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The enactment effect, remembering self-performed action phrases better than identical phrases learned verbally, is a robust effect documented in many studies with adults and older children. Evidence for the enactment effect in children younger than 8 years of age, however, is equivocal. Some studies indicate that children as young as six years of age show the enactment effect while others reveal that the effect does not emerge until later in development. Previous research has indicated that memory for actions may be related to executive function (EF) skills. The present study examined whether working memory (WM) and cognitive flexibility (CF; cognitive abilities associated with EF) predicted the enactment effect in 4- to 6-year-olds. Results indicated that when imaginary objects are used during enactment, the enactment effect is expressed, but this was only true for 6-year-olds. Additionally, WM and CF predicted the production of the enactment effect. These findings suggest that increases in cognitive abilities associated with EF contribute to increased memory benefits from physical actions.

DEVELOPMENT OF THE ENACTMENT EFFECT: EXAMINING INDIVIDUAL DIFFERENCES IN EXECUTIVE FUNCTION TO PREDICT INCREASED MEMORY FOR ACTION

by

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Approved by

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Committee Chair

To my husband, Christopher Chatley.
Thank you for your support, encouragement, and, above all, putting up with me.

APPROVAL PAGE

This thesis written by Naomi Chatley has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

Much of what we remember and think about concerns things that we have done, are doing, or plan to do in the future (Koriat & Pearlman-Avnion, 2003). These can be mundane, day-to-day activities (Did I remember to pay that bill?) to important events (When did I get that promotion?). Actions as simple as gesturing during speech have been shown to facilitate recall (Cook, Yip, & Goldin-Meadow, 2010). Research in recent years has focused on the processes involved in memory for actions (Zimmer et al., 2001). Action memory, even as examined in a laboratory setting, represents more closely typical "real world" memory which often involves planning and executing goal-directed actions. This is in contrast to the typical laboratory task which usually requires the participant to be a passive observer and encoder of information (Zimmer & Cohen, 2001). Action performance produces encoding and retrieval effects that differ from memory for information that is learned verbally, and should be considered a distinct type of memory (Zimmer et al., 2001). This includes prospective memory (remembering to perform an intended action at the appropriate time; Ellis & Freeman, 2008), procedural memory (memory for performed actions that results in the acquisition of skills; Willingham, Nissen, & Bullemer, 1989), and controlling actions when executing plans and multitasking (Ellis & Cohen, 2008).

Another aspect of action memory that is commonly studied is the enactment effect which is a phenomenon in which participants demonstrate better memory for action phrases that have been performed compared to similar phrases that have been learned verbally (for a review see Zimmer et al., 2001). While memory for actions appears to be non-strategic and automatic (Cohen, 1981), there is evidence that action memory does require a certain amount of cognitive resources to attend to and process the actions to be remembered (Mecklenbräuker, Steffens, Jelenec, & Goergens, 2011). Executive function skills are cognitive processes that allow for flexible, goal-directed behaviors involved in problem solving (Zelazo, Müller, Frye, & Marcovitch, 2003). As memory for performed action phrases requires the representation of multiple modalities of action performance (e.g., verbal and motor; Bäckman, Nilsson, & Chalom, 1986), and having the memory resources to encode these modalities, it is possible that EF —particularly working memory and cognitive flexibility — may be related to the enactment effect in children.

Enactment Effect

Studying memory for self-performed tasks (SPTs) has been particularly popular in action memory research (Cohen, 1981). A common method used to study action memory is the enactment paradigm, in which either adult or child participants are required to learn a series of action phrases (e.g., “break a match” “open the bottle”) by enacting the phrases, watching an experimenter enact the phrases, or learning the phrases verbally (Zimmer et al., 2001). A typical SPT involves the presentation of action phrases one at a time, and the participant enacts each phrase before the next one is presented. Memory for SPTs is typically compared to memory for verbal tasks (VTs) or observed experimenter performed tasks (EPTs) in which participants learn similar action phrases without the requirement to enact them (Zimmer et al., 2001). Verbal tasks involve a participant reading either silently or aloud, or listening to a list of action phrases. Experimenter performed tasks involve the participant passively watching as an experimenter performs the action phrases. It is well-documented that, in adults, SPTs are remembered better than VTs and EPTs (Engelkamp, 2001; Koriat & Pearlman-Avnion, 2003). Additionally, instructions to imagine performing an action phrase or anticipate performing an action phrase at recall also results in the enactment effect (Koriat, Ben-Zur, & Nussbaum, 1990; Nillson et al., 2000).

Memory for SPTs is qualitatively different from verbal memory, enhancing recall at times and hindering recall at others. The encoding processes that occur during a SPT appear to be fundamentally different from those that occur during VTs. Enhanced recall of performed actions in adults may be due to the multimodal features of such events. Verbal tasks generally involve the encoding of a stimuli list through one modality (i.e., hearing or reading the list of words; Bäckman, Nilsson, & Chalom, 1986). In contrast, memory for enacted phrases is processed motorically (Koriat & Pearlman-Avnion, 2003) and with the object being acted upon (Mecklenbräuker et al., 2010), in addition to the typical visual or auditory input. Importantly, reenacting previously learned SPTs leads to increased recognition of learned actions even while blindfolded indicating the significance of motor performance in action memory (Mulligan & Hornstein, 2003) The ability to process environmental stimuli in multiple ways through sensory perception is seen as crucial to adaptive and mature cognitive functioning (Bremner, Lewkowicz, &

Spence, 2012). Perceptions from multiple sensory modalities allow for adaptive actions and interactions with the surrounding environment (Bremner, Holmes & Spence, 2012).

A dual-conception view of action memory has been proposed by Bäckman, Nilsson, and Chalom (1986) emphasizing that the verbal and motor components of SPTs are encoded differently and are enhanced by different types of strategies. The use of distracter tasks during SPTs highlights the differences of verbal and motor encoding. Adult participants were asked to perform action phrases while concurrently performing a secondary task to divide attention. The participants experienced difficulty remembering the verbal aspect of the SPT (i.e., the verbal label) when the distracter task was verbal in nature (e.g. backwards counting). In contrast, participants experienced difficulty remembering the motor aspects of SPTs when the distracter task involved physical action (Kormi-Nouri, Nilsson, & Bäckman, 1994). This dissociation implies that SPTs are encoded through different mechanisms than the typical VT.

Theories concerning the nature of action encoding are conflicting, however. The results of some studies indicate that encoding of action events is automatic, not requiring the use of intentional strategies and cognitive resources (Zimmer & Cohen, 2001). Participants typically do not show intentional strategy use while learning action phrases. The fact that participants do not recall using intentional memory strategies after task performance involving the enactment paradigm has been used as evidence for the non-strategic nature of action memory (Cohen & Stewart, 1982). Other studies indicate that evidence for strategy use is present even though it appears unintentional. For example, adults show memory integration of the objects to be acted upon during a SPT (Steffens, Buchner, Wender, & Decker, 2007) and for clustering of phrases that require similar types of movement (Koriat & Pearlman-Avnion, 2003) even though they do not recall using intentional strategies during learning and recall.

Further, certain aspects of SPTs are likely to be attended to even without evidence of intentional strategy use and this attention results in increased recall (Steffens, Jelenec, Mecklenbräuker, & Thompson , 2006). When the SPT involves acting on a physically present object, memory for action phrases is enhanced as compared to acting on an imaginary object. Even though participants do not report using any particular memory strategy, it appears that the object being acted upon is integrated into memory and assists in later recall, whether or not the item is present during recall (Steffens et al., 2007).

While there is evidence for strategy use during recall of actions, some types of commonly used strategies are more effective than others. There is evidence for organizational strategy use in recall for SPTs. In VTs, organizational processing usually results in the formation of categorically based clusters during free recall (e.g., a cluster of automobiles could include a car, truck, and van; Bjorklund, Coyle, & Gaultney, 1992). Although organizational processing in encoding of SPTs appears to be different and does not involve categorical processing, organization at free recall is apparent. Participants tend to cluster recall of SPTs by similarity of actions. For example, the phrases “clip a rose” and “cut the string” would be remembered together (Koriat & Pearlman-Avnion, 2003). Thus, while memory for SPTs appears to be incidental and not require intentional effort, multiple encoding processes appear to assist in increasing memory for SPTs, which results in the enactment effect.

Certain strategies that aid in memory for VTs do not assist in memory for SPTs. Performance on verbal learning tasks is increased when participants engage in intentional strategy use (Zimmer & Cohen, 2001). For example, repeated practice sessions are a common and useful strategy that increases memory retention in VTs. Repeated practice of SPTs, however, does not increase recall (Zimmer, 1996). Similarly, deep levels-of-processing (stimuli that is highly meaningful) enhances recall of stimuli that are learned verbally, but not motorically (Craik & Tulving, 1975). Emphasizing the importance of remembering certain stimuli items increases recall of the highlighted items in VTs, but emphasizing specific SPTs as being more important than others does not change the pattern of recall; the SPTs referred to as less important are recalled similarly to SPTs emphasized as important (Cohen, 1983).

Although action performance has been established as beneficial to memory, there are some cases in which SPTs may be detrimental to memory. Enactment decreases recall in paired-association tasks where participants are required to learn pairs of unassociated phrases either verbally or through action performance (Zimmer & Cohen, 2001). Participants are then given one element of a pair as a cue to recall the target word. Recall of target words was decreased when they were learned by SPTs as compared to performance on the VT, even though participants could recall more self-performed items when allowed to recall freely. Additionally, implicit instructions to remember or forget specific stimuli are effective in the selective retrieval of verbal stimuli. However, procedures designed to encourage memory and forgetfulness are less effective for SPTs (Cohen, 1983; Earles & Kersten, 2002).

Memory for VTs shows primacy and recency effects, with items learned first and last recalled better than items that fall in the middle of the serial order. Although memory for SPTs does show recency effects, items learned at the beginning of an item list do not experience the same advantage as the same items in a VT (Helstrup, 1986). Also, source memory (recalling where an object was located in physical and temporal space) is reduced in SPTs as compared to VTs, even though the actual SPTs were remembered better than items learned verbally (Koriat, Ben-Zur, & Druch, 1991). In all, strategies that enhance memory retention of and the encoding processes that occur during action performance are very different from those that augment memory for information learned verbally.

As a general rule, memory for action phrases is increased significantly when the phrases are enacted as compared to learned verbally. Although memory for action phrases occurs without indication of intentional strategy use, evidence for encoding strategies is apparent. Not only do certain strategies seem to aid in recall of SPTs making them better remembered then VTs, memory for action is affected differently by strategies that assist in memory for VTs. The multiple modalities involved in encoding, and the differences in recall between SPTs and phrases learned verbally indicate that memory for actions is a fundamentally different type of learning than the traditionally studied VT. As memory for action is one of the most prominent types experienced in the natural environment, understanding the mechanisms of this type of memory is important. By studying the development of and the cognitive processes that may underlie the enactment effect, a greater understanding of this memory phenomenon may be achieved.

Action Memory in Children

Children first experience and learn from the world through their physical interactions with the environment around them (Thelen, Schöner, Scheier, & Smith, 2001). Even after the development of language, and into the elementary school years, children retain a learning advantage when they have the opportunity for hands-on, interactive experiences, as compared to traditional classroom practices such as lecturing and rote learning (Ballantyne & Packer, 2009). For example, students' understanding of mathematical concepts is enhanced when they are given objects (e.g., blocks) to act upon during learning (Park, Chae, & Boyd, 2008), or simply instructed to use their fingers as counting objects (Gracia-Bafalluy & Noël, 2008). Additionally, strategy use in elementary school students is enhanced when they are instructed to interact physically with objects during learning, as compared to performance using pencil and paper, or using no material at all (Manches, O'Malley, & Benford, 2010).

Motor skill development was the first topic explored by developmental psychologists studying infants which provided the biological foundation for other topics of interest in psychology (e.g., cognition and learning; Thelen, 1995). These ideas not only inform us about the motor development of infants, but may provide information about human motor development in general (Thelen, 1995). During the past three decades, a trend towards viewing cognition as embodied (i.e., guided by a body with specific perceptual and motor capabilities) has been reintroduced to the realm of cognitive psychology (Núñez, 2012). In this view, cognitive skills such as memory and reasoning are inseparable and highly influenced by the body within which they are situated (Thelen et al., 2001). In fact, all forms of cognition must have originally arisen through the sensorimotor activities of infants before the development of language occurs (Piaget & Cook, 1952). Although children will eventually develop symbolic and abstract thought, these cognitions are not separable from the physical body that perceives and acts upon the environment (Thelen et al., 2001).

To understand the development of motor skills and the cognitions that occur in accordance with them, it is beneficial to view the body and mind as a dynamic system (Thelen et al., 2001). Cognitive, perceptual, and motor systems are continually interacting with and adapting to environmental stimuli. Developmental change can be defined as states of stability and instability, with phases of instability resulting in rapid changes in patterns of behavior (Thelen, 1995). The transition between walking to running can be used as a simple example of instability resulting in changes in behavioral patterns. As the speed of the individual increases, the gait of walking no longer provides stability and a new more efficient behavioral pattern (i.e., running) emerges suddenly due to the physical constraints of the individual. Additionally, once new patterns of behavior are discovered they are originally inaccurate and must be honed through experience and practice to become efficient and stable. This can be evidenced in the frequent falls of an infant learning to walk, and, once experienced walking has been accomplished, in the similar falling behavior that occurs with inexperienced running.

Cognitions are also shaped, constrained, and changed by the physical environment, and become more efficient over the course of development (Thelen et al., 2001). With regards to memory for SPTs in children, a dynamic systems approach would predict that younger and less experienced preschool aged children (i.e., 4-year-olds) would produce greater variability and less efficiency in their actions, and would, therefore, be less efficient in encoding and remembering the actions they performed. As such, I predict that the enactment effect would be most likely exhibited in older children who have experience in benefitting from action performance itself, and in the multiple encoding properties of action phrase performance.

Most developmental research on memory involves VTs (e.g., Bjorklund, 2005; Coffman, Ornstein, McCall, & Curran, 2008), despite growing evidence for the embodied nature of cognitions, and the positive impact of hands-on experiences and physical interactions with learning materials in the educational environment. In contrast, little research has been conducted to study the effects of physical action even though both language and action are important components in how memories are formed.

Researchers have studied the enactment effect across a wide age range from 6-year-olds to older adults (Foley & Ratner, 2001). As mentioned previously, the ability to integrate multiple perceptual modalities and use this information is crucial to adaptive cognitive functioning and interactions with the environment. Sensory input from multiple modalities also contributes to enhanced attention, learning, and memory in infants (Bahrick & Lickliter, 2012). Infants are able to perceive events more easily when they are presented bimodally as compared to a unimodal presentation (Bahrick & Lickliter, 2004). In early development, however, input from multiple modalities may overtax an infant's attentional abilities and prevent them from benefitting from multiple sensory inputs in the domain of memory. In fact, better attention and memory often occur when only one sensory modality is available (e.g., attending to a face is enhanced when an infant is not also exposed to auditory input of speaking; Bahrick & Lickliter, 2012). Similar findings extend to 4-year-olds (Bahrick, Krogh-Jespersen, Argumosa, & Lopez, 2013). Although the multimodal features of an action event are clearly beneficial and enhance memory in adults and older children, younger children (particularly 4-year-olds and younger) may find the multiple sensory inputs from an action event difficult to attend to.

Evidence for the enactment effect in the child research is inconsistent. Cohen and Stewart (1982) found no differences in recall for SPTs in 9- to 13-year-old children; however, they did find developmental differences in word recall. A limitation of this study was that performance of action phrases was not compared with verbal learning of comparable action phrases. Instead memory for a list of 2-syllable words was compared to action phrase memory. Studies that did include a verbal learning condition using action phrases produce contradictory results. Some studies showed a comparable enactment effect in 6- to 10-year-olds (e.g., Baker-Ward, Hess, & Flanagan, 1990; Wippich, Mecklenbräuker, & Sidiropoulos, 1990), while others indicate that older children within this age group show a larger enactment effect (e.g., Foellinger & Trabasso, 1977; Foley & Johnson, 1985; Price & Goodmen, 1990; Ratner & Hill, 1991).

The discrepancies in the results of these studies are likely due to methodological differences. Specifically, the studies that show similar levels of the enactment effect across age groups use real objects for children to act upon when learning the action phrases (e.g., unscrewing the cap on a real bottle when enacting the phrase “open the bottle”; Mecklenbräuker et al., 2011). Those that showed a larger enactment effect with increased age, however, required that children perform actions on imaginary objects (Ratner & Hill, 1991) or perform actions that required no objects (e.g., make a motion like an airplane; Foley & Johnson, 1985). It is possible that interacting with objects during enactment or even the mere presence of relevant objects during learning may assist in encoding the action phrase and lead to better memory of SPTs (Mecklenbräuker et al., 2011).

In adults, the enactment effect is more robust when objects are present (but not acted upon) as compared to an identical condition in which objects are not present (Steffens et al., 2006). This effect occurs even when the participant's attention is not intentionally directed towards the object. During VTs, however, object integration and enhanced memory only occurs when participants are specifically instructed to use the present object to aid in memory retention (Steffens, Buchner, & Wender, 2003). Results from developmental research provide stronger evidence for the incidental nature of object encoding during SPTs. Although they show evidence of using simple and less effective strategies (e.g., reattending to stimuli), children less than 8 years of age generally do not show spontaneous use of more complex and effective strategies (Schwenk, Bjorklund, & Schneider, 2009). Additionally, young children do not use objects as retrieval cues without being trained in this type of strategy use (Ackerman, 1986). However, children as young as 6 years of age show the enactment effect without strategy training if the relevant objects are present during performance of SPTs as compared to an identical condition in which items are not present, similar to adult research (Mecklenbräuker et al., 2011).

Evidence suggests that object encoding is not automatic and does require a certain amount of cognitive resources for processing. Children that are given additional distractors in the experimental environment (i.e., children were presented with a green stuffed alien who needs to learn about life on earth and were then instructed to remember the items later to teach to the alien) do not show the enactment effect when relevant objects are present in the experimental environment (Mecklenbräuker et al., 2011). By diverting the attention of the children to a distractor item, children were unable to benefit from context integration of the present relevant objects. This result also occurs in adults, such that when attention is diverted away from objects present context integration does not occur (Steffens et al., 2006).

The Role of Executive Function in Memory for Action

The inability to use relevant objects present in the environment when attention is diverted may reflect a taxing of cognitive resources, which has limited reserves and can be reduced due to environmental influences (Engle, 2010). Even though context integration seems to be incidental, it also appears to be conditional on attention (Mecklenbräuker et al., 2011) which is related to EF abilities (Garon, Bryson, & Smith, 2008). Executive function is regarded as flexible, goal-related behaviors that assist an individual in problem solving (Marcovitch & Zelazo, 2009). Executive function abilities are most strongly associated with the prefrontal cortex which plays a role in controlling behavior and cognition by both inhibiting and activating other parts of the brain. The prefrontal cortex is one of the slowest developing areas of the brain (Garon et al., 2008), and large improvements in EF occur throughout the childhood years, particularly between

3 to 5 years of age (Marcovitch & Zelazo, 2009). Executive function can be thought of as an attentional process, and the ability to attend selectively is crucial for the development and use of other EF abilities (Garon et al., 2008). Selective attention allows for several types of measureable cognitive abilities; WM (i.e., holding and manipulating information in mind), inhibition (i.e., inhibiting prepotent responses), and CF (i.e., modifying thought and behavior according to changes in situational context; Lehto, Juujärvi, Kooistra & Pullkinen, 2003). These specific abilities related to EF have been shown to contribute differently to distinct types of memory (e.g., source monitoring and memory for distinctive information; Ruffman, Rustin, Garnham, & Parkin, 2001). There are few studies that examine the contribution of EF to memory development, however, and no studies that examine the role of EF to the development of the enactment effect in preschool children. For the purpose of this study, two types of cognitive abilities associated with EF—WM and CF— were particularly of interest in the development of the enactment effect. It is possible that certain constructs associated with EF, such as WM and CF, may be related to the ability to encode the multimodal components of SPTs.

Higher levels of EF may be required for an enactment task when phrases are enacted using imaginary objects as compared to tasks in which the relevant objects are present. Memory for action phrases learned without relevant objects present not only requires encoding of the phrase and physical action, but also requires children to represent mentally the object of the phrase as there is no object available to facilitate encoding. This should require children to use more cognitive resources as EF abilities are taxed. As such, children with higher levels of WM and CF should be able to remember more phrases learned through enactment, and therefore show the enactment effect. Children with lower levels of EF abilities should not show the enactment effect as they would not be able to benefit from multimodal encoding because the cognitive load of the multiple components of action phrase performance would be too high.

Working memory. Working memory can be understood as a system for maintaining and manipulating information over short spans of time (de Abreu, Conway, & Gathercole, 2010), and improves throughout childhood (Gaillard, Barrouillet, Jarrold, & Camos, 2011). Currently, there is no research that examines the role of WM in memory for action in children. Limited research indicates that higher WM predicts enhanced memory for action in older adults although it does not predict the enactment effect in young adults (Earles, 1996). Presumably this is because memory for action requires integration of stimuli from multiple modalities which is more difficult for older adults as they experience decreases in WM. Encoding actions may place extra demands on an individual's WM, as compared to learning stimuli verbally.

Working memory likely plays a critical role in the development of cognitive skills (Bjorklund, 2005). In both adults and children, acquiring a new skill (e.g., memory for action) is effortful and taxes cognitive resources. As the skill becomes less effortful and more automatic, more resources are freed to process other information that is relevant to the task. WM has been shown to improve throughout childhood, particularly between 4 to 8 years of age (Nevo & Breznitz, 2013). As such, older children should be more likely to show the enactment effect due to higher levels of WM and greater experience with encoding actions. Additionally, high levels of WM should predict the enactment effect over and above age. Specifically, regardless of age, children that have higher WM capacity should be able to benefit from the multimodal encoding properties of a performed action phrase despite the increased cognitive load and, therefore, remember actions they have performed better than action phrases they learned verbally.

Cognitive flexibility. Another cognitive ability related to EF that may influence children's ability to benefit from memory for actions is cognitive flexibility, also known as set shifting (Garon et al., 2008). Inflexibility of cognitions has long been recognized as a barrier to problem solving and is often studied by measuring perseverative behavior once the context of a situation has changed and a new behavior is adaptive for task success (Zelazo et al., 2003). Cognitive flexibility involves switching from one mental representation to another as task demands change (Garon et al., 2008).

Cognitive flexibility may contribute to the development of the enactment effect as the effective encoding of action phrases requires representing the action phrase in multiple ways to achieve multimodal encoding. Children must represent the verbal component of the action phrase, the imaginary object to be acted upon when objects are not present, and the physical performance of the action itself. Additionally, children who have low CF experience difficulties disengaging from one dimension of stimuli in favor for another, more adaptive one (Garon et al., 2008). As discussed previously, certain aspects of the action phrase (i.e., the object being acted upon) may aid memory for actions better than others. Children with low CF may be unable to disengage attention from one aspect of the SPT in favor of a more adaptive dimension.

Another indicator of high CF is the strength of the initial dimension of a stimulus attended to by children. If the first dimension attended to is strong and therefore easy to process, cognitive resources to attend to additional dimensions is increased (Munakata, Morton, & Yerys, 2003). Therefore, greater experience with the multiple dimensions of SPTs should lead to better encoding of action phrases, and thus children who exhibit higher levels of CF will be more likely to experience the enactment effect.

Although both WM and CF are expected to play key roles in the development of the enactment effect, these two abilities may play different roles in the expression of the enactment effect. Garon et al. (2008) assert that all tasks requiring CF depend and build upon WM. Specifically, the number of dimensions children are able to represent may be constrained by WM capacity. While children need to be able to represent a stimulus mentally in multiple contexts to experience increased memory, this may not be a useful aid in memorization and recall if children are unable to maintain actively all the aspects of learning the action phrase (i.e., the phrase itself, the imagined object, and physical movement) within WM.

On the other hand, the ability to represent and switch attention to multiple dimensions of action performance simultaneously may be the cognitive skill that allows for memory improvement resulting from action performance. Manipulations of CF tasks that increase memory demands (e.g., removing target cards during DCCS performance) actually improve performance (Zelazo et al., 2003). This suggests that while the ability to represent multiple dimensions of a stimulus in WM is important, children must represent and understand successfully conflicting dimensions of stimuli at the same time.

Present Research

The goal of the current study was to compare memory for action performance with memory for action phrases learned verbally and through watching action performance of an experimenter in 4- to 6-year-olds. Additionally, WM and CF were examined as predictors of the enactment effect. I hypothesized that children who showed high WM and CF would be more likely to benefit from the multiple sensory inputs of SPTs and show the enactment effect. Children with lower levels of WM should not show the same benefits of action performance.

Six-year-olds were expected to remember more SPTs than the younger age groups; however, measures of EF may predict the actual expression of the enactment effect. Children with high EF should be more likely to experience the enactment effect regardless of age. Children with low EF should remember less phrases overall, and should remember a similar amount of SPTs and phrases learned verbally.

In some cases, 6-year-olds remember actions best when they watch EPTs, as compared to SPTs (Ratner & Hill, 1991). This may occur because the children still receive the advantage of experiencing physical performance of the action phrases without having to work towards producing the action correctly themselves as they are able to rely on another individual to produce the actions for them. Additionally, the fact that these children do not have to encode the physical sensation of action performance results in a decrease in the number of modalities to be encoded. The task of creating and encoding specific actions may be cognitively taxing to less experienced children and cause decreases in SPT memory. Therefore, an EPT condition was included in this study. It is possible that children with the lowest levels of EF may benefit the most from the EPT condition, as compared to the SPT and verbal conditions. Children with higher levels of EF, however, should still outperform lower EF children in memory performance on the EPT task.

CHAPTER II

METHODS

Participants

Children from a midsized city in the Southeast United States were recruited from local daycare centers and from a database of parents who had previously indicated interest in having their children participate in developmental research. Children received a small gift for participating in the study. The study was approved by the Institutional Review Board, and participants were treated in accordance with the ethical standards of the American Psychological Association. The sample consisted of 24 4-year-olds (M = 4.54 years, SD = .26, 15 females), 24 5-year-olds (M = 5.44 years, SD = .26, 8 females), and 24 6-year-olds (M = 6.50 years, SD = .33, 13 females). Children were from families of varying levels of economic status; 55.6 percent reported household earnings over $60,000, 16.7% reported earnings between $40- and $60,000, 6.9% reported earnings between $20- and $40,000, 5.6% under $20,000, and 15.3% did not respond. The sample was racially diverse; 70.8 percent self-identified as white, 16.7% as black or African American, 6.9% as mixed, and 5.6% did not respond.

Materials

For the enactment task, three lists of six action phrases were used (see Table 1). Each action phrase consisted of a verb that could be easily performed by the participant and a noun depicting a commonly manipulated external item (e.g., “Push the button”). All phrases comprised of nouns and verbs that were familiar to young children.

For the auditory backward word span, stimuli were presented by an orange lion puppet named “Leo” or a pink and white rabbit puppet named “Fluffy”. For the Visual Digit Span, laminated cards (20 cm X 20 cm) depicted colored pictures of apples and teddy bears for the training phase and ladybugs and frogs for the testing phase. Each card had eight pictures, and the number of apples and teddy bears or ladybugs and frogs varied on each card.

For the Dimensional Change Card Sort- Borders Version, laminated cards (14 cm X 11 cm) depicted pictures of a yellow car, a yellow flower, a green car, or a green flower. All pictures were approximately 8 cm X 8 cm. Cards that had borders had 1 cm thick black lines around the perimeter. Cards were sorted into two black sorting boxes (23 cm X 15 cm X 14 cm) with slits cut into the lids.

Procedure

Children completed the enactment task (three within-subjects conditions: SPTs, EPTs, and verbally learned phrases), two WM tasks (i.e., Auditory Backward Word Span and Visual Digit Span) and one CF task (i.e., the Dimensional Change Card Sort, Borders Version). Every experimental session began with one of the enactment conditions, and the other two enactment conditions were administered 3rd and 5th within the task order, counterbalanced across participants. The order of the WM tasks was counterbalanced and administered between the enactment task conditions (i.e., 2nd and 4th). The CF task was always administered last (i.e., 6th, see Table 2 for an example of the task order). A delay of at least 15 minutes was imposed between Enactment Task conditions. If the WM tasks were completed before the end of the 15 minute delay, children were allowed to color or play a game with the experimenter.

Enactment task. The enactment task design was inspired by the paradigm reported by Koriat and Pearlman-Avnion (2003).Three 6-item lists of action phrases were taught to each participant. Children learned all three lists, and each list was learned in a different manner (i.e., verbal learning, SPTs, and EPTs) counterbalanced across lists.

In the verbal learning condition, the experimenter asked children if they would play the copycat game. They instructed children to listen carefully because after the game they wanted the children to remember all of the things the experimenter said. The experimenter then said an action phrase and prompted children to repeat the phrase. If they responded incorrectly the experimenter repeated the phrase and the children were asked to repeat the phrase again. To ensure sufficient encoding of the list items, the experimenter presented the list of items twice in the same order.

In the EPT condition, the experimenter explained that they were going to pretend to perform some actions. The experimenter instructed children to sit on their hands, or if they did not want to, place their hands in their lap and to only use their eyes and mouth for this task. The experimenter instructed children to listen and watch carefully because after the game they wanted the children to remember all of the things the experimenter did. The experimenter then performed the action phrase, said the phrase aloud, and prompted children to say the phrase aloud. If children responded incorrectly the experimenter repeated the phrase and the children were asked to repeat the phrase again.

If children attempted to imitate the experimenter, they were reminded to only use their eyes and mouth, and either sit on their hands or keep their hands in their lap. The experimenter presented the list of items twice in the same order.

In the SPT condition, the experimenter instructed children to listen and watch very carefully, and then imitate the physical action they saw because after the game they wanted them to remember all of the things the children and experimenter pretended to do. The experimenter then performed the action phrase, said the phrase aloud, and prompted children to imitate the action and say the phrase aloud. If they responded incorrectly the experimenter repeated the phrase and action and asked the children to repeat the phrase and action again. The experimenter presented the list of items twice.

In each condition, a thirty second delay was imposed between the learning and test phases, and children were asked to count to twenty during the period as a distractor task to minimize the possibility that children were using rehearsal strategies. After the delay, children were asked to recite all of the phrases they remembered. Children were allowed to recall as much as possible without interruption. Once they had not recalled any items for 10 seconds, children were given an additional memory prompt (i.e., Do you remember anything else? Try to think really hard about the things that you learned.).

Performance on the individual conditions of the enactment task (i.e., SPT, EPT, and VT) was scored by summing the number of correct action phrases recalled (Max = 6), disregarding any repetitions (Mecklenbräuker et al., 2011; Ratner & Hill, 1991). An answer was only considered correct if both the action verb and noun were correctly recalled; however, synonym substitutions were accepted if the meaning of the action phrase was the same (e.g., “Press the Button” rather than “Push the Button”). If the meaning of the recalled phrase was ambiguous, two raters were required to agree on the scoring of the phrase through discussion. If the experimenters could not come to consensus the phrase was scored as incorrect.

Auditory backward word span (Carlson, Moses, & Breton, 2002). During training, children were introduced to “Leo” the silly lion puppet or “Fluffy” the silly bunny puppet who says everything backwards. Children were presented with lists consisting of two words (e.g., book, cup), and instructed on how Leo or Fluffy would say the list (e.g., cup, book). Children then had to produce the list backwards just as Leo or Fluffy would. Children passed the training and moved on to the testing phase when they correctly repeated two 2-word training lists backwards (n = 10 children did not pass the training phase). In the testing phase, the experimenter began by administering three trials consisting of two words and said, “If Leo (or Fluffy) says everything backwards, what would he say?” If children reproduced at least one 2-word list correctly the experimenter increased the list size by one, repeating the procedure with 3-, 4-, and 5-word lists. Children were given a score based on the highest word span they were able to remember in at least one of the three lists presented (max score: 5). Children who failed to reproduce a two-word list during training received a score of zero, and children who failed to reproduce a two-word list during test trials received a score of one.

Visual digit span (Case, Kurland & Goldberg, 1982). During training, children were presented with two laminated cards which depicted apples and frogs. The experimenter instructed them to count and remember only the number of apples, and presented one card at a time. The cards were then removed from view, and children were asked the recall the number of apples on each card in order of presentation. Children were exposed to the practice trials of two cards until they were able to produce the correct response (n = 4 children did not pass the training phase). In the testing phase, children were shown cards that contained pictures of ladybugs and frogs, and were instructed to count only the ladybugs. Each card had eight pictures and the number of ladybugs and frogs varied on each card. The experimenter administered three sets of 2 cards each. If children correctly recalled the number of ladybugs in at least one 2-card set, the experimenter increased the list size by one, repeating the procedure with 3-, 4-, and 5-card sets. Children were given a score based on the highest digit span they were able to remember in at least one of the three sets presented (max score: 5). Children who failed to reproduce a two-card set during training received a score of zero, and children who failed to produce a two-card set during test trials received a score of 1.

Dimensional change card sort, borders version (Zelazo, 2006). Children were asked to play a sorting game where they would match experimental cards to target cards that could be identified by two dimensions (i.e., a yellow flower and a green car). The experimental cards (i.e., yellow cars and green flowers) could be sorted to match the targets on the dimension of color or shape. During the pre-switch phase, the experimenter demonstrated two training trials on the pre-switch dimension (color or shape, counterbalanced). Then children were asked to sort six experimental cards on the pre-switch dimension to target cards affixed to two boxes with slits cut in the lids. All children sorted at least five out of six cards correctly during the pre-switch phase. In the post-switch phase, the sorting rules were changed (i.e., if children sorted by color in the pre-switch phase they were asked to sort by shape). Children were scored as passing the task if they sorted at least five out of six trials correctly in the post-switch phase (Zelazo, 2006).

Children who passed the post-switch phase were administered the more difficult borders version. Children were informed that they would be playing the sorting game again, only this time it was going to be more “tricky”. During training, children were shown two test cards that were identical to the experimental cards in the standard version, as well as two cards that had a black border. Children were instructed that when a card has a border they should play the color game, and when the card does not have a border they should play the shape game. Twelve experimental cards were administered, and half of the cards were marked with a black border around the perimeter. Before each trial children were reminded the rules of the game (i.e., if the card has a border they should play the color game and if the card does not have a border they should play the shape game). The experimenter then showed children an experimental card, labeled it as having a border or not having a border, and asked children to sort it by the relevant game. Children were scored as passing the task if they sorted 9 out of 12 experimental cards correctly (Zelazo, 2006).

CHAPTER III

RESULTS

Correlations between Age, Sex, recall of SPTs, EPTs, and VTs, Auditory Backward Word Span (continuous), Visual Digit Span (continuous), and DCCS performance (continuous) are depicted in Table 1. Preliminary analyses on action phrase recall for the three enactment task conditions failed to reveal any main effects or interactions with sex or condition order, and these variables were not included in subsequent analyses. [1]

Effects of Age on Memory for Action

A 3x3 mixed ANOVA with age (4-, 5-, and 6-year-olds) as the between subjects variable and condition (SPT, EPT, and VT) as the repeated measures variables revealed a main effect of age, $F(1, 69) = 4.53$, $p = .01$, and condition, $F(2, 138) = 4.01$, $p = .02$. The main effects were qualified by a marginal interaction between age and condition, $F(4, 138) = 2.15$, $p = .08$, such that condition type had differing effects across age groups.

To explore the interaction, one-way ANOVAs were conducted with age as the independent variable to assess differences in recall for each condition.

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[1] To assess the effect of condition order on performance during the enactment conditions, three one-way ANOVAs were performed with enactment condition (SPT, EPT, or VT) as the dependent variable and condition order (1^{st}, 2^{nd}, and 3^{rd}) as the dependent variable. No effect of condition order was found for SPTs, $F(2, 69) = 1.36$, $p = .26$, EPTs, $F(2, 69) = .49$, $p = .62$, or VTs, $F(2, 69) = 1.05$, $p = .36$. To assess the effect of sex on enactment condition, a 2x3 mixed ANOVA with sex (male and female) as the between subjects variable and condition (SPT, EPT, and VT) as the repeated measures variables revealed no effect of sex, $F(1, 70) = .90$, $p = .45$.

Table 1

Correlations between Age, WM Span, DCCS, and action phrase recall

	1	2	3	4	5	6	7	8
1.) Age	1	-0.03	0.35**	0.30**	-0.01	0.56**	0.53**	0.49**
2.) Sex		1	0.14	-0.04	0.16	-0.1	0.01	0.02
3.) SPTs			1	0.13	0.22	0.22	0.29*	0.22
4.) EPTs				1	-0.05	0.21	0.22	-0.02
5.) VTs					1	-0.01	-0.06	-0.22
6.) BWS						1	0.42**	0.36**
7.) VDS							1	0.29*
8.) DCCS								1

Note. *p <.05 **p <.01

An ANOVA on SPT recall revealed significant differences between age groups, $F(2, 69) = 4.92$, $p = .01$. Tukey's HSD comparisons indicated significant differences in recall between 6-year-olds and 4-year-olds ($p = .01$), and between 6-year-olds and 5-year-olds ($p = .05$). An ANOVA on EPT recall revealed significant differences between age groups, $F(2, 69) = 4.06$, $p = .02$. Tukey's HSD comparisons indicated significant differences in recall between 6-year-olds and 4-year-olds ($p = .02$). An ANOVA on VTs revealed no differences between age groups, $F(2, 69) = .03$, $p = .97$ (see Figure 1).

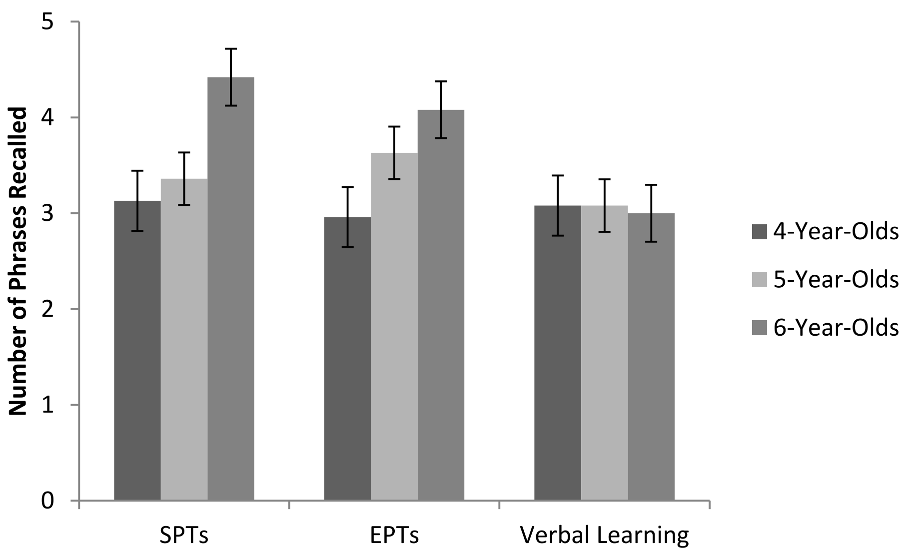

Figure 1. Mean (and standard error) recall of action phrases by condition and age

To assess the enactment effect, a difference score was created by subtracting the total number of VTs from the total number of SPTs recalled. A positive difference score represents higher recall of SPTs as compared to VTs (i.e., the enactment effect). To assess the EPT effect, a difference score was created by subtracting the total number of VTs from the total number of EPTs recalled. A positive difference score in this instance represents greater recall of EPTs as compared to VTs. Finally, to assess the SPT effect (i.e., the difference between phrases learned by participant enactment as compared to viewing experimenter action), a difference score was created by subtracting the total number of EPTs recalled from the total number of SPTs recalled. A positive difference score indicates higher recall of the phrases learned by SPT as compared to EPT.

One sample t-tests were performed to determine whether enactment effect scores were different from 0 (i.e., no difference between memory for SPTs and VTs) by age group. Six-year-olds showed the enactment effect (M = 1.42, SD = 1.59), $t(23) = 4.38$, $p < .001$, while neither 4-year-olds (M = .04, SD = 1.99), $t(23) = .10$, $p = .92$, nor 5-year-olds (M = .29, SD = 1.90), $t(23) = .75$, $p = .46$, did. One sample t-tests were also performed to determine whether EPT effect scores were different from 0 (i.e., no difference between memory for EPTs and VTs) by age group. Six-year-olds showed the EPT effect (M = 1.08, SD = 1.82), $t(23) = 2.92$, $p = .008$. Additionally, 5-year-olds showed the EPT effect with marginal significance (M = .54, SD = 1.53), $t(23) = 1.73$, $p = .09$. Four-year-olds, however, did not show the EPT effect (M = -.13, SD = 2.64), $t(23) = -.23$, $p = .82$. Finally, one sample t-tests were performed to determine whether SPT effect scores were different from 0 (i.e., no difference between memory for SPTs and EPTs) by age group. Neither 4-year-olds (M = .17, SD = 2.58), $t(23) = .32$, $p = .76$, 5-year-olds (M = -.25, SD = 2.03), $t(23) = -.60$, $p = .55$, nor 6-year-olds (M = .33, SD = 1.20), $t(23) = 1.36$, $p = .19$, had SPT effect scores that differed from 0 (see Figure 2).

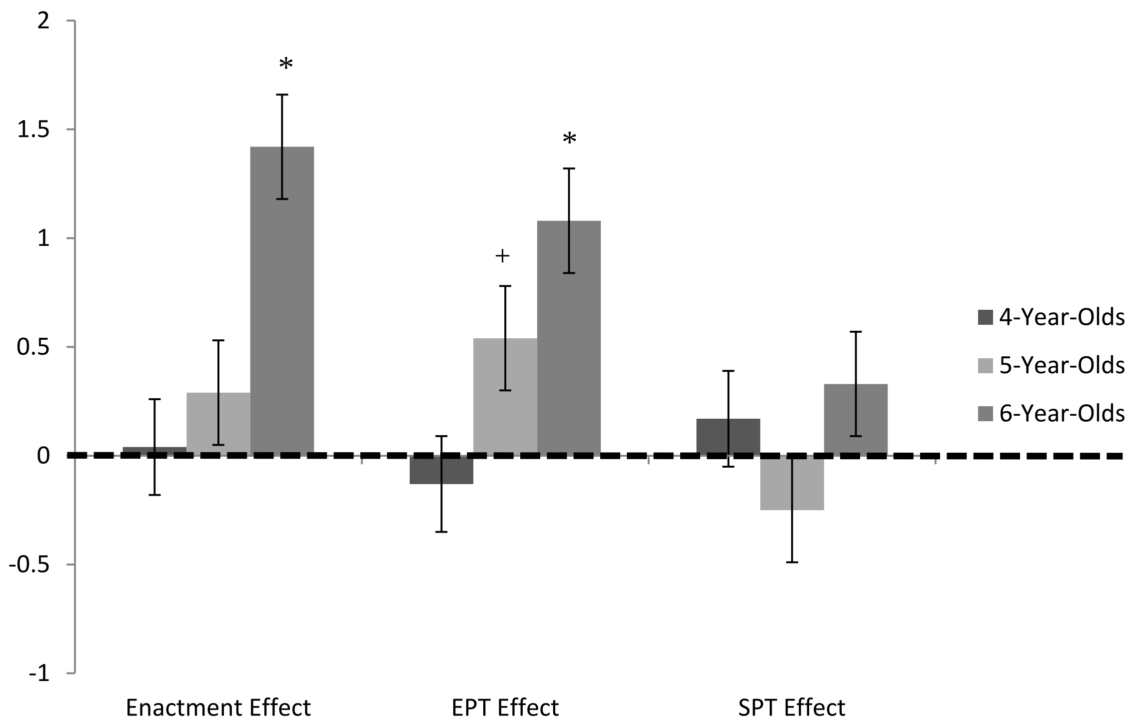

Figure 2. Mean (and standard error) enactment task difference scores by age
*+ p <.10 * p <.01*

An ANOVA on the enactment effect revealed significant differences between age groups, $F(2, 69) = 3.83$, $p = .03$. Tukey's HSD comparisons indicated a significant difference between 6-year-olds and 4-year-olds ($p = .03$), and a marginally significant difference between 5-year-olds and 6-year-olds ($p = .09$). Neither an ANOVA on the EPT effect, nor an ANOVA on the SPT effect revealed significant differences between age groups, $F(2, 69) = 2.09$, $p = .13$, and $F(2, 69) = .53$, $p = .59$ respectively.

Executive Function and Memory for Action

The effects of WM on memory for actions were assessed. The auditory backward word span and visual digit span were significantly correlated, $r(70) = .42$, $p < .001$, and a WM composite score was creating by converting the variables to z-scores and averaging the scores. A regression analysis was performed with the enactment effect as the dependent variable, and the independent variables were entered in three steps: (1) AGE, (2) WM composite, and (3) AGE X WM. Age significantly predicted the enactment effect, $\beta = .30$, $t = 2.59$, $p = .01$, $R^2 = .09$, such that children were more likely to show the enactment effect with increasing age. Neither WM composite ($\Delta R^2 = .02$, $F(2, 69) = 1.63$, $p = .21$) nor the Age X WM interaction ($\Delta R^2 = .02$, $F(3, 68) = 1.13$, $p = .29$) improved prediction of the enactment effect (see Table 2).

Table 2

Regression of the enactment effect on AGE, WM, and AGE X WM

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.09*
AGE	.66*	.25	.30*	
Step 2				.02
AGE	.39	.33	.18	
WM	.43	.34	.19	
Step 3				.02
AGE	.45	.33	.20	
WM	2.38	1.87	1.27	
AGE X WM	-.18	.17	-.89	

Note. $^*p < .05$

A regression analysis was also performed with the EPT effect as the dependent variable. AGE predicted the EPT effect with marginal significance, $\beta = .21$, $t = 1.83$, $p = .07$, $R^2 = .05$, such that children were more likely to show the EPT effect with increasing age. Neither WM composite ($\Delta R^2 = .01$, $F(2, 69) = .81$, $p = .37$) nor the AGE X WM interaction ($\Delta R^2 = .01$, $F(3, 68) = .49$, $p = .49$) improved prediction of the enactment effect (see Table 3).

Table 3

Regression of the EPT effect on AGE, WM, and AGE X WM

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.05+
AGE	.52+	.28	.21+	
Step 2				.01
AGE	.31	.37	.13	
WM	.34	.38	.14	
Step 3				.01
AGE	.35	.38	.15	
WM	1.80	2.11	.72	
AGE X WM	-.14	.20	-.61	

Note. +*p* <.10

A final regression analysis was performed with the SPT effect (i.e., SPT-EPT) as the dependent variable. AGE did not predict the SPT effect, β = .06, t = .50, p = .62, R^2 = .003. Neither WM composite (ΔR^2 = .001, $F(2, 69)$ = .06, p = .82) nor the AGE X WM interaction (ΔR^2 = .001, $F(3, 68)$ = .06, p = .81) improved prediction of the SPT effect (see Table 4).

Table 4

Regression of the SPT effect on AGE, WM, and AGE X WM

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.003
AGE	.14	.28	.06	
Step 2				.001
AGE	.08	.37	.04	
WM	.09	.38	.04	
Step 3				.001
AGE	.10	.38	.04	
WM	.58	2.10	.28	
AGE X WM	-.05	.19	-.21	

Next, analyses on the effects of CF on memory for actions were performed. The measure of CF, DCCS performance, was calculated by summing the number of cards sorted correctly during the pre-switch, post-switch, and borders phases of the DCCS (range: 0-24). A regression analysis was performed with the enactment effect as the dependent variable, and the independent variables were entered in three steps: (1) AGE, (2) DCCS performance, and (3) AGE X DCCS. The addition of DCCS performance in the second step significantly improved prediction, $\beta = .27$, $t = 2.13$, $p = .04$, $R^2 = .14$, indicating that DCCS performance significantly predicts recall, over and above age, $\Delta R^2 = .06$, $F(2, 69) = 4.52$, $p = .04$. The Age X WM interaction did not improve prediction of the enactment effect ($\Delta R^2 = .001$, $F(3, 68) = .08$, $p = .78$; see Table 5).

Table 5

Regression of the enactment effect on AGE, DCCS, and AGE X DCCS

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.09*
AGE	.65*	.25	.30*	
Step 2				.06*
AGE	.37	.28	.16	
DCCS	.08*	.04	.27*	
Step 3				.001
AGE	.56	.77	.25	
DCCS	.14	.23	.49	
AGE X DCCS	-.01	.04	-.28	

Note. *p <.05

A regression analysis was also performed with the EPT effect as the dependent variable. Neither DCCS performance (ΔR^2 = .01, F(2, 69) = .81, p = .37) nor the AGE X DCCS interaction (ΔR^2 = .01, F(3, 68) = .49, p = .49) improved prediction of the enactment effect (see Table 6).

Table 6

Regression of the EPT effect on AGE, DCCS, and AGE X DCCS

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.05+
AGE	.52+	.28	.21+	
Step 2				.002
AGE	.46	.33	.19	
DCCS	.02	.04	.05	
Step 3				.000
AGE	.45	.89	.19	
DCCS	.01	.27	.05	
AGE X DCCS	.001	.05	.01	

Note. +p <.10

A final regression analysis was performed with the SPT effect (i.e., SPT-EPT) as the dependent variable. Neither DCCS performance (ΔR^2 = .03, $F(2, 69) = 2.32$, $p = .13$) nor the AGE X DCCS interaction (ΔR^2 = .001, $F(3, 68) = .07$, $p = .80$) improved prediction of the SPT effect (see Table 7).

Table 7

Regression of the SPT effect on AGE, DCCS, and AGE X DCCS

Variable	*B*	*SE*(*B*)	*β*	ΔR^2
Step 1				.003
AGE	.14	.28	.06	
Step 2				.03
AGE	-.10	.32	-.04	
DCCS	.06	.04	.21	
Step 3				.001
AGE	.11	.86	.05	
DCCS	.13	.26	.42	
AGE X DCCS	-.01	.05	-.27	

To assess whether group differences in DCCS performance predict the enactment effect children were divided into three groups based on pass/fail performance (i.e., fail post-switch, pass post-switch, and pass borders). Children's scores on the post-switch phase are generally distributed bimodally (i.e., children sort all cards either correctly or incorrectly; Zelazo, 2006), and DCCS performance is often scored using a pass/fail criteria (e.g., Farrant, Maybery, & Fletcher, 2011; Hongwanishkul, Happaney, Lee, & Zelazo, 2005; Henning, Spinath, Aschersleben, 2010). Children who failed post-switch sorted less than 5 out of 6 cards correctly during the initial post-switch phase. Children who passed post-switch sorted at least 5 out of 6 cards correctly, but sorted less than 9 out of 12 cards correctly in the

Borders phase. Children who passed borders sorted at least 9 out of 12 borders cards correctly in the Borders phase.

A one-way ANOVA with the enactment effect as the dependent variable and DCCS performance (DCCS; fail post-switch, pass post-switch, pass borders) and age (4-, 5-, and 6-year-olds) as independent variables revealed a main effect of DCCS, $F(2,63) = 3.84$, $p = .03$. There was no main effect of age, $F(2, 63) = .90$, $p = .42$. The main effect was not qualified by a DCCS X age interaction, $F(4, 63) = 1.21$, $p = .32$.

One sample t-tests were performed to determine whether enactment effect scores were different from 0 among children who failed post-switch, passed post-switch, and passed borders. Children who failed post-switch did not show the enactment effect, $t(24) = -.61$, $p = .55$. Children who passed post-switch did show the enactment effect, $t(31) = 2.60$, $p = .01$, and children who passed borders also showed the enactment effect, $t(14) = 3.56$, $p = .003$ (see Figure 3).

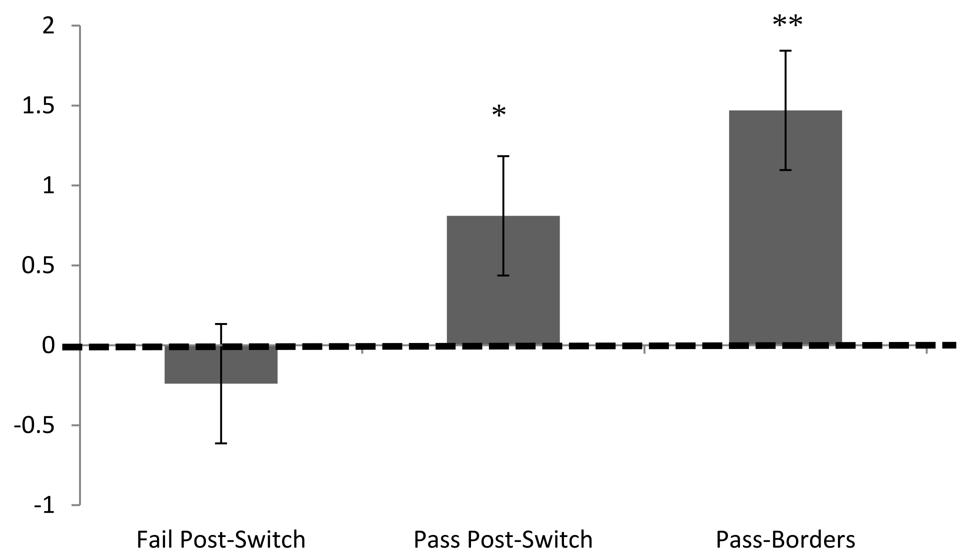

Figure 3. Mean (and standard error) enactment effect difference scores by DCCS performance (collapsed across age as there were no interactions by age)
** p <.05 ** p <.01*

A one-way ANOVA with the EPT effect as the dependent variable and DCCS performance (DCCS; fail post-switch, pass post-switch, pass borders) and age (4-, 5-, and 6-year-olds) as independent variables revealed no main effect of DCCS, $F(2,63) = 2.03$, $p = .14$, and no main effect of age, $F(2, 63) = .23$, $p = .80$. There was no DCCS X age interaction, $F(4, 63) = 1.23$, $p = .31$.

A one-way ANOVA with the SPT effect as the dependent variable and DCCS performance (DCCS; fail post-switch, pass post-switch, pass borders) and age (4-, 5-, and 6-year-olds) as independent variables revealed no main effect of DCCS, $F(2, 63) = 1.53$, $p = .23$, and no main effect of age, $F(2,63) = .13$, $p = .88$. There was no DCCS X age interaction, $F(4, 63) = .03$, $p = .99$.

Finally, to assess the contributions of WM and CF within the same model, regression analyses were performed with the independent variables entered in three steps: (1) AGE, (2) WM composite and DCCS, and (3) AGE X WM, AGE X DCCS, WM X DCCS, and AGE X WM X DCCS. A regression analysis was performed with the enactment effect as the dependent variable. The addition of WM composite and DCCS predicted the enactment effect with marginal significance, $\Delta R^2 = .07$, $F(3, 68) = 2.82$, $p = .07$. WM composite did not predict the enactment effect, $\beta = .15$, $t = 1.05$, $p = .30$; however, children with high performance on the DCCS showed the enactment effect, $\beta = .25$, $t = 1.98$, $p = .05$. Addition of interaction terms did not improve prediction of the enactment effect, $\Delta R^2 = -.04$, $F(7, 64) = .78$, $p = .54$ (see Table 8).

Table 8

Regression of the enactment effect on AGE, WM and DCCS, and interaction terms

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.09*
AGE	.66*	.25	.30*	
Step 2				.07+
AGE	.17	.34	.08	
WM	.17	.17	.15	
DCCS	.07*	.04	.25*	
Step 3				.04
AGE	.47	.97	.21	
WM	-.33	2.34	-.29	
DCCS	.18	.30	.63	
AGE X WM	.03	.46	.14	
AGE X DCCS	-.02	.06	-.39	
WM X DCCS	.13	.14	1.80	
Age X WM X DCCS	-.02	.03	-1.54	

Note. +p <.10 *p <.05

To assess the contributions of WM and CF, a parallel regression analysis was performed with the EPT effect as the dependent variable. WM composite and DCCS performance did not predict the EPT effect, $\Delta R^2 = .01$, $F(3, 68) = .44$, $p = .65$. Addition of interaction terms did not improve prediction of the EPT effect, $\Delta R^2 = .01$, $F(7, 64) = .27$, $p = .90$ (see Table 9).

Table 9

Regression of the EPT effect on AGE, WM and DCCS, and interaction terms

Variable	*B*	*SE*(*B*)	*β*	ΔR^2
Step 1				.05+
AGE	.52+	.28	.21+	
Step 2				.01
AGE	.27	.39	.11	
WM	.16	.19	.13	
DCCS	.01	.04	.04	
Step 3				.02
AGE	.42	1.14	.18	
WM	2.26	2.74	1.82	
DCCS	.05	.36	.17	
AGE X WM	-.45	.54	-1.96	
AGE X DCCS	-.01	.08	-.21	
WM X DCCS	-.07	.17	-.84	
Age X WM X DCCS	.02	.03	1.17	

Note. +p <.10

To assess whether WM and CF predict performance on the SPT effect, a parallel regression analysis was performed with the SPT Effect as the dependent variable. WM composite and DCCS performance did not predict the SPT effect, $\Delta R^2 = .03$, $F(3, 68) = 1.15$, $p = .32$. Addition of interaction terms did not improve prediction of the SPT effect, $\Delta R^2 = .03$, $F(7, 64) = .48$, $p = .79$ (see Table 10).

Table 10

Regression of the SPT effect on AGE, WM and DCCS, and interaction terms

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.003
AGE	.14	.28	.06	
Step 2				.03
AGE	-.11	.38	-.05	
WM	.01	.19	.01	
DCCS	.06	.04	.21	
Step 3				.03
AGE	.05	1.01	.02	
WM	-2.60	2.66	-2.17	
DCCS	.13	.34	.42	
AGE X WM	.47	.52	2.17	
AGE X DCCS	-.01	.07	-.16	
WM X DCCS	.20	.16	2.58	
Age X WM X DCCS	-.04	.03	-2.67	

Executive Function Tasks as Primary Variables of Interest

As measures of EF are generally highly correlated with age in children, the contribution of EF is often examined by entering EF task performance in the first step of a regression model (e.g., Marcovitch, Boseovski, Knapp, & Kane, 2010). Due to the multicollinearity between age and WM composite (r (70) = .64, p < .001), additional regression analyses were run with the independent variable of main interest, WM composite, entered into the analyses before age. A regression analysis was performed with the enactment effect as the dependent variable, and the independent variables were entered in three steps: (1) WM composite, (2) AGE, and (3) WM X AGE. Scores on the WM composite significantly predicted the enactment effect, β = .30, t = 2.63, p = .01, R^2 = .09, such that children with higher overall WM are more likely to show the enactment effect. Neither AGE (ΔR^2 = .02, $F(2, 69) = 1.43$, $p = .24$) nor the WM X Age interaction (ΔR^2 = .02, $F(3, 68) = 1.13$, $p = .30$) improved prediction of the enactment effect (see Table 11).

Table 11

Regression of the enactment effect on WM, AGE, and WM X AGE

Variable	*B*	*SE*(*B*)	β	ΔR^2
Step 1				.09*
WM	.34*	.13	.30*	
Step 2				.02
WM	.21	.17	.19	
AGE	.39	.33	.18	
Step 3				.02
WM	1.19	.93	1.05	
AGE	.45	.33	.2	
WM X AGE	-.18	.17	-.88	

Note. *p <.05

A regression analysis was also performed with the EPT effect as the dependent variable. Scores on the WM composite predicted the EPT effect with marginal significance, $\beta = .22$, $t = 1.86$, $p = .07$, $R^2 = .05$, such that children with higher overall WM are more likely to show the EPT effect. Neither AGE (ΔR^2 = .01, $F(2, 69) = .67$, p = .41) nor the WM X Age interaction (ΔR^2 = .007, $F(2, 68) = .50$, $p = .49$) improved prediction of the EPT effect (see Table 12).

Table 12

Regression of the EPT effect on WM, AGE, and WM X AGE

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.05+
WM	.27+	.15	.22+	
Step 2				.01
WM	.17	.19	.14	
AGE	.31	.37	.13	
Step 3				.007
WM	.90	1.10	.72	
AGE	.35	.38	.15	
WM X AGE	-.14	.20	-.61	

Note. + p <.10

A final regression analysis was performed with the SPT effect as the dependent variable. Scores on the WM composite did not predict the SPT effect, $\beta = .06$, $t = .50$, $p = .62$, $R^2 = .004$. Neither AGE ($\Delta R^2 = .001$, $F(2, 69) = .53$, $p = .82$) nor the WM X Age interaction ($\Delta R^2 = .001$, $F(3, 68) = .58$, $p = .81$) improved prediction of the SPT effect (see Table 13).

Table 13

Regression of SPT effect on WM, AGE, and WM X AGE

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.004
WM	.07	.14	.06	
Step 2				.001
WM	.04	.19	.04	
AGE	.08	.37	.04	
Step 3				.001
WM	.29	1.05	.24	
AGE	.10	.38	.04	
WM X AGE	-.05	.19	-.21	

Next, similar analyses were run to assess the effects of CF on memory for actions. Due to the multicollinearity between age and DCCS performance (*r* (70) = .49, $p < .001$), the independent variable of main interest, DCCS performance, was entered into regression analyses before age. For the first analysis, DCCS was entered into the regression at the first step, AGE was entered in the second step, and the DCCS X AGE interaction was entered third. DCCS performance significantly predicted the enactment effect, $\beta = .35$, $t = 3.14$, $p = .003$, $R^2 = .12$, such that increased scores on the DCCS predicted the enactment effect. Neither AGE ($\Delta R^2 = .02$, $F(2, 69) = 1.66$, $p = .20$) nor the DCCS X Age interaction ($\Delta R^2 = .001$, $F(3, 68) = .08$, $p = .78$) improved prediction of the enactment effect (see Table 14).

Table 14

Regression of the enactment effect on DCCS, AGE, and DCCS X AGE

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.12**
DCCS	.10**	.30	.35**	
Step 2				.02
DCCS	.08	.04	.27	
AGE	.37	.28	.16	
Step 3				.001
DCCS	.14	.23	.49	
AGE	.56	.77	.25	
DCCS X AGE	-.01	.04	-.26	

Note. $**p < .01$

To assess whether CF predicts the EPT effect, a parallel regression analysis was performed with the EPT effect as the dependent variable. DCCS did not predict the EPT effect, β = .05, t = 1.20, p = .24, R^2 = .02. Neither AGE (ΔR^2 = .03, F(1, 68) = 1.99, p = .16) nor the DCCS X Age interaction (ΔR^2 < .001, F(4, 64) < .001, p = .99) improved prediction of the EPT effect (see Table 15).

Table 15

Regression of the EPT effect on DCCS, AGE, and DCCS X AGE

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.02
DCCS	.05	.04	.05	
Step 2				.03
DCCS	.02	.04	.05	
AGE	.46	.33	.19	
Step 3				.000
DCCS	.01	.27	.04	
AGE	.45	.89	.19	
DCCS X AGE	.001	.05	.01	

To assess whether CF predicts performance on the SPT Effect, a parallel regression analysis was performed with the SPT Effect as the dependent variable. DCCS did not predict performance on the SPT Effect, β = .19, t = 1.59, p = .12, R^2 = .04. Neither AGE (ΔR^2 = .008, F(1, 68) = .09, p = .76) nor the DCCS X Age interaction (ΔR^2 = -.006, F(4, 64) = .06, p = .80) improved prediction of the SPT Effect scores (see Table 16).

Table 16

Regression of SPT effect on DCCS, AGE, and DCCS X AGE

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.04
DCCS	.06	.04	.19	
Step 2				.001
DCCS	.06	.04	.21	
AGE	-.10	.32	-.04	
Step 3				.001
DCCS	.13	.26	.42	
AGE	.11	.89	.05	
DCCS X AGE	-.01	.05	-.27	

Finally, to assess the contributions of WM and CF within the same model, regression analyses were performed with the independent variables entered in three steps: (1) WM composite and DCCS, (2) AGE, and (3) WM X AGE, DCCS X AGE, WM X DCCS, and WM X DCCS X AGE. A regression analysis was performed with the enactment effect as the dependent variable. Scores on the WM composite and the DCCS significantly predicted the enactment effect, $\Delta R^2 = .15$, $F(2, 69) = 6.30$, $p = .003$. WM composite did not predict the enactment effect, $\beta = .19$, $t = 1.60$, $p = .11$; however, children with high performance on the DCCS showed the enactment effect, $\beta = .28$, $t = 2.29$, $p = .03$. Neither AGE ($\Delta R^2 = .003$, $F(1, 68) = .24$, $p = .63$) nor the interaction terms ($\Delta R^2 = .04$, $F(4, 64) = .78$, $p = .54$) improved prediction of the enactment effect (see Table 17).

Table 17

Regression of the enactment effect on WM and DCCS, AGE, and interaction terms

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.15**
WM	.44	.27	.19	
DCCS	.08*	.04	.28*	
Step 2				.003
WM	.35	.33	.15	
DCCS	.07*	.04	.26*	
AGE	.17	.34	.08	
Step 3				.04
WM	-.67	4.67	-.29	
DCCS	.18	.30	.63	
AGE	.48	.97	.21	
WM X AGE	.03	.46	.14	
DCCS X AGE	-.02	.06	-.39	
WM X DCCS	.13	.14	1.80	
WM X DCCS X AGE	-.02	.03	-1.54	

Note. +p <.10 *p <.05 **p <.01

To assess the contributions of WM and CF, a parallel regression analysis was performed with the EPT effect as the dependent variable. WM composite and DCCS performance did not predict the EPT effect, $\Delta R^2 = .05$, $F(2, 69) = 1.86$, $p = .16$. Neither AGE ($\Delta R^2 = .007$, $F(1, 68) = .48$, $p = .49$) nor the interaction terms ($\Delta R^2 = .02$, $F(4, 64) = .27$, $p = .90$) improved prediction of the EPT effect (see Table 18).

Table 18

Regression of the EPT effect on WM and DCCS, AGE, and interaction terms

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.05
WM	.48	.32	.19	
DCCS	.02	.04	.07	
Step 2				.007
WM	.33	.38	.13	
DCCS	.01	.04	.04	
AGE	.27	.39	.11	
Step 3				.02
WM	4.51	5.49	1.82	
DCCS	.05	.35	.17	
AGE	.43	1.14	.18	
WM X AGE	-.45	.54	-1.96	
DCCS X AGE	-.01	.07	-.21	
WM X DCCS	-.07	.17	-.84	
WM X DCCS X AGE	.02	.03	1.17	

To assess whether WM and CF predict performance on the SPT effect, a parallel regression analysis was performed with the SPT Effect as the dependent variable. WM composite and DCCS performance did not predict the SPT effect, $\Delta R^2 = .04$, $F(2, 69) = 1.25$, $p = .29$. Neither AGE ($\Delta R^2 = .001$, $F(1, 68) = .08$, $p = .78$) nor the interaction terms ($\Delta R^2 = .03$, $F(4, 64) = .43$, $p = .80$) improved prediction of the SPT effect (see Table 19).

Table 19

Regression of the EPT effect on WM and DCCS, AGE, and interaction terms

Variable	*B*	*SE*(*B*)	*β*	*ΔR²*
Step 1				.04
WM	-.04	.31	-.02	
DCCS	.06	.04	.19	
Step 2				.001
WM	.02	.37	.01	
DCCS	.06	.04	.21	
AGE	-.11	.39	-.05	
Step 3				.03
WM	-5.18	5.32	-2.17	
DCCS	.13	.34	.42	
AGE	.05	1.10	.02	
WM X AGE	.47	.52	2.17	
DCCS X AGE	-.01	.07	-.16	
WM X DCCS	.20	.16	2.58	
WM X DCCS X AGE	-.04	.03	-2.67	

CHAPTER IV

DISCUSSION

The present study assessed memory for action phrases in 4-, 5-, and 6-year-olds. The primary goal of the study was to explore cognitive skills that may contribute to the development of the enactment effect (i.e., better memory for phrases learned through SPTs as compared to VTs). In previous research with 6- to 10-year-olds, developmental changes in the enactment effect were found in some studies but not in others. As memory for action may require more cognitive resources as compared to memory for VTs, higher levels of EF, which increases the amount of information children are able to process and encode, should predict the enactment effect. As such, cognitive skills associated with EF (i.e., WM and CF) were measured. Also of interest was the EPT effect (i.e., memory for experimenter performed actions as compared to memory for VTs), as EPTs may require less cognitive resources than SPTs. The SPT effect (i.e., memory for SPTs as compared to EPTs) was also examined as it was hypothesized that higher levels of WM and CF may not be as critical for memory of EPTs as compared to memory of SPTs.

Executive Function and Memory for Action

Upon initial analysis, WM did not predict the memory for actions. This result was due to multicollinearity between WM performance and age. As such, the effect of WM on memory for actions was analyzed again with WM performance into the first step of regression analyses. Children that performed well on the WM tasks were more likely to show increased memory for SPTs suggesting that WM is involved in the development of increased memory for actions. While the relationship between WM and the enactment effect has not been studied previously in children, these results are consistent with research with older adults indicating that the enactment effect is only expressed by individuals who show higher WM abilities (Earles, 1996). Working memory may be necessary in the development of the enactment effect because memory for action requires encoding and integration from multiple modalities, and individuals with lower WM experience difficulties with memory integration of complex events (Earles, 1996). This might be due to decreased cognitive resources available for processing and integrating the multiple modalities of action phrase performance. Children who scored highly on the WM tasks were also more likely to show the EPT effect. Although it was hypothesized that children with lower WM abilities may benefit from EPTs even if they did not show increased memory for SPTs, children with the lowest WM did not show the EPT effect. There is, however, evidence that EPTs do require fewer cognitive resources than SPTs as 5-year-olds showed the EPT effect even though they did not show the enactment effect, and significant increases in WM task performance have been demonstrated in children between 5 and 7 years of age (Nevo & Breznitz, 2013).

Unlike analyses on WM, CF predicted the enactment effect in regression analyses whether it was entered in the first step before age or in the second step after age indicating that CF is a more robust predictor of the enactment effect. Children with higher levels of CF are more likely to show a memory benefit for self-performed actions. Only children who passed the post-switch phase of the task showed the enactment effect, and children who passed the borders phase showed the largest enactment effect indicating that increasingly complex CF skills are important for the development of the enactment effect. According to the Cognitive Complexity and Control Theory, successful performance on the DCCS is contingent upon the integration and successful use of incompatible rules during task performance (Zelazo et al., 2003). Specifically, children must reflect upon and appreciate that multiple rules can apply to the same stimuli. For example, if children are playing the color game, they must understand that yellow cars go in the first box and green flowers go in the second box. If children are playing the shape game, however, they must understand that green flowers go in the first box and yellow cars go second box. Children that fail the DCCS are unable to integrate this rule system and represent only one rule within the experimental session. Therefore failure of the DCCS is the result of a failure to use flexibly the rules of the task. The ability to represent stimuli dimensions flexibly should assist children with high CF to benefit from the multimodal encoding that results in the enactment effect.

Higher CF may also allow children to show increased memory for SPTs because children who have higher CF are able to disengage from one aspect of stimuli in favor for a more adaptive one (Garon et al., 2008). These children may be able to attend to elements of action performance that enhance memory (i.e., the action and the object being acted upon) while focusing a smaller amount of attention on less useful elements (i.e., the verbal label; Smith & Vela, 2001). Children with high CF also have the ability to attend to more dimensions of stimuli, as they have greater cognitive resources than children with low CF (Munakata, Morton, & Yerys, 2003).

Although DCCS performance did predict the enactment effect, it did not predict the EPT effect. It is possible that EPTs require less cognitive resources than SPTs as children expend less cognitive resources encoding the EPTs due to the decreased modalities that must be processed (i.e., children are not required to reproduce and encode the physical performance of an action phrase). As such, even children with lower CF may have the cognitive resources to represent and encode an action phrase when there are fewer modalities that must be processed.

Working Memory and CF contribute differentially to the development of memory for action. Individual differences in WM ability predict both the enactment effect and the EPT effect only when task performance was considered before the contribution of increasing age, while CF predicted only the enactment effect. Additionally, a model assessing the dual contributions of WM and CF in the same step revealed that only CF predicts the enactment effect indicating that variance unique to DCCS performance drives the prediction of the enactment effect. The WM tasks assessed in this study required children to encode information, remember a rule required for successful completion of the task, and then manipulate the information accordingly. The DCCS also requires the maintenance of task rules, and information manipulation. It is necessary, however, that children recognize multiple dimensions of task stimuli and use multiple, incompatible rules. Additionally, use of these dimensions must be switched flexibly as the rules of the task change. This ability to recognize the multiple dimensions of stimuli, and use dynamic rule systems successfully, may also allow children to switch attention flexibly to the multimodalities provided by action performance. WM has been shown to play a more general role in children's memory abilities (Ruffman et al., 2001) and allows children to consider and encode the multiple modalities of both SPTs and EPTs. Memory for SPTs, in particular, is taxing to cognitive resources, and the ability to switch attention flexibly to the multiple dimensions of SPT performance may be necessary to experience the enactment effect. As such, the development of CF appears to be uniquely important to the development of the enactment effect. The decreased cognitive requirements of EPTs may make the ability to switch attention to different modalities while manipulating information within WM less important to the EPT effect. Flexible shifting between dimensions and the ability to attend to more modalities may not be necessary for increases in memory of EPTs to occur.

After individual differences in WM and CF were accounted for, age did not predict the enactment effect or the EPT effect. Developmental increases in EF skills such as WM and CF most likely underlie the development of increased memory for actions, while other age-related processes (e.g., increases in short term memory; Purser et al., 2012) are less likely to be involved in the expression of the enactment effect. The development of increased action memory between 4 to 6 years of age is a result of rapid increases in these cognitive skills during the preschool years. Specifically, the enactment effect does not occur simply because action performance offers increased encoding opportunities through multiple modalities. It is the cognitive manipulation of the multimodal properties of action performance that allows them to be encoded and integrated, and the flexible switching of attention to the most salient and useful aspects of the enacted phrase that produces the enactment effect. As such, EF abilities encourage enhanced and adaptive processing of action performance.

Future Directions and Limitations

The role of EF in the enactment effect has not been studied in older children, and developmental differences in the enactment effect have been shown in children up to 11 years of age (Zimmer et al., 2001). Future research should assess whether EF predicts the enactment effect in older children as EF continues its most expansive period of development through 8 years of age (Nevo & Breznitz, 2013). EF should continue to predict the enactment effect in school-age children strengthening the theory that EF abilities underlie the expression of the enactment effect. In contrast, if measures of EF do not predict the enactment effect in older children, additional strengthening of EF abilities beyond the preschool years produces no additional effect on action recall. This finding would imply that the enactment effect requires relatively low levels of EF ability, and would give evidence as to why the enactment effect is such a robust and universal experience in adolescents and adults.

Inconsistencies in task protocol across studies may be responsible for the fact that developmental differences in the enactment effect were found in some studies but not in others (Zimmer et al., 2001). Six- to 8-year-old children are more likely to show the enactment effect when performing actions on real objects as compared to imaginary ones (Mecklenbräuker et al., 2011). An analogous task comparing memory for actions when objects are present and not present in the experimental space should be administered to younger children (i.e., 4- to 6-year-olds), and measures of WM and CF should be administered. It is feasible that when objects are present, memory for SPTs may require less cognitive resources as compared to an identical task using imaginary objects. As such, higher EF skills may not be necessary for the expression of the enactment effect, and children may benefit from action performance sooner than previously thought. However, even if 4-year-olds exhibit the enactment effect when objects are present, the effect may not be as robust as in older children. EF skills may predict the magnitude of the enactment effect indicating that the development of EF underlies the development of increased memory for actions even in situations with reduced task demands. This would suggest that even though children with lower EF are showing a benefit from action performance, action memory will continue to improve as EF continues to develop. Previous studies have indicated that directing attention towards aspects of action phrase performance that enhance encoding increase action memory (Mecklenbräuker et al., 2011). Therefore, the enactment effect may be increased even in children with lower EF if they are given instructions to focus their attention to the physical action they are performing, or, if an object is present, the object being acted upon.

In adults, the differential effects of WM and CF on the enactment effect have not been examined. WM does not predict the enactment effect in younger adults, but is a particularly important predictor of the enactment effect in older adults (Earles, 1996). The ability to represent multiple dimensions of an action phrase and switch attention flexibly between those dimensions seems to be a relevant aspect of encoding actions, and older adults experience problems doing so. Older adults experience greater difficulty maintaining larger amounts of information in mind outside of the scope of attention, and are therefore less likely to access this information when they attempt to re-attend to it. Younger adults experience less difficulty maintaining and retrieving information that has fallen outside of the scope of attention (Basak & Verhaeghen, 2011). As such, examining the contribution of CF in older adults may contribute meaningful knowledge to the lifespan development of the enactment effect. Given that the enactment effect is robust and unvarying in older children and young adults (Zimmer et al., 2001), but varies in young children and older adults (Earles, 1996, Mecklenbräuker et al., 2011), is it likely that CF plays an important and unique role in the expression of the enactment effect as these are groups that often show deficits in CF (Marcovitch & Zelazo, 2009; Verhaeghen & Hoyer, 2007).Different methods of assessing memory often yield different results (Perlmutter & Lange, 1978). Using another measure of recollection (i.e., recognition) may allow for more sensitive measurement of children's memory for actions. Age differences in memory performance of preschoolers are reduced during assessments of recognition memory as compared to recall (Perlmutter & Lange, 1978), and 3-year-olds have been shown to perform comparably to 6-year-olds during a recognition task administered immediately after a learning event (Myers et al., 2003).

In adults, reenactment of previously performed action phrases (Engelkamp, Zimmer, Mohr, & Sellen, 1994) and experimenter reenactment of an EPT (Mulligan & Hornstein, 2003) increases recognition (i.e., the reenactment effect). Enactment of phrases previously learned verbally, however, does not increase recognition. As such, providing children with recognition cues (i.e., allowing children to reenact or see experimental reenactment of previously performed action phrases in conjunction with previously unlearned action phrases) may allow children to remember more phrases overall. Examining memory through recognition may be a more sensitive measure of the memory for actions if younger children (i.e., 4- and 5-year-olds) and children with low EF are experiencing a memory benefit from enacting action phrases but are unable to generate the phrases through recall. Higher recall would make the difference between memory for actions and VTs easier to assess.

Language skills have been shown to predict the amount of items children are able to remember during free recall (Archibald & Joanisse, 2013). The present study required children to recall the noun-verb action phrase verbally, and this may have been difficult for the youngest children. The design did not include an assessment of memory for action devoid of verbal recall, and it is possible that some children had a hard time remembering the phrases even though they may have remembered the actions performed. Research on the development of grammatical understanding indicates that before children are able to express their knowledge of actions through the use of a verb-noun phrase, they are able to use physical actions (i.e., gestures) to communicate an action being performed upon an object (Ingram, 1971). As such, children who have not developed a sufficient understanding of grammatical rules may have a hard time remembering and expressing an action phrase. However, these children may show the enactment effect if they are allowed to recall through action only. Additionally, an assessment of grammatical knowledge (e.g., Test of Language Development-Primary-Fourth Edition; Hammill & Newcomer, 2008) may predict the production of the enactment effect as children with a better understanding of grammatical rules may remember action phrases better than those who do not.

Understanding the role of physical actions in children's memory abilities may also be beneficial in the classroom environment. Children should be encouraged to interact physically with learning materials, as previous studies have indicated increased learning in multiple domains when physical interactions are encouraged (e.g., Gracia-Bafalluy & Noël, 2008; Park et al., 2008). School-age children are more likely to be engaged positively in educational information (Ballantyne & Pascal, 2009) and master complex skills earlier (Park et al.) when they are allowed interactive experiences as compared to teacher lecture and worksheets. Klahr and Li (2005) showed that children benefit equally when using hands on materials and computer simulations of the same materials to learn scientific information. However, computer simulations still allow children to encode physical actions visually and manipulate information in an interactive manner as compared to the rote learning that occurs with teacher lecture. The current study extends knowledge on the potential benefits of an interactive learning environment within the classroom. While previous studies showed that physical interactions with learning materials lead to the development of specific mathematics and science skills, the current study indicates that physical actions may also play a more general role in memory. Thus, encouraging actions and interactive play in the classroom may lead to better retention of information. Younger children and children who have lower EF skills are less likely to show a memory benefit from physical enactment, and, therefore educators and parents should be aware that these memory benefits may not occur rapidly, especially for preschoolers.

Conclusions

The present study contributes to the limited developmental research involving the enactment effect, and is the first of its kind to examine the contribution of EF to the development of the enactment effect. The current study highlights the importance of WM and CF to enhanced memory for action, and indicates that the development of the enactment effect occurs in conjunction with the development of these cognitive skills. As the results of the study indicate the significance of EF to the enhanced memory for actions, future research should consider these cognitive skills when studying memory for action.

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APPENDIX A

ACTION PHRASE LISTS

1. Break the Stick
2. Twist the Bottle Cap
3. Tear the Paper
4. Bite the Carrot
5. Honk the Horn
6. Push the Button

1. Open the Book
2. Pour the Milk
3. Drive the Car
4. Cradle the Baby
5. Hammer the Nail
6. Brush your teeth

1. Cut the Cake
2. Blow the Bubbles
3. Hug the Teddy Bear
4. Ring the Bell
5. Throw the Ball
6. Stack the Blocks

APPENDIX B

EXPERIMENTAL TASK ORDER

1. Enactment Task- SPT Condition
2. WM Task- Visual Digit Span
3. Enactment Task- EPT Condition
4. WM Task- Auditory Backwards Word Span
5. Enactment Task- VT Condition
6. CF Task- DCC