your friend's board?" • Experimenter (pointing to corresponding spot on felt board): "See this?" • Cece: "Where else can I hide? Watch me to see another hiding place."
Testing	Introduction	• Cece: "Now it's time to play the game!" • Experimenter occludes felt board.
	Hiding Event 	• Cece: "Look! I'm going to hide now! Then you can find me on your friend's board! Watch me to see where I will hide!" • Character moves behind one of the four objects. • Experimenter occludes screen.
	Search Event 	• Experimenter (turning felt board around so child cannot see it): "Now I'm going to hide Cece, and you can try to find her!" • Experimenter (revealing felt board): "Where is Cece? Can you find her?" • If children are incorrect on their first attempt, experimenter encourages them to try another place.

Figure 5. Script and protocol for training and testing in the between-context transfer condition. The same script and protocol were used in the within-context transfer condition, except that a second touch-screen tablet computer was used in place of the felt board. See the Procedure section for more information.

Procedure

Two researchers conducted experimental sessions in an empty classroom at a preschool or in a laboratory on the university campus as described in Study 1.

Object Retrieval Task. The object retrieval task had two phases: (a) correspondence training with the hiding and search spaces and (b) testing. See Figure 5 for a full script and procedure during training and test. In brief, the experimenter began by placing the tablet computer and the felt board on two side-by-side stands (Fig. 4). During training, the animated character moved to each hiding location on the screen and then the experimenter called attention to the corresponding location on either the tablet computer or the felt board. During testing, there were four object-retrieval trials. In each trial, the child watched the character hide on the tablet computer. The experimenter occluded the touch screen, turned the felt board (or second tablet computer) away from the child, and hid the sticker on the felt board (or launched the corresponding application on the tablet computer). Then the experimenter turned the felt board/tablet toward the child and asked the child to find Cece. To retrieve the sticker, the child had to either lift the felt piece (between-context transfer) or tap the hiding location on the screen (within-context transfer). If the child pointed to a location rather than searching beneath it (between-context) or tapping it (within-context), the experimenter encouraged the child to lift it up/touch it. If the child was incorrect, the experimenter encouraged the child to search another place until the child found the sticker. Thus, each trial ended with the child finding Cece. The same procedure was followed for each of the four trials.

Assessments and Parent Survey. Children's scores on the spin-the-pots task and receptive vocabulary and parent survey information were used from Study 1. See Chapter 2 for descriptions of the procedure and coding method for these assessments.

Coding

For the object retrieval task, search events were coded to denote whether each trial resulted in an errorless search (i.e., the child searched the correct location on the first try). If a child made an error during Trials 2 through 4, the error was further classified as either a perseverative error (i.e., the child searched behind the location that was correct on the previous trial) or a nonperseverative error (i.e., the child searched one of the other two incorrect locations on the first try).

Results

Parent Survey and Preliminary Analyses

Preliminary analyses indicated that child gender, child race and ethnicity, parent education, child exposure to television and touch-screen devices, and the order of hiding locations did not differ significantly across experimental conditions. Moreover, none of these variables predicted search performance. Thus, they were not considered further.

Probability of errorless search by trial and condition

Prior research demonstrated that toddlers' object retrieval using video changes over trials, such that performance is often higher on the first trial than on subsequent trials (Choi & Kirkorian, 2016; Kirkorian, Lavigne, et al., 2016; Schmidt et al., 2007; Schmitt & Anderson, 2002). Thus, search performance on each trial (rather than total correct searches across all four trials) was considered as an outcome measure. A two-level linear mixed-effects model with trials (Level 1) nested within participants (Level 2) was used to assess the effect of condition on errorless search. Given that each trial had a binary outcome—successful (coded as 1) or unsuccessful (coded as 0)—a generalized linear mixed-effects model was specified with binomial error structure and logit link function. See Choi & Kirkorian (2016) for a similar

approach. Models were estimated using the function glmer from the package lme4 (Version 7.0.1; Bates, Maechler, Bolker, & Walker, 2014) in the R software environment (Version 3.2.0; R Development Core Team, 2015). Two measures of model comparison were used to evaluate fitted models: Akaike's information criterion (AIC) and log-likelihood ratio (LLR) tests derived from the maximum log-likelihood by taking into account the number of parameters.

The model structure was as follows:

Level 1 Model:

$$\text{Probability}(ES_{ti} = 1) = \phi_{ti}$$

$$\log[\phi_{ti}/(1 - \phi_{ti})] = \eta_{ti}$$

$$\eta_{ti} = \pi_{0i} + \pi_{1i} \times \text{trial}_{ti} + \varepsilon_{ti}$$

Level 2 Model:

$$\pi_{0i} = \beta_{00} + \beta_{01} \times \text{age}_i + \beta_{02} \times \text{vocabulary}_i + \beta_{03} \times \text{condition}_i + \beta_{04} \times \text{WM}_i + \beta_{05} \times \text{condition}_i \times \text{WM}_i + \gamma_{0i}$$

$$\pi_{1i} = \beta_{10} + \beta_{11} \cdot \text{condition}_i + \gamma_{1i}$$

Combined Model:

$$\eta_{ti} = \beta_{00} + \beta_{01} \times \text{age}_i + \beta_{02} \times \text{vocabulary}_i + \beta_{03} \times \text{condition}_i + \beta_{04} \times \text{WM}_i + \beta_{05} \times \text{condition}_i \times \text{WM}_i + \beta_{10} \times \text{trial}_{ti} + \beta_{11} \times \text{trial}_{ti} \times \text{condition}_i + \gamma_{0i} + \gamma_{1i} \times \text{trial}_{ti} + \varepsilon_{ti}$$

In these models, ϕ_{ti} and η_{ti} represent the probability of errorless search (ES) and the log of the odds of ES, respectively, at trial *t* for participant *i*. π_{pi} represents the trajectory parameter for participant *i* associated with the polynomial of degree *p* ($p = 0, 1$). β_{00} represents the overall intercept, and β_{0q} represents the effect of variable *q* ($q = 1, 2, 3, 4, 5$) on π_{0i} and β_{0r} represents the

effect of variable *q* (r =1) *on* π_{1i}. β_{10} represents an average linear regression slope, and ε_{ti} represents the residual in the log of the probability of ES.

The age and trial variables were treated as continuous predictors and centered at the first point (i.e., a centered age of 0 represents 27 months, and a centered trial of 0 represents Trial 1). The two experimental conditions were represented by one dummy variable, which represented the contrast between the coded condition (within-context) and the reference condition (between-context). All of the predictors were modeled as fixed effects except γ_{0i} and γ_{1i}, which represents the random intercept and random slope, respectively. The residual in the log of the probability of ES was represented as ε_{ti}.

All fixed effects from the final model are reported in Table 3, and the modeled probability of errorless retrieval is plotted in Figure 6 as a function of trial, condition, and working memory (WM). Child age and vocabulary were added as control variables. Child's vocabulary was a significant predictor of errorless retrieval, $\beta_{02} = 0.82$, *SE* = 0.25, Wald $z = 3.33$, $p < .001$, OR = 2.27. As children's vocabulary increased, so did their performance during the search task. After controlling for the other factors, the age of the child was not a significant predictor of errorless retrieval, $\beta_{01} = 0.12$, *SE* = 0.12, Wald $z = 0.97$, $p > .250$, odds ratio (OR) = 1.12.

Table 3. Fixed Effects From the Final Mixed Logit Model Predicting the Probability of Errorless Search

Predictor	β	*SE*	Wald *z*	OR	95% CI (OR)
Intercept (β_{00})	−0.75	0.67	−1.36	0.47	[0.13, 1.72]
Age (β_{01})	0.12	0.12	0.97	1.12	[0.88, 1.42]
Vocabulary (β_{02})	0.82	0.25	3.33***	2.27	[1.40, 3.67]
Condition (β_{03})	1.63	0.64	2.53*	5.12	[1.45, 18.10]
WM (β_{04})	0.63	0.32	1.99*	1.88	[1.01, 3.50]
Condition × WM (β_{05})	−0.52	0.45	−1.16	0.59	[0.24, 1.44]
Trial (β_{10})	0.41	0.24	1.69†	1.50	[0.94, 2.41]
Trial × Condition (β_{11})	−1.15	0.37	−3.08**	0.32	[0.51, 0.66]

Note: The Level 1 variable was trial number; this predictor was centered at the first trial, such that the intercept reflects data at Trial 1. Condition, age, vocabulary, and WM were included as Level 2 variables. Condition was dummy-coded: between-context (reference category) and within-context. Age was centered at 27 months. Vocabulary and WM scores were standardized using z-scores and centered at 0 as the mean values. OR = odds ratio; CI = confidence interval. † $p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$.

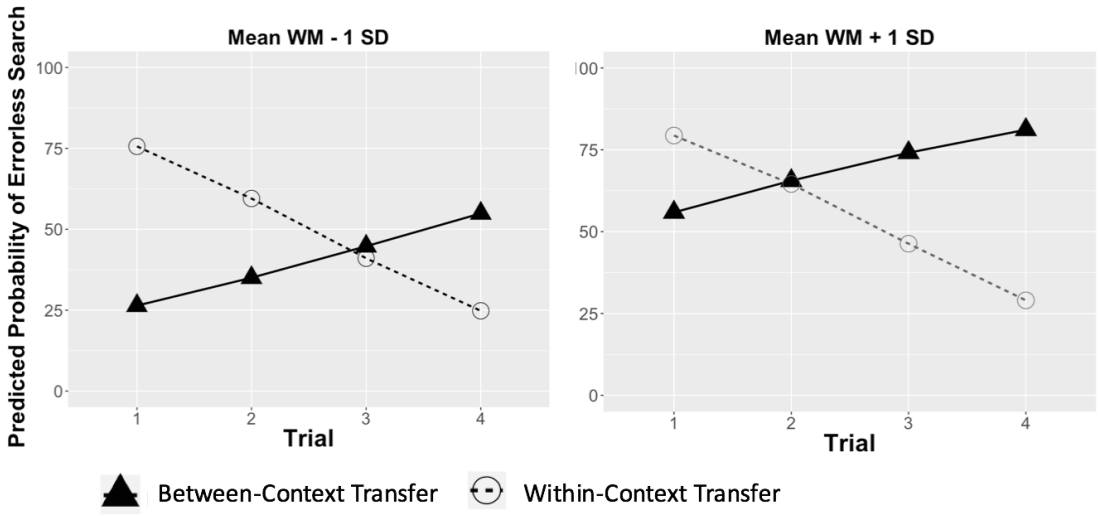

Figure 6. Predicted probability of errorless search as a function of trial for the between-context and within-context transfer conditions. Fitted regression lines plotted at the age of 27 months and the vocabulary (z score) of 0. WM was a continuous predictor and standardized (z score); however, for illustrative purposes, the predicted probability is presented separately for children at 1 *SD* above the mean and at 1 *SD* below the mean.

The main effect of condition reflects the effect on Trial 1 (i.e., centered trial = 0). Condition was a significant predictor such that the probability of an errorless search was higher for the first trial in the within-context condition than in the between-context condition, β_{03} = 1.63, *SE* = 0.64, Wald *z* = 2.53, *p* = .011, OR = 5.12. In terms of probability, the youngest children in the within-context condition were about twice as likely to search correctly on Trial 1 as their peers in the between-context condition. Thus, this condition effect existed on the very first trial, before children faced competition between multiple mental representations (i.e., of the current hiding event and previous search event).

The main effect of WM reflects the influence of WM on search performance in the between-context (reference) condition while the condition × WM interaction tested whether the influence of WM differed between conditions. Toddlers' object retrieval performance improved as their WM increased: children's working memory positively predicted the probability of an errorless retrieval, β_{04} = 0.63, *SE* = 0.32, Wald *z* = 1.99, *p* = .046, OR = 1.88. However, the interaction between WM and condition was not a significant predictor of errorless retrieval, β_{05} = –0.52, *SE* = 0.45, Wald *z* = –1.16, *p* = .247, OR = 0.59. Thus, children's WM predicted search performance equally in the two experimental conditions.

Finally, the main effect of trial tested for change across the four search trials in the between-context condition, while the trial and condition interaction tested whether the trial effect differed across the two conditions. The model revealed changes in object-retrieval performance across the four trials, including a marginally significant linear increase across trials, β_{10} = 0.41, *SE* = 0.24, Wald *z* = 1.69, *p* = .09, OR = 1.50. The main effect of trial was modified by a significant interaction with condition, such that the size of the condition effect decreased as trial increased, eventually reversing in the later trials, β_{11} = –1.15, *SE* = 0.37, Wald *z* = –3.08, *p* =

.002, OR = 0.32. In other words, the within-subject condition improved object retrieval in the earlier trials but hindered object search for the later trials (Fig. 6).

Follow-up analyses revealed that neither a two-way interaction between WM and trial nor a three-way interaction among WM, trial, and condition had a significant effect on the probability of errorless search. In addition to the fitted random-slope model (defined as Model 1), the quadratic slope of trial was examined (defined as Model 2). Model 1 was compared with Model 2 to determine whether adding quadratic slope would increase the fit to the data. The assessment of relative differences in model comparisons suggested that Model 2 did not provide a better fit than Model 1, AIC for Model 1 = 219.12, AIC for Model 2 = 220.42, LLR $\chi 2(4) = 6.70$, $p = .153$. Thus, the quadratic slope was excluded from the analysis.

Probability of perseverative errors by trial and condition

Prior research suggested that performance in the between-context condition would decrease across trials because of a relatively high frequency of perseverative errors in Trials 2 to 4. Consistent with the prior findings, the majority of errors (53.20%) were perseverative across Trials 2 to 4 and across all children in the current study. Of particular interest was whether the likelihood that an error was perseverative varied as a function of child characteristics (age, vocabulary, WM), condition, and trial. A two-level (trials within subjects) generalized linear mixed-effects model was used to predict the probability of making a perseverative error given that an error was made. Only the instances in which errors were made on Trials 2 to 4 were included in this analysis. The outcome measure was a dichotomous variable indicating whether the error was perseverative in nature. The model structure was as follows:

Level 1 Model:

$$\text{Probability } (PE_{ti} = 1) = \phi_{ti}$$

$$\log[\phi_{ti}/(1 - \phi_{ti})] = \eta_{ti}$$

$$\eta_{ti} = \pi_{0i} + \pi_{1i} \times \text{trial}_{ti} + \varepsilon_{ti}$$

Level 2 Model:

$$\pi_{0i} = \beta_{00} + \beta_{01} \times \text{age}_i + \beta_{02} \times \text{vocabulary}_i + \beta_{03} \times \text{condition}_i + \beta_{04} \times WM_i + \beta_{05} \times \text{condition}_i \times WM_i + \gamma_{0i}$$

$$\pi_{1i} = \beta_{10} + \beta_{11} \times \text{condition}_i$$

Combined Model:

$$\eta_{ti} = \beta_{00} + \beta_{01} \times \text{age}_i + \beta_{02} \times \text{vocabulary}_i + \beta_{03} \times \text{condition}_i + \beta_{04} \times WM_i + \beta_{05} \times \text{condition}_i \times WM_i + \beta_{10} \times \text{trial}_{ti} + \beta_{11} \times \text{trial}_{ti} \times \text{condition}_i + \gamma_{0i} + \varepsilon_{ti}$$

In these models, ϕ_{ti} and η_{ti} represent the probability that an error would be perseverative (PE) and the log of the odds of PE, respectively, at trial *t* for participant *i*. ε_{ti} represents the residual in the log of the probability of PE. All of the predictors were modeled as fixed effects except γ_{0i}, which represents the random intercept. All other terms have the same meanings as in the prior set of equations. A full report of fixed effects can be found in Table 4. Frequencies of errorless searches, perseverative errors, and nonperseverative errors are graphed in Figure 7 as a function of trial and condition.

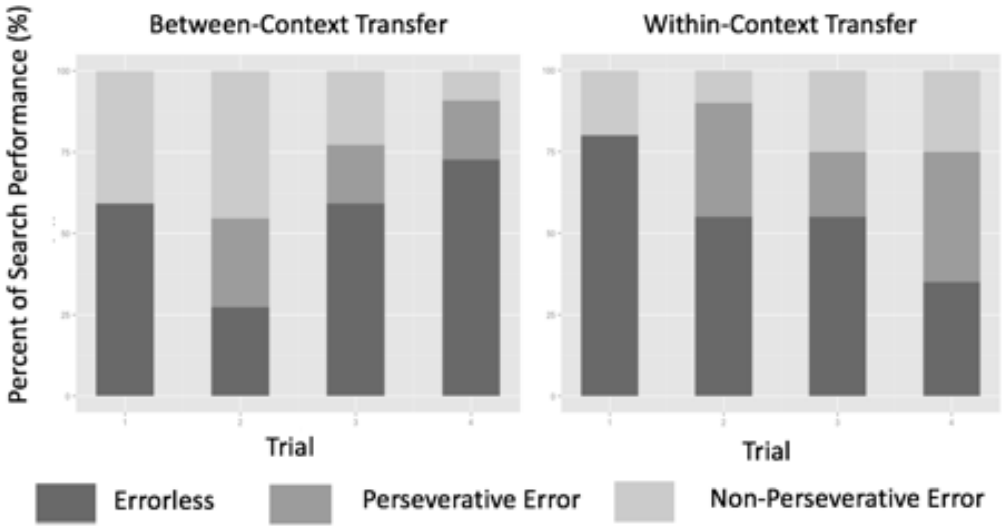

Figure 7. Search performance as a function of trial and condition for errorless searches, perseverative errors, and nonperseverative errors

Table 4. Fixed Effects From the Final Mixed Logit Model Predicting the Probability That An Error Would Be Perseverative

Predictor	β	*SE*	Wald *z*	OR	95% CI (OR)
Intercept (β_{00})	−2.29	1.09	−2.09*	1.10	[0.01, 0.86]
Age (β_{01})	0.36	0.20	1.82†	1.43	[0.97, 6.33]
Vocabulary (β_{02})	−0.16	0.32	−0.52	0.85	[0.46, 1.58]
Condition (β_{03})	1.63	0.64	2.53†	6.10	[0.82, 45.32]
WM (β_{04})	−0.36	0.42	−0.85	0.70	[0.31, 1.59]
Condition × WM (β_{05})	−0.90	0.80	−1.13	0.89	[0.27, 2.92]
Trial (β_{10})	0.75	0.55	1.34	1.50	[0.71, 6.33]
Trial × Condition (β_{11})	−0.11	0.60	−0.19	0.41	[0.09, 2.12]

Note: The Level 1 variable was trial number; this predictor was centered at the first trial, such that the intercept reflects data at Trial 1. Condition, age, vocabulary, and WM were included as Level 2 variables. Condition was dummy-coded: between-context (reference category) and within-context. Age was centered at 27 months. Vocabulary and WM scores were standardized using z-scores and centered at 0 as the mean values. OR = odds ratio; CI = confidence interval.
$^{\dagger}p < .10$. *$p < .05$.

There was a marginally significant effect of age on the likelihood that an error was perseverative, $\beta_{01} = 0.36$, $SE = 0.20$, Wald $z = 1.82$, $p = .069$, OR = 1.43. After controlling for the other factors, child's vocabulary was not a significant predictor of making a perseverative error, $\beta_{02} = -0.16$, $SE = 0.32$, Wald $z = -0.51$, $p > .250$, OR = 0.85. As child's age increased, so did the rate of perseveration during the search task.

The condition was a marginally significant predictor such that the probability of making a perseverative error was higher for the within-context condition than the between-context condition, $\beta_{03} = 1.63$, $SE = 0.64$, Wald $z = 2.53$, $p = .069$, OR = 6.10.

There was neither the main effect of WM, $\beta_{04} = -0.36$, $SE = 0.42$, Wald $z = -0.85$, $p > .250$, OR = 0.70, nor the interaction between WM and condition, $\beta_{05} = -0.90$, $SE = 0.80$, Wald $z = -1.13$, $p > .250$, OR = 0.89. Thus, the probability that an error was perseverative did not vary as a function of WM in either condition.

Neither trial nor the interaction between trial and condition was a significant predictor of the probability that an error was perseverative, $\beta_{10} = 0.75$, $SE = 0.55$, Wald $z = 1.34$, $p = .180$, OR = 1.50, and $\beta_{11} = -0.11$, $SE = 0.60$, Wald $z = -1.19$, $p > .250$, OR = 0.41, respectively. That is, the rates of perseverative errors were similar across trials: 52.00% (13 of 25 errors) in Trial 2, 44.44% (8 of 18 errors) in Trial 3, and 63.16% (12 of 19 errors) in Trial 4. Follow-up analyses revealed that neither a two-way interaction between WM and trial nor a three-way interaction among WM, trial, and condition had a significant effect on the probability that an error was perseverative.

Discussion

The purpose of this study was to determine (a) the extent to which working memory predicts transfer from screens and (b) how toddlers would learn from screens when the

differences between the encoding and retrieval contexts are reduced. Of particular interest was the effect of contextual differences across multiple trials with the presence of competition between mental representations. Consistent with prior research (Zack et al., 2009), toddlers were more likely to transfer from video when they were tested on another screen that was visually identical to the former screen. However, learning was improved only in the earlier trials and the effect was reversed in the later trials. Toddlers with higher working memory skills performed better than toddlers with lower working memory skills in the object retrieval task regardless of the difference in the retrieval contexts.

Toddlers' working memory predicted learning even after controlling for child's age and vocabulary. Thus, this finding is consistent with the representational flexibility account in that transferring information from screens is cognitively demanding for toddlers and requires working memory resources (Barr 2010; 2013). According to this account, reducing the contextual differences supports limited working memory skills by lowering cognitive load. Therefore, working memory should predict learning more strongly in the more cognitively demanding between-context condition. However, this pattern was not found in the current study. Thus, reducing the contextual differences may influence cognitive components other than working memory demands (e.g., individual differences in inhibitory control).

Making the retrieval context similar to the encoding context helped toddlers' retrieval of information displayed on screens in the initial trial. This is consistent with findings that infants (15-16 months) improved imitation of modeled actions that were presented on a touch screen when their recall was tested using the same touch screen rather than using a similar felt object (Zack et al., 2009). This finding also aligned with the facilitative impact of increasing physical similarity among 2.5- and 3-year-olds in other symbol-based retrieval tasks (DeLoache, Kolstad,

& Anderson, 1991; Marzolf & DeLoache, 1994). Thus, this research suggests that the match between encoding and retrieval contexts is an important factor for young children's transfer from symbolic media.

However, this effect was reduced over trials and reversed in the later trials, which is consistent with the graded representations account. This drop in the within-context transfer condition was primarily due to the increase in perseverative errors. That is, toddlers in the within-context condition often made systematic errors by searching the location from the previous trial rather than the current trial. The frequent perseverative errors suggest that the similarity between the two touch screens caused confusion for toddlers, preventing them from selecting the correct mental representation during search events.

In this sample, perseverative errors appear to increase with age, which is not consistent with prior research (Choi & Kirkorian, 2016). Given that the analysis was based on the proportion of errors that were perseverative (when error was made), this reversal may be due to the fact that younger children just made more errors overall, including those that were apparently random (i.e., selecting one of the distractors) whereas older children mainly made perseverative errors.

Together, the findings from this study provide partial support for the representational flexibility account. Consistent with its claim, transfer of learning from screens is cognitively challenging for toddlers as evidenced by better performance as working-memory skills increased. However, while reducing the contextual differences supported learning, the effect was not modified by toddlers' working memory. Moreover, reducing contextual differences facilitated transfer initially but later led to higher rates of perseveration, suggesting that this manipulation made it more difficult for children to distinguish between different mental representations.

Therefore, the representation flexibility account should be modified to consider the mechanisms underlying the effects of contextual differences and to take into account the influence of graded representations in multiple trials.

Chapter IV. Study 3: The Impact of Interactivity on Toddlers' Object Retrieval and the Role of Working Memory

Interactive features in media are expected to increase cognitive load (Strommen, 1993). Given the information processing theories' claim that increasing cognitive load should reduce performance (Baddeley & Hitch, 1974), one might expect toddlers to show an even greater transfer deficit when using interactive media. Yet several studies demonstrate better learning in interactive conditions (Choi & Kirkorian, 2016; Kirkorian, Choi, & Pempek, 2016; Lauricella et al., 2010). The current study was designed to address this paradox by examining associations between working memory and learning from interactive versus noninteractive video. Study 2 revealed that toddlers' ability to transfer from video to real-life objects was predicted by individual differences in working memory, suggesting that transfer from screens to real-world events is cognitively demanding and is supported by working memory. Thus, investigating the moderating role of working memory has potential to further inform the underlying mechanisms of the benefits of interactive media on learning. Such investigations have implications for understanding who is affected by media – for good or ill – and under what conditions.

There are three possible hypotheses for why interactive touch screens may help toddlers to transfer from screens to real objects. First, interactivity may assist information processing of children with low working memory by guiding their attention to the most important information (Choi & Kirkorian, 2016; Kirkorian et al., 2016). In general, young children allocate attention less systematically than adults and deploy attention to irrelevant but salient features (Franchak et al., 2015; Frank, et al., Kirkorian et al., 2012). Attentional support may lessen cognitive load by reducing the number of items to be processed, thus, interactive media may be particularly useful for children who experience difficulty holding and updating relevant information in mind. In this

case, toddlers with low working memory would benefit from interactive experience with screens whereas toddlers with high working memory would learn equally well from both noninteractive and interactive video. In this scenario, interactive media may help to reduce achievement gaps between children with low versus high working-memory skills.

Alternatively, working memory may moderate the impact of interactive media in the opposite direction. Physically interacting while watching video on a touch-screen device requires greater cognitive resources compared to watching video without any interactions (Strommen, 1993). Therefore, interactive media may be beneficial only for children who already possess sufficient working memory skills. In other words, perhaps only toddlers with strong working memory would learn better from interactive video compared to noninteractive video, whereas toddlers with low working memory would experience difficulty learning from both interactive and noninteractive video. In this scenario, interactive media may actually increase achievement gaps between children with low versus high working-memory skills.

Lastly, perhaps interactivity facilitates toddlers' learning regardless of working-memory skills. In that case, children with both low and high working memory would benefit equally from interactive experience with media perhaps due to increased arousal and engagement or the increased salience of the video hiding event relative to prior search events (Kuhl, 2007; Richards & Anderson, 2004). In this scenario, all children would benefit equally from interactive media, regardless of working memory.

The purpose of this study was to test the three hypotheses by exploring the role of working memory (WM) as a moderator of screen-based learning, independent of age-related change. The remaining toddlers from Study 1 were randomly assigned to a third, interactivity condition for Study 3. These children were compared to the noninteractivity, between-context

transfer group from Study 2 in order to assess the impact of interactivity on transfer from screens. Whereas toddlers in the noninteractivity condition watched video without interacting, toddlers in the interactivity condition touched a specific location on the screen in order to view hiding events. As in Study 2, the outcome measures were toddlers' errorless retrieval and perseverative errors. In addition, toddlers' receptive vocabulary and visual-spatial working memory (i.e., spin-the-pots task) were assessed (see Study 1).

Given that interactivity supported learning from screens in prior studies (Choi & Kirkorian 2016; Kirkorain, Levigne, 2016; Lauricella et al., 2009), it was hypothesized that toddlers who actively touched the screen would be more successful in searching for hidden objects than those who passively watched video. If interactive media support toddlers with lower cognitive skills by scaffolding their attention (Kirkorian, Choi, Pempek, 2016), it was expected that there would be an interaction between condition and working memory such that toddlers with relatively low working-memory skill would benefit most from interactive media. Conversely, if manipulating interactive media in itself requires sufficient cognitive abilities, then toddlers with high working-memory skill would benefit most from interactive media. Finally, if interactive media support learning for children despite their individual differences in working memory capacity, it was expected that toddlers' object retrieval would be higher in the interactivity condition than the noninteractivity condition, regardless of working memory capacity.

Method

Participants and Recruitment

The remaining toddlers from Study 1 were randomly assigned to a third, interactivity condition for Study 3 ($n = 20$, 9 females; mean age = 30.88 months). These children were

compared to the noninteractivity, between-context transfer group from Study 2 in order to assess the impact of interactivity on transfer from screens (n = 22, 14 females, mean age = 31.18 months).

Stimuli and Apparatus

The stimuli for the interactive group in Study 3 were nearly identical to those in the noninteractivity, between-context transfer group in Study 2. However, for the interactivity group, Cece (the cartoon bear) told the child to "touch me" (rather than "watch me"), and the video resumed only when the child touched the character (rather than automatically resuming after a 1-s delay); touching anywhere else on the screen resulted in no change (Fig. 8).

Figure 8. Correspondence training in no-interactivity condition (left) and interactivity condition (right).

Procedure

Two researchers conducted experimental sessions in an empty classroom at a preschool or in a laboratory on the university campus following the same procedure described in Study 1.

Object Retrieval Task. The object-retrieval procedure was the same as in Study 2 except that the toddlers in the interactivity condition were asked to touch the screen during the correspondence training and testing. If needed, the experimenter encouraged the child to follow directions (e.g., "What did she say? She said to touch the bear!").

Assessments. Children's scores on spin-the-pots, receptive vocabulary, and parent survey information were used from Study 1. See Chapter 2 for descriptions of the procedure and coding method for these assessments.

Results

Parent Survey and Preliminary Analyses

Preliminary analyses indicated that child gender, child race and ethnicity, parent education, child exposure to television and touch-screen devices, and the order of hiding locations did not differ significantly across experimental conditions. Moreover, these variables did not predict search performance. Thus, they were not considered further.

Probability of errorless search by trial and condition

As in Study 2, search performance was analyzed using hierarchical linear modeling with binary outcomes. Trial was entered as a level-1 predictor, while age, vocabulary, working memory (WM), and condition were entered as level-2 predictors. The model structure was as follows:

Level 1 Model:

$$\text{Probability}(ES_{ti} = 1) = \phi_{ti}$$

$$\log[\phi_{ti}/(1 - \phi_{ti})] = \eta_{ti}$$

$$\eta_{ti} = \pi_{0i} + \pi_{1i} \times \text{trial}_{ti} + \pi_{2i} \times \text{trial}^2_{ti} + \varepsilon_{ti}$$

Level 2 Model:

$$\pi_{0i} = \beta_{00} + \beta_{01} \times \text{age}_i + \beta_{02} \times \text{vocabulary}_i + \beta_{03} \times \text{condition}_i + \beta_{04} \times \text{WM}_i + \beta_{05} \times \text{condition}_i \times \text{WM}_i + \gamma_{0i}$$

$$\pi_{1i} = \beta_{10} + \gamma_{1i}$$

$$\pi_{2i} = \beta_{20} + \gamma_{2i}$$

Combined Model:

$$\eta_{ti} = \beta_{00} + \beta_{01} \times age_i + \beta_{02} \times vocabulary_i + \beta_{03} \times condition_i + \beta_{04} \times WM_i + \beta_{05} \times condition_i \times WM_i + \beta_{10} \times trial_{ti} + \beta_{20} \times trial_{ti} + \gamma_{0i} + \gamma_{1i} + \gamma_{2i} + \varepsilon_{ti}$$

All terms have the same meanings as in the prior set of equations in Study 2. The only difference is the addition of β_{20} and γ_{2i}, which represent an average quadratic regression slope and a random slope, respectively. A full report of fixed effects can be found in Table 5.

All fixed effects from the final model are reported in Table 5, and the modeled probability of errorless retrieval is plotted in Figure 9 as a function of trial, condition, and WM. For illustrative purposes, Figure 10 plotted the estimated probability of errorless search as a function of condition, and WM. As in Study 2, vocabulary was a significant predictor of errorless retrieval, $\beta_{02} = 0.55$, $SE = 0.28$, Wald $z = 1.97$, $p = .049$, odds ratio (OR) = 1.73. As children's vocabulary increased, so did their performance during the search task. In addition, the age of the child was a marginally significant predictor of errorless retrieval, $\beta_{01} = 0.29$, $SE = 0.15$, Wald $z = 1.93$, $p = .053$, OR = 1.34.

Table 5. Fixed Effects From the Final Mixed Logit Model Predicting the Probability of Errorless Search

Predictor	β	*SE*	Wald *z*	OR	95% CI (OR)
Intercept (β_{00})	−0.64	0.80	−0.80	0.53	[0.11, 2.53]
Age (β_{01})	0.29	0.15	1.93†	1.34	[1.00, 1.80]
Vocabulary (β_{02})	0.55	0.28	1.97*	1.73	[1.00, 2.98]
Condition (β_{03})	1.63	0.56	2.91**	5.10	[1.70, 15.24]
WM (β_{04})	1.09	0.42	2.54*	2.97	[1.28, 6.90]
Condition × WM (β_{05})	−0.90	0.58	−1.55	0.41	[0.13, 1.27]
Trial (β_{10})	−0.29	0.87	−3.77***	0.04	[0.01, 0.26]
Trial^2 (β_{20})	1.34	0.37	3.62***	3.82	[1.85, 7.91]

Note: The Level 1 variable was trial number (both linear and quadratic components); this predictor was centered at the first trial, such that the intercept reflects data at Trial 1. Condition and age were included as Level 2 variables. Condition, age, vocabulary, and WM were included as Level 2 variables. Condition was dummy-coded: no-interactivity (reference category) and interactivity. Age was centered at 27 months. Vocabulary and WM scores were standardized using z-scores and centered at 0 as the mean values. OR = odds ratio; CI = confidence interval. $^{\dagger}p < .10$. *$p < .05$. **$p < .01$. **$p < .001$.

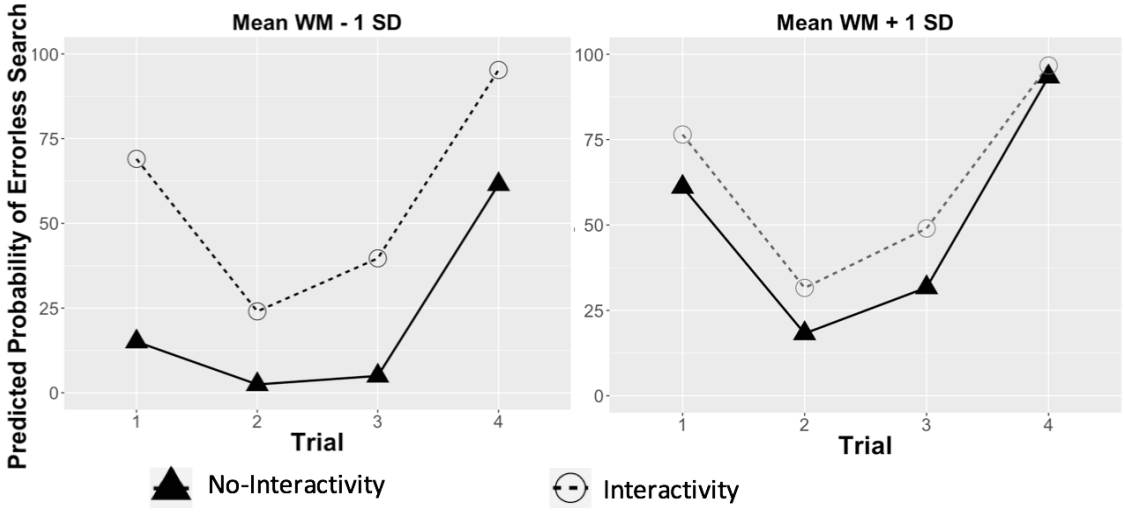

Figure 9. Predicted probability of errorless search as a function of trial for the no-interactivity and interactivity conditions. Fitted regression lines plotted at the age of 27 months and the vocabulary (z score) of 0. WM was a continuous predictor and standardized (z score); however, for illustrative purposes, the predicted probability is presented separately for children at 1 *SD* above the mean and at 1 *SD* below the mean.

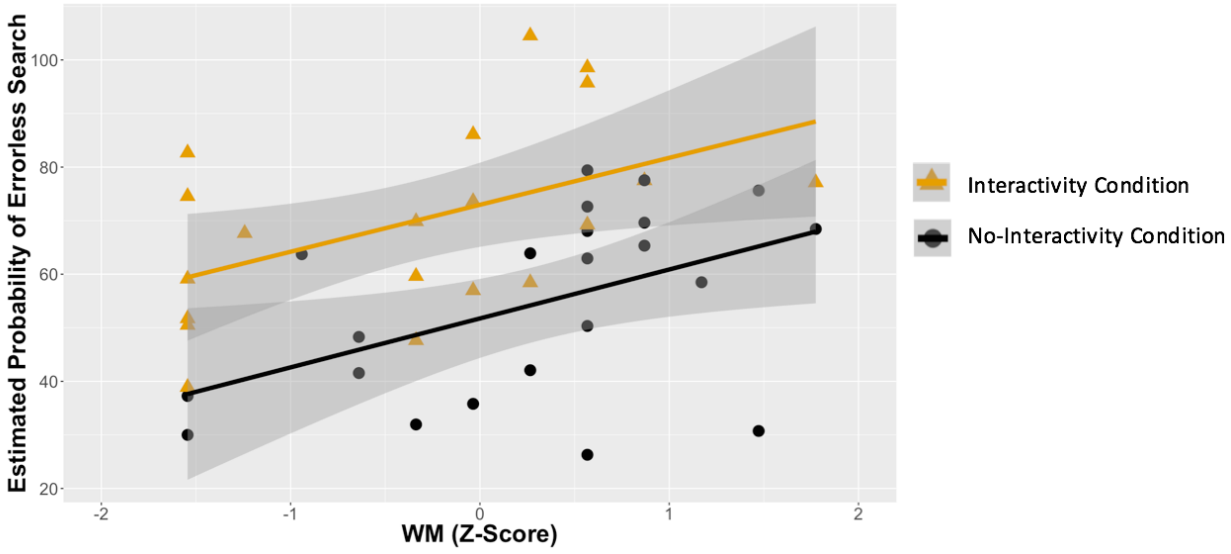

Figure 10. Estimated probability of errorless search as a function of WM and experimental condition, controlling for age and vocabulary. Fitted regression lines were plotted by regressing estimated probability of errorless search on z-scores of WM at the age of 27 months and the vocabulary (z score) of 0. The shaded areas represent 95% confidence interval.

The condition was a significant predictor such that the probability of an errorless search was higher for the interactivity condition than in the no-interactivity condition, $\beta_{03} = 1.63$, $SE = 0.56$, Wald $z = 2.91$, $p = .003$, OR = 5.10. In terms of probability, the youngest children in the interactivity condition were about twice as likely to search correctly as their peers in the no-interactivity condition.

As in Study 2, children's WM positively predicted the probability of an errorless retrieval in all conditions. The main effect of WM was significant such that object retrieval performance improved as WM increased, $\beta_{04} = 1.09$, $SE = 0.42$, Wald $z = 2.54$, $p = .011$, OR = 2.97. However, the interaction between WM and condition was not significant, $\beta_{05} = -0.90$, $SE = 0.58$, Wald $z = -1.55$, $p = .121$, OR = 0.41. Thus, children's WM predict search performance regardless of the experimental condition (Fig. 10).

The model revealed changes in object-retrieval performance across the four trials, including a marginally significant linear decrease across trials, $\beta_{10} = -0.29$, $SE = 0.87$, Wald $z = -3.77$, $p < .001$, OR = 0.04, and a positive quadratic component, $\beta_{20} = 1.34$, $SE = 0.37$, Wald $z = 3.62$, $p = < .001$, OR = 3.82. Together, the linear and quadratic effects reflected a U-shaped pattern such that performance initially decreased across the first few trials and then increased at the final trial (Fig. 9).

The final model included the quadratic term of trial based on the prior study using the same experimental design (Choi & Kirkorian, 2016). The assessment of relative differences in model comparisons also suggested that the model with the quadratic term (Model 3) provided a better fit than the model without the term (Model 4); AIC for Model 3 = 199.10, AIC for Model 4 = 214.77, LLR $\chi2(4) = 23.67$, $p <.001$. Thus, the quadratic term was included in the model. Follow-up analyses revealed non-significant effects of the two-way interaction between WM and trial, the two-way interaction between trial and condition, and the three-way interaction among WM, trial, and condition.

Probability of perseverative errors by trial and condition

As in Study 2, the likelihood that an error was perseverative was evaluated as a function of child characteristics (age, vocabulary, WM), condition, and trial. A two-level (trials within subjects) generalized linear mixed-effects model was used to predict the probability of making a perseverative error after having made an error given that an error was made. Only the instances in which errors were made on Trials 2 to 4 were made were included in this analysis. The outcome measure was a dichotomous variable indicating whether the error was perseverative in nature. The model structure was as follows:

Level 1 Model:

Probability ($PE_{ti} = 1$) = ϕ_{ti}

$\log[\phi_{ti}/(1 - \phi_{ti})] = \eta_{ti}$

$\eta_{ti} = \pi_{0i} + \pi_{1i} \times trial_{ti} + \varepsilon_{ti}$

Level 2 Model:

$\pi_{0i} = \beta_{00} + \beta_{01} \times age_i + \beta_{02} \times vocabulary_i + \beta_{03} \times condition_i + \beta_{04} \times WM_i + \beta_{05} \times condition_i \times WM_i + \gamma_{0i}$

$\pi_{1i} = \beta_{10} + \beta_{11} \times condition_i$

Combined Model:

$\eta_{ti} = \beta_{00} + \beta_{01} \times age_i + \beta_{02} \times vocabulary_i + \beta_{03} \times condition_i + \beta_{04} \times WM_i + \beta_{05} \times condition_i \times WM_i +$

$\beta_{10} \times trial_{ti} + \beta_{11} \times trial_{ti} \times condition_i + \gamma_{0i} + \varepsilon_{ti}$

All terms have the same meanings as in the prior set of equations in Study 2. A full report of fixed effects can be found in Table 6.

There were no significant effect of age on the likelihood that an error was perseverative, $\beta_{01} = 0.14$, $SE = 0.18$, Wald $z = 0.79$, $p = >.250$, OR = 1.15. Child's vocabulary was a significant predictor of making a perseverative error, $\beta_{02} = -0.72$, $SE = 0.36$, Wald $z = -2.00$, $p = .045$, OR = 0.49. Thus, as child's vocabulary increased, the likelihood that an error was perseverative decreased.

The condition did not significantly predict the probability of making a perseverative error, $\beta_{03} = 0.37$, $SE = 0.68$, Wald $z = 0.54$, $p = .591$, OR = 1.44. Moreover, there was neither the main effect of WM nor an interaction between WM and condition, $\beta_{04} = -0.39$, $SE = 0.43$, Wald $z = -0.91$, $p > .250$, OR = 2.67, and $\beta_{05} = 0.65$, $SE = 0.68$, Wald $z = 0.97$, $p > .250$, OR = 1.92,

respectively. Thus, the rate of perseveration was similar regardless of condition or working memory skills.

Finally, there was no main effect of trial on the probability that an error would be perseverative, $\beta_{10} = 0.36$, $SE = 0.40$, Wald $z = 0.89$, $p = >.250$, OR = 1.43. That is, the rates of perseverative errors were similar across trials: 40.74% (11 of 27 errors) in Trial 2, 52.94% (9 of 17 errors) in Trial 3, and 60.00% (6 of 10 errors) in Trial 4. Follow-up analyses revealed non-significant effects of the two-way interaction between WM and trial, the two-way interaction between trial and condition, and the three-way interaction among WM, trial, and condition.

Table 6. Fixed Effects from the Final Mixed Logit Model Predicting the Probability That An Error Would Be Perseverative

Predictor	β	*SE*	Wald *z*	OR	95% CI (OR)
Intercept (β_{00})	−1.13	0.93	−1.21	0.32	[0.05, 2.01]
Age (β_{01})	0.14	0.18	0.79	1.15	[0.81, 1.65]
Vocabulary (β_{02})	−0.72	0.36	−2.00*	0.49	[0.24, 0.98]
Condition (β_{03})	0.37	0.68	0.54	1.44	[0.38, 5.49]
WM (β_{04})	−0.39	0.43	−0.91	2.67	[0.29, 1.58]
Condition × WM (β_{05})	0.65	0.68	0.97	1.92	[0.51, 7.26]
Trial (β_{10})	0.36	0.40	0.89	1.43	[0.65, 3.12]

Note: The Level 1 variable was trial number (both linear and quadratic components); this predictor was centered at the first trial, such that the intercept reflects data at Trial 1. Condition and age were included as Level 2 variables. Condition, age, vocabulary, and WM were included as Level 2 variables. Condition was dummy-coded: no-interactivity (reference category) and interactivity. Age was centered at 27 months. Vocabulary and WM scores were standardized using z-scores and centered at 0 as the mean values. OR = odds ratio; CI = confidence interval.
*$p < .05$.

Discussion

The purpose of Study 3 was to address the apparent paradox that toddlers learn better from more cognitively demanding interactive media than from simpler noninteractive media. The role of working memory was examined as a moderator of screen-based learning to investigate for whom interactive experience with media could be beneficial. Consistent with earlier studies, toddlers who physically interacted with the screen outperformed those who passively watched video on the screen. (Choi & Kirkorian, 2016; Kirkorian, Choi, & Pempek, 2016; Lauricella et al., 2010). In addition, toddlers with higher working memory learned information better than those with lower working memory through both interactive and noninteractive video. Together, these findings replicate previous research by demonstrating that toddlers can learn from video with the support of interactivity, and it extends previous research by demonstrating that transfer from both interactive and noninteractive media requires working memory resources.

If interactive media support toddlers with lower working memory skills by guiding their attention and reducing the amount of information to process, toddlers' working memory would have a greater influence on object-retrieval performance in the no-interactivity condition than in the interactivity condition. However, there was no interaction between the condition and working memory capacity. As indicated by the overall better performance for children in the interactive condition than in the non-interactive condition, making video interactive increases toddlers' performance regardless of their working memory skills. In other words, this facilitative effect of interactive media was consistent regardless of the levels of toddlers' working memory.

There are at least two possible explanations for why toddlers' working memory did not moderate the impact of interactivity. One possibility is that interactive media may simultaneously reduce cognitive load by guiding children's attention to the most important

information and also add new demands by requiring children to coordinate motor activities (e.g., touching the screen), thus canceling out any impact of the decrease in cognitive load. Another possibility is that interactive media benefits all children equally regardless of their working memory skills through other mechanisms such as enhancing visual attention (Kirkorian, Choi, & Pempek, 2016) or increasing overall arousal and engagement (Richards & Anderson, 2004) rather than operating on working memory skills specifically.

In conclusion, toddlers can learn and transfer information from video after interacting with screens regardless of individual differences in working memory. These results replicate previous findings by suggesting that toddlers may benefit more from interactive media than from non-interactive video, and they extend earlier work by demonstrating that this is true even for those children with relatively low working memory skills. Overall, the results indicate that interactivity plays an important role in supporting young children's transfer from screens, even for those who may otherwise have difficulty learning from screens.

Chapter V. General Discussion

According to information processing theories, increasing cognitive load results in a decrease in learning, especially because of taxing the limited capacity of working memory. (Case, 1995; Dempster, 1981). The purpose of this dissertation was to identify the role of working memory in screen-based learning under the presence of three types of cognitive demands: (a) contextual differences between encoding and retrieval, (b) competing mental representations across multiple learning trials, and (c) physical interaction with screens. Of particular interest was screen-based learning among toddlers, an age group that has particular difficulty learning from screens. Prior studies attempted to explain the role of working memory in toddlers' transfer from video, but these studies generated mixed findings probably due to different task difficulty levels across the studies (e.g., Barr & Hayne, 1999; Huang & Charman, 2005; Meltzoff, 1988; Flynn & Whiten, 2008; Gerhardstein et al., 2009; Hayne et al., 2003). Moreover, none of these studies directly assessed individual differences in working memory skills in order to test associations with screen-based learning. This dissertation attempted to measure individual variations in working memory using an age-appropriate task, enabling a direct examination of how child's own cognitive characteristics play a role in screen-based learning with the presence of the different type of cognitive load.

Impact of Task Demands on Learning

One source of cognitive load is the perceptual difference between encoding and retrieval contexts. This dissertation demonstrates that the effects of contextual differences on young children's transfer from symbolic media are complex and influenced by the timing of learning. That is, reducing contextual differences can either increase or decrease cognitive demands depends on when learning happens. According to the representational flexibility account,

reducing contextual differences would reduce cognitive load on all learning trials (Barr, 2010; Eichenbaum, 1997). The graded representations account, on the other hand, would predict that reducing contextual differences would increase cognitive demands by increasing competition between mental representations (Troseth, 2010; Munakata, 2001). Study 2 was designed to examine these different hypotheses with the object retrieval task including multiple trials. Study 2 found that toddlers who transferred within the same context outperformed those who transferred between different contexts on the first trial. However, this effect was reversed in later trials due to the presence of competing representations, which resulted in a greater likelihood of making perseverative errors. The findings partially support the representational flexibility account insofar as contextual differences do play a role in transfer on the first trial but not on the subsequent trials. Thus, the representational flexibility account can be modified with consideration of the graded representations account to address competing mental representations as an additional source of cognitive demands.

Another source of cognitive load of interest was the need to plan and execute responses when using interactive media. However, prior research suggests that young children may benefit from active engagement (Choi & Kirkorian, 2016; Kirkoiran, Choi, & Pempek, 2016; Lauricella et al., 2011) despite the likelihood to increase working memory load. Replicating prior research, study 3 also found that toddlers who physically interacted with screens during video viewing outperformed those who passively watched video on the screen. Despite young children's difficulty of transfer from screens (Anderson & Pempek, 2005; Kirkroiran & Anderson, 2015), this finding provides further evidence to support that incorporating interactive features may help young children overcome the difficulty of learning from screen media.

The Role of Working Memory in Screen-Based Learning

Early development of working memory has shown to be a strong predictor of other cognitive abilities (e.g., Bierman et al, 2008). This dissertation demonstrates the role of working memory in toddlers' screen-based learning by directly assessing individual differences in order to resolve the mixed results from previous research. Using the age-appropriate task identified in Study 1, Studies 2 and 3 found that toddlers' working memory is required to successfully transfer information from screens to solve real-world problems, even after controlling for age and vocabulary. These findings suggest that learning and transfer from screens are challenging for toddlers (Barr 2010; 2012) and this transfer difficulty is related to the child's own ability to maintain and update information in memory (Munakata, Synder, & Chatham, 2012), providing important evidence to further explore the individual differences in working memory when examining media effects.

Studies 2 and 3 revealed that the association between working memory and screen-based transfer did not vary as a function of task demands. In Study 2, the moderating role of working memory was examined to understand for whom reducing contextual differences would be helpful. According to the representational flexibility account, reducing the contextual differences should reduce cognitive load and facilitate transfer. Therefore, additional working memory is required to be successful in the between-context transfer condition more so than the within-context transfer condition. However, this hypothesis was not supported. Rather, reducing the contextual differences influenced all toddlers to the same extent regardless of the individual differences in working memory capacity. Thus, reducing the contextual differences certainly influences performance, but the mechanisms of the effect might be something other than working memory (e.g., the ability to inhibit interference from mental representations of previous trials).

Study 3 examined whether the facilitative impact of interactive media would be moderated by working memory. Again, working memory positively predicted search performance equally in all conditions. Although physically manipulating features can be cognitively demanding (Strommen, 1993), interactive media did not disrupt learning for toddlers with low working memory. Rather, even toddlers with low working memory skills benefited from interactive experience with screens. It appears that any cognitive demands that occur by requiring children to actively respond to the screen may be compensated by supporting children in some other way, perhaps through increasing arousal and engagement or through helping children focus on the most important information on the screen (Kirkorian, Choi, Pempek, 2016; Kuhl, 2007).

Limitations and Future Directions

The current studies provide evidence to explain toddlers' difficulty in transfer of learning from screens through individual differences in working memory. However, further research is needed to fully understand how individual differences in cognitive skills play a role in young children's learning and transfer in various contexts and diverse populations. Research on individual differences as a moderator of media effects is greatly needed to understand who is susceptible to media effects and under what conditions (Valkenburg & Peter, 2013). In the current studies, the sample was a relatively small and homogeneous group from a university community, which might result in low variability in working memory. Thus, future research must include a more diverse sample to strengthen the external validity of the findings. Moreover, additional research is needed to develop more age-appropriate measures to capture variations in working memory for children between 2-3 years of age, given that findings in the current study are limited to only one assessment. Future research should also examine the role of other

possible mechanisms such as inhibitory control or verbal working memory (as opposed to visual-spatial working memory) to fully capture the individual differences that may moderate media effects.

In addition, future research is needed to extend the findings from this dissertation to different mediums or contexts. For example, it is possible that reducing perceptual differences only hinders learning from screens but not from real-life situations. Given that toddlers require more time to process information that is presented on video than in-person (Kirkorian, Lavigne, et al., 2016), processing two screens for multiple trials may require more cognitive resources than processing two objects. Therefore, it remains unclear whether the effects of contextual differences in learning are specifically related to screen-based transfer or reflect transfer between any contexts in general. Also, there was no real-life demonstration in the current study, making it impossible to test for the video deficit (i.e., toddlers' relative inability to learn from screens compared to real-world demonstrations). Thus future research should examine the role of working memory (and other skills) in toddlers' ability to transfer across a variety of contexts.

Finally, findings from this dissertation reveal that working memory predicts learning but did not moderate the effects of contextual differences or interactivity. Thus, these effects may be related to other types of mechanisms. For example, increased transfer might have been due to the support of other cognitive control skills such as inhibitory control rather than working memory, given that these skills are dissociable during development (Diamond, 2002). Using a visual-spatial search task involving real objects, Jenkins and Berthier (2014) found that toddlers' (2.5- to 3-years of age) inhibitory control —but not working memory—predicted their search performance. Although this study did not directly examine the ability to transfer from screens, it suggests that success in a visually guided search task requires inhibitory control, an ability to

inhibit salient but incorrect information and allocate attention to the most relevant information. Alternatively, the effects of contextual differences or interactive media may be due to other cognitive processes such as selective or sustained attention. A follow-up eye-tracking study can examine how visual attention, independent from working memory, influences screen-based learning and whether attentional processes moderates the impact of contextual differences or interactivity.

Conclusion

It is becoming increasingly important for researchers to understand individual differences and contextual influences that moderate media effects (Valkenburg & Peter, 2013). This dissertation represents a first step in understanding the extent to which task demands and working memory skills moderate screen-based learning and transfer. Theoretically, this dissertation demonstrate how working memory is associated with toddlers' screen-based learning in ecologically valid contexts by using video games on touch screens. Also, current findings suggest the possibility of combining representation flexibility and graded representations accounts to improve the explanatory scopes of both accounts in the video deficit. Practically, these findings provide parents, educators, media professionals, and policy makers with much-needed information about not only whether but also how to utilize interactive media and for whom these experiences can be beneficial. For example, the findings from this dissertation suggest that using the same medium for teaching and for testing may be helpful for initial assessment, but it may disrupt the accuracy of assessments over time. Therefore, when using screens, parents and educators may consider allocating enough temporal spacing between learning events. Furthermore, interactive experience with screens may help children to transfer information from screen media to solve real-world problems, even for very young children or

those with relatively low working memory skills. Given the significance of the early development of working memory in cognitive and academic outcomes (e.g., Blair & Razza, 2007; Diamond et al, 2007), this research will fill an important gap in our understanding of the role of working memory in screen-based learning. Further research to identify the specific conditions that lead to the best learning outcomes for individual children is greatly needed in order to maximize the benefits of educational media for all children.

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