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The Role of Executive Functions in Item Recognition and Temporal Order Memory Development

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ABSTRACT
Item recognition and temporal order memory follow different developmental trajectories during middle childhood, with item recognition performance stabilizing and temporal order memory performance continuing to improve. We investigated the potential unique role of individual executive functions on item recognition and temporal order memory during this critical developmental period. Our results replicate and expand on previous findings, suggesting that executive functions, specifically inhibitory control and working memory, may be more crucial for successful temporal order memory than for item recognition during middle childhood.

Memory is a flexible process that exists at varying levels of complexity. For example during recognition tasks, participants are shown a series of images (i.e., memory encoding; Melton, 1963; Tulving & Thomson, 1973) then asked to indicate if they have seen a presented item or image before (old/new judgment; Egan, 1958). This task may be made more complex by manipulating the stimuli, such as showing an image of a blue car during the image presentation but then testing with both a blue and a red car. Another method of increasing complexity is to ask participants to retrieve (i.e., remember; Melton, 1963; Tulving & Thomson, 1973) additional contextual elements related to the presented images (e.g., shown a black and white car during test and asked to indicate the color from image presentation). These added task manipulations all share one common component: context. In order to be successful, participants must retrieve the contextual information, rather than rely on there cognition of the item alone, in order to be successful. Perhaps not surprisingly, the addition of context questions results in poorer performance when compared to general old/new judgments. Source theories of human memory posit that two primary processes account for observed performance differences: item and contextual (e.g., temporal) memory (Glisky, Polster, & Routhieaux, 1995; Shimamura & Squire, 1987). Item memory involves remembering a specific item while contextual memory is remembering the context in which the item appeared. For example, if a child is shown an image of a duck with a red border and a cow with a blue border then their item memory would be that they saw a duck and cow. Their contextual memory would involve additional details, such as they saw a red border with a duck and a blue border with a cow (item-color context association) or they saw the duck first and then the cow (item-temporal context association).

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Differences in item recognition and temporal order memory performance are especially pronounced in childhood, when neural regions (Ghetti & Lee, 2014; Riggins, Blankenship, Mulligan, Rice, & Redcay, 2015) and behavioral strategies, such as ordering memories based on goals (Blankenship & Kibbe, 2019) and clustering (Horn, Bayen, & Michalkiewicz, 2021), are still developing. Indeed, early childhood (≤6 years) has received a great amount of attention, with many researchers focusing on the emergence and development of contextual memory for sources (Drummey & Newcombe, 2002; Rajan, Cuevas, & Bell, 2014; Riggins, Rollins, & Graham, 2013) and time (Mooney, Johnson, Prabhakar, & Ghetti, 2021). Middle childhood (6–9 years) has received considerably less attention. This is surprising given that the research that does exist suggests considerable improvements in contextual memory compared to item memory from early to middle childhood (Ghetti & Angelini, 2008; Ghetti & Bunge, 2012; Rhodes, Murphy, & Hancock, 2011). The development of contextual memory is dependent on the type of information children are asked to retrieve, with temporal memory showing more protracted development when compared to item (Pathman & Ghetti, 2014) and spatial memory (Picard et al., 2012).

One factor that may be driving the development of temporal memory is the ability to exert control over cognitive processes (i.e., cognitive control). Cognitive control is essential for typical functioning, contributes to fundamental cognitive processes (e.g., episodic memory or detail rich memory; Blankenship & Bell, 2015; de Chastelaine, Friedman, & Cycowicz, 2007; Raj & Bell, 2010; Rajan & Bell, 2015; Tulving, 1972), and displays a protracted development throughout childhood (Davidson, Amso, Anderson, & Diamond, 2006), as observed with temporal memory. Executive functions (EF) are often used to describe the underlying mechanisms driving cognitive control (Diamond, 2013). EF as a unitary construct has been associated with contextual memory during middle childhood (Rajan & Bell, 2015). Evidence suggests, however, that while these processes often operate in a unitary manner, they also serve distinct functions (Miyake et al., 2000). For example, Blankenship and Bell (2015) reported that cognitive flexibility (flexibly switch between mental sets), but not inhibitory control (suppress dominant response) or working memory (maintain and manipulate information) contributed to episodic memory in a sample of 9–12-year-old children. Their findings may have partially been driven by the memory task used (i.e., cued recall). The task required children to recall images that were associated with a specific border color. This item to color matching may not require the same EFs as temporal order memory. The need to order a set of memories based on temporal information may be more demanding on working memory and inhibitory control mechanisms than item to color matching. Given these findings, investigating the unique roles of the components of EF may provide insight into the differences observed in temporal order and item recognition memory during middle childhood.

Each EF component is believed to serve both coupled and distinct functions in regards to cognitive control. Inhibitory control regulates responses, such as suppressing a dominant or prepotent response in favor of another more appropriate response. The ability to suppress dominant responses is necessary during memory tasks because of potential interference during memory encoding (e.g., not being distracted by stimuli in the environment) and retrieval (e.g., not being distracted by environmental stimuli and internal memory interference; Collette, Germain, Hogge, & Van der Linden, 2009; Wimber, Rutschmann, Greenlee, & Bäuml, 2009). Working memory allows for information to be maintained and manipulated. In fact, information is brought into long-term memory and later retrieved through the maintenance and manipulation provided by working memory (Baddeley, 2000; Tulving, 1972). Finally, cognitive flexibility allows for quick and efficient shifts in cognitive processing. This is essential for effective memory encoding and retrieval, because it allows for changes to be made between potential memory strategies (i.e., allowing for the most effective strategy to be selected; Cosden, Ellis, & Feeney, 1979; Taconnat et al., 2009).

Given the association between unitary EF (Rajan & Bell, 2015), and individual components of EF (Blankenship & Bell, 2015), to episodic memory, it is likely they also serve unique roles to item recognition and recognition requiring context retrieval (i.e., temporal order). Temporal order memory judgment follows a developmental trajectory more similar to EF than item recognition. Due to the developmental similarities between contextual memory and EFs in general, we anticipate that the components of EF will contribute to temporal order memory in a more uniform manner (i.e., all components will contribute) compared to item recognition. Although temporal order memory may be more dependent on EFs, it is likely that working memory will contribute to both components, given its role in general retrieval. Inhibitory control and cognitive flexibility, however, are less likely to be critical for item recognition performance, as these processes occur when there is conflict and increased strategy use, which may be less needed when engaging in item recognition, as it is less effortful than temporal order memory (Blankenship, Keith, Calkins, & Bell, 2018; Cabeza, Anderson, Houle, Mangels, & Nyberg, 2000). To better understand the development of item recognition and temporal order memory during middle childhood, we investigated the unique contributions of working memory, inhibitory control, and cognitive flexibility during the later half of middle childhood (i.e., 9-years).

As noted, item recognition and temporal memory are distinct processes that support memory retrieval. Critically, temporal recollection continues to improve throughout middle childhood (Ghetti & Angelini, 2008), and into adolescence, while item memory seems to stabilize around 9 years (Picard et al., 2012). In the following study, we addressed these performance differences by examining how individual EFs (inhibitory control, working memory, and cognitive flexibility) differentially contribute to item recognition and temporal order memory in a sample of 9-year-old children. We focused on this age because item recognition ability is believed to stabilize at this point while temporal order memory ability is continuing to mature (Picard et al., 2012). We had two primary aims. First, we wanted to investigate performance differences in 9-year-old item recognition and temporal order memory performance. Previous work suggests that item recognition tasks are completed with more ease than context-dependent tasks in children (Blankenship & Bell, 2015; Blankenship et al., 2018; Ghetti & Angelini, 2008; Picard et al., 2012) and adults (for review see Yonelinas, 1994). We aimed to replicate this finding using a task that taps into item recognition and temporal order memory. We hypothesized that children would perform better, and respond faster, on item recognition compared to temporal order questions. Second, we aimed to replicate previous findings suggesting a relation between EF and context dependent memory (Blankenship & Bell, 2015; Picard et al., 2012; Rajan & Bell, 2015) by investigating the predictive roles of inhibitory control, working memory, and cognitive flexibility on item recognition and temporal order memory performance. Working memory is essential for general memory encoding and retrieval, whereas inhibitory control and cognitive flexibility are more important for encoding and retrieval strategy selection (Taconnat et al., 2009; Wimber et al., 2009). Therefore, we hypothesized working memory would predict both item recognition and temporal order memory performance, but that inhibitory control and cognitive flexibility would only contribute to temporal order memory. Critically, this replication will advance our understanding of the unique role of individual EFs on temporal order memory in a large sample of 9-year-old children. Previous studies have relied on smaller samples (Blankenship & Bell, 2015; Picard et al., 2012) and aggregated their analyses across a broad age range (4–16 year; Picard et al., 2012). Our method will help elucidate the unique contributions during a period associated with rapid improvement in temporal memory (i.e., middle childhood; Picard et al., 2012).

Method

Participants

Our sample was comprised of 204 children (*M* = 9.51, *SD* = 0.50; 48% Female) who were part of two cohorts from an on-going longitudinal study on cognition and emotion. The two cohorts were recruited at two research locations. Eighty children were seen at the Blacksburg, Virginia location, while the remaining 124 children were seen at the Greensboro, North Carolina location. The children came from a diverse racial background with 15.7% reported as Black or African American by their parents, 8.3% as more than one race, .5% as Asian, and 75.5% as White. Regarding parent education, 78% of fathers and 91.2% of mothers completing some form of education beyond high school. Parents received a $75 gift certificate and children received a $20 gift certificate, as well as a small gift.

Procedure

Identical protocols were used at both data collection locations. Research assistants from each location were trained together by the project's Principal Investigator (the 3rd author) on protocol administration, as well as on data collection and coding. Upon arrival at the research laboratory, a research assistant explained the study procedures and obtained verbal and signed assent from the child and signed consent from the mother. After a brief warm-up period, children participated in a variety of behavioral tasks assessing cognitive and emotional development, including the tasks that are the focus of the current report. The session video feed was digitally recorded for later behavioral coding.

Memory task

Memory was assessed using a task adapted from the Corsi-Milner memory task (Milner, Corsi, & Leonard, 1991). Prior to the start of the task children completed practice trials to ensure understanding. During practice, three standardized images (Bank of Standardized Stimuli; Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010) were shown sequentially then children were requested to make an item recognition selection between two images one of which was part of the sequence of images and another that was new (i.e., item recognition; "Which of these images have you seen before?"). Children repeated this sequence until they answered correctly. After completing the item recognition practice, they saw three different images sequentially and were requested to make a temporal order selection between two images one of which they saw at beginning of the sequence and the other at the end (i.e., temporal order; "Which of these images have you seen most recently?"). Again, the sequence was repeated until they answered correctly. After children answered both the item recognition and temporal order questions correctly and appeared to understand the task, they began the first test block.

The task was separated into four blocks. Each block began with a sequential presentation of 25 images, resulting in 100 images total, each image was shown for 1.5 seconds with a 1 second intertrial interval. Following the image presentation, participants were immediately prompted to begin answering questions. The questions consisted of two images denoted with A or B and the participants indicated the correct answer using the keyboard. A total of 5 item recognition and 5 temporal order questions were asked in each block, resulting in a total of 20 questions for each condition. Importantly, the images used in the item recognition questions did not overlap with the images used in the temporal order questions. The task was programed using SuperLab 4.5 (SuperLab Pro Edition) software developed by Cedrus, and the variables of interest were proportion correct for both item recognition and temporal order questions. See Figure 1 for examples of temporal order (Figure 1a) and item recognition (Figure 1b) questions.

Inhibitory control task

Inhibitory control was assessed using a computerized number Stroop task (Ruffman et al., 2001). The task was separated into three conditions: letters, numbers, and mixed. We focused on the mixed condition of this task, because it induces the most conflict, and thus need for inhibitory control, as it includes trials from both the letters and numbers conditions. Prior to the start of the task children completed practice trials to ensure understanding. During mixed test trials, children were told to count either letters ("AAAA" = 4) or number digits ("3333" = 4) that appeared on the computer screen and to indicate their response as quickly as possible on the keyboard. The inclusion of both the letter and digit conditions required the most conflict resolution because children had to rapidly shift responses from the easier letter condition to the harder digit condition. The variable of interest was the reaction time for responses during mixed test trials.

Working memory task

Working memory was assessed using a backwards digit span (BDS) task. Our BDS task was based on the version given in the Wechsler Intelligence Scale for Children-Revise (WISC-R; Wechsler, 1974). Prior to the start of the task, two practice BDS trials were

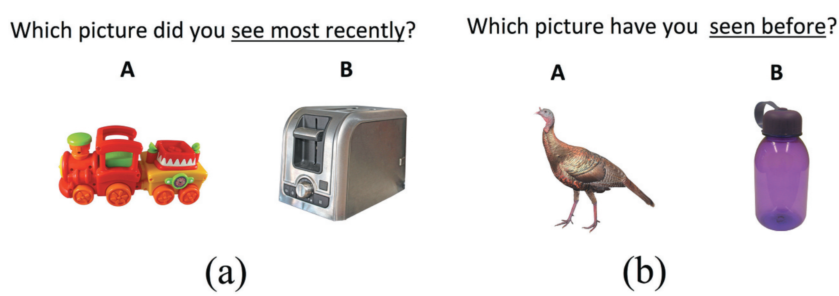

Figure 1. Examples of questions given in memory task. (a) is an example of a temporal order question, while (b) is item recognition.

given to ensure understanding. During the test trials, children were initially presented with two digits and instructed to repeat the sequence backwards. Attempt at recall of the same digit span with at least one correct trial for two trials was required before lengthening the span by one digit. The digit span was lengthened until errors were produced on two consecutive trials of the same span. The variable of interest was the highest digit successfully answered.

Cognitive flexibility task

Cognitive flexibility was assessed using a computerized version of the Wisconsin Card Sorting Task (WCST-64; Heaton & PAR staff, 2003). During the task, children were instructed to sort cards by matching the stimulus card, at the bottom of the screen, with one of four key cards at the top of the screen. Contrary to adult instruction and to prevent floor effects, children were further instructed to sort cards based on three dimensions (color, shape, and quantity). After children sorted the cards correctly for a period of time the dimension used to sort the cards changed (e.g., from color to shape), and they had to flexibly change their strategy in order to be successful on the task. The variable of interest was perseverative errors. Perseverative errors are made by continuously using the same matching rule even after receiving feedback that the rule was no longer correct. This variable taps into cognitive flexibility (Miyake et al., 2000).

Verbal IQ proxy

Verbal IQ was measured using The Peabody Picture Vocabulary Test IV (PPVT; Dunn & Dunn, 2007). The PPVT is a measure of both receptive vocabulary and verbal comprehension; it is often used as a proxy for verbal IQ. Because intelligence is typically correlated with EFs and memory performance, we controlled for this variable in our analyses. The PPVT is a nationally standardized instrument, and the measure of interest was participants' standardized score.

Results

Comparison of item recognition and temporal memory performance

First, we compared performance on both the item recognition and temporal memory questions to chance levels (50% proportion correct). Children's performance was above chance on both item recognition (M = 89% correct, SD = 13.2%), $t(200) = 46.44$, $p < .001$ and temporal order (M = 62% correct, SD = 12.1%), $t(200) = 12.89$, $p < .001$. This suggests that children were able to successfully use both item recognition and temporal order to make memory judgments.

To investigate the level of difficulty for temporal order compared to item recognition trials, we ran independent samples t-tests, one comparing proportion correct performance between item recognition and temporal order test trials and another comparing the children's reaction time for each condition (i.e., the amount of time for them to make a response to a test question). In terms of overall accuracy, children performed better on item recognition than temporal order questions, $t(200) = -21.12$, $p < .001$. In terms of reaction time, children responded faster to item recognition (M = 3752 ms, SD = 1223 ms) than temporal order (M = 4232 ms, SD = 1552 ms) questions, $t(200) = 7.55$, $p < .001$. Together these results suggest that temporal order trials were more challenging for 9-year-olds than recognition trials.

Correlations among study variables

For descriptive statistics and correlations refer to Table 1. Briefly, children reproduced an average highest digit of 3.81 (SD = .99) on the working memory task (i.e., BDS), an average reaction time of 2295 ms (SD = 589 ms) on the inhibitory control task (i.e., Stroop), and an average of 11.46 (SD = 5.32) perseverative errors on the cognitive flexibility task (i.e., WCST). Out of the 204 children in the study, one did not complete the memory and inhibitory control task, two did not complete the memory task, and three did not complete the inhibitory control task. Verbal IQ was positively correlated with both item recognition and temporal order performance. Inhibitory control was negatively correlated to temporal order performance, which is expected given that faster RT's suggest better inhibitory control, but was not correlated with item recognition performance. Working memory performance was positively correlated with both item recognition and temporal order performance. Finally, cognitive flexibility was not correlated with either item recognition or temporal order performance.

Contributions of executive functions to memory performance

Hierarchical regressions were used to examine the contributions of inhibitory control, working memory, and cognitive flexibility to item recognition and temporal order.Verbal IQ (i.e., PPVT) was entered into the first step of each equation, to control for potential effects of verbal IQ on item recognition and temporal order performance. Inhibitory control, working memory, and cognitive flexibility were entered into the second step of each equation, to investigate potential unique contributions of each component of EF on item recognition and temporal order performance.

Verbal IQ Step 1 accounted for 7% of the variance in item recognition performance. The variables in Step 2 accounted for an additional nonsignificant 2% of the variance in item recognition performance (see Table 2). These results suggest that individual executive functions do not contribute to item recognition performance, above and beyond verbal IQ.

Verbal IQ Step 1 accounted for 10% of the variance in temporal order performance. The variables in Step 2 accounted for an additional significant 7% of the variance in temporal order performance (see Table 3), with inhibitory control (2%) and working memory (3%)

Table 1. Correlations and descriptive statistics.

Variables	1	2	3	4	5	6
1. Item Recognition	–					
2. Temporal Order	.355***	–				
3. Inhibitory Control	−.097	−.206**	–			
4. Working Memory	.153*	.286***	−.166*	–		
5. Cognitive Flexibility	−.099	−.134	−.041	−.011	–	
6. Verbal IQ	.251***	.321***	−.176*	.273***	−.066	–
Mean	.895	.620	2295.244	3.814	11.456	112.706
SD	.121	.131	589.322	.995	5.321	14.880

Table 2. Hierarchical regression analyses of executive functions predicting item recognition performance.

	R	R^2	$R^2\Delta$	$F\Delta$	F	β	t	sr^2
Step 1:	.26	.07			14.09***			
Verbal IQ Proxy						.26	3.75***	.07
Step 2:	.29	.09	.02	1.33		4.54***		
Verbal IQ Proxy						.22	3.00**	.04
Inhibitory Control						−.04	−.63	.00
Working Memory						.10	1.35	.01
Cognitive Flexibility						−.09	−1.29	.01

****p* ≤ .001; ***p* ≤ .01; **p* ≤ .05. (*n* = 198).

contributing unique variance. These results suggest that inhibitory control and working memory contribute to temporal order performance, above and beyond verbal IQ.

Discussion

We investigated 9-year-old children's memory performance on a recognition task designed to tap into item recognition and temporal order memory, and how inhibitory control, working memory, and cognitive flexibility differentially contributed to these memory measures. We had two primary aims. First, we aimed to validate our recognition task by demonstrating it displayed performance patterns observed in item recognition and temporal order memory tasks. Specifically, we hypothesized that 9-year-olds would perform better and react faster on questions measuring item recognition than temporal order. Our findings support our hypothesis, replicating tasks comparing item recognition and temporal order performance (Blankenship et al., 2018; Picard et al., 2012).

We also investigated the contributions of individual EF on item recognition and temporal order memory performance in 9-year-old children, a critical developmental period for both temporal order memory (Billingsley, Smith, & McAndrews, 2002; Picard et al., 2012) and EF (Davidson et al. 2006). We had two primary hypotheses under this aim. First, we hypothesized that working memory would contribute to both item recognition and temporal order memory, given the necessary role of working memory for long term memory encoding and retrieval. We partially supported this hypothesis, with working memory contributing to temporal order, but not item recognition performance. This was surprising but could potentially suggest that item recognition is less dependent on working memory than temporal order memory. Indeed, item recognition has been argued to be an unconscious, automatic process (Wagner, Gabrieli, & Verfaellie, 1997), which might not require effortful memory processes such as working memory. Working memory did, however, contribute to temporal order memory performance. Retrieval and ordering of temporal details is an

Table 3. Hierarchical regression analyses of executive functions predicting temporal order performance.

	R	R^2	$R^2\Delta$	$F\Delta$	F	β	t	sr^2
Step 1:	.32	.10			22.25***			
Verbal IQ Proxy						.32	4.72***	.10
Step 2:	.41	.17	.07	5.31**	9.91***			
Verbal IQ Proxy						.23	3.39***	.05
Inhibitory Control						−.14	−2.01*	.02
Working Memory						.19	2.75**	.03
Cognitive Flexibility						−.12	−1.78	.01

****p* ≤ .001; ***p* ≤ .01; **p* ≤ .05. (*n* = 198).

effortful process because it may require vivid retrieval and ordering of context-dependent memories (Deker & Pathman, 2021; Picard et al., 2012), relying on working memory.

Second, we hypothesized that inhibitory control and cognitive flexibility would both contribute to temporal order memory, but not item recognition. Our findings partially supported this hypothesis. Inhibitory control (measured via reaction time) contributed unique variance to temporal order memory, but not item recognition, performance. Cognitive flexibility, however, did not contribute to either memory measure. Inhibitory control has previous been linked to successful temporal processing, but with a focus on adults (Cabeza et al., 2000; Cabezas & Carriedo, 2020). Our work expands this connection by examining the relation between inhibitory control and temporal order memory during middle childhood, a period when both of these processes are undergoing rapid development. Our focus on a specific age (9 years) where temporal memory ability improves (Picard et al., 2012) allows for a more precise observation of this relation during middle childhood.

The link between inhibitory control and temporal order memory may be partially explained by the need to suppress interference, which is necessary for successful temporal order memory judgments. This suppression may have been especially important during our task, because we required children not only to retrieve memories but to also make temporal judgments. Organization of the temporal order of memories is dependent on cognitive control mechanisms (Cabeza et al., 2000; Picard et al., 2012), including working memory and inhibition. For example, extraction of the relevant information from memories (i.e., the accurate memories and their temporal order) requires inhibition of the irrelevant information, while the reordering of the relevant memories likely occurs within working memory. The lack of relation between cognitive flexibility and temporal order was not expected. Indeed, previous work found that cognitive flexibility was critical to episodic memory tasks requiring recall (Blankenship & Bell, 2015). One explanation is that successful recall requires more flexible strategy use than recognition. For example, previous work with elderly adults found that their word list recall performance was negatively impacted by their lack of strategy use (i.e., clustering; Taconnat et al., 2009), which in turn was associated with cognitive flexibility. Further, similar strategies have been found to improve recall, but not recognition performance (Channon, Baker, & Robertson, 1993). Together, these studies suggest that cognitive flexibility may be more critical for recall than recognition memory because success on recall tasks requires greater strategy use. Future research should further examine the relationship between cognitive flexibility and episodic memory on a variety of measures to elucidate these observed differences.

Together our results may suggest that developmental improvements in inhibitory control and working memory capacities may contribute to the improvements observed in temporal order memory during middle childhood. The developmental maturation of inhibitory control and working memory may result in more mature strategies and efficient encoding and retrieval of episodic memories, resulting in better temporal order memory. While our study provides support for this account, we did not examine this relationship longitudinally across middle childhood. Future research should examine the relationship between inhibitory control, working memory, cognitive flexibility, item recognition, and temporal order memory longitudinally across middle childhood to better understand how individual EF supports episodic memory development.

Our findings may also have implications for the dual process literature, which separates recognition memory into recollection (vivid retrieval of details/context) and familiarity (sense of experiencing something before; Yonelinas, 2002). Similar to temporal order and item recognition memory, recollection develops more slowly than familiarity, with familiarity stabilizing around the same age (i.e., 8 years; Ghetti & Angelini, 2008) as item recognition (i.e., 9 years; Picard et al, 2012). Familiarity is also less effortful than recollection, so it possible these memory processes would have similar relations with EFs as was observed with item recognition and temporal memory, respectively. Future studies should directly examine how EFs may differentially contribute to these similar memory processes.

In sum, we replicated previous studies by finding a relation between context-dependent memory and executive functions (e.g., Blankenship & Bell, 2015; Picard et al., 2012). Our study extends beyond previous work by examining the contributions of EF to both temporal order memory and item recognition during a developmental period associated with rapid improvement in temporal memory performance. We found evidence that EFs, specifically inhibitory control and working memory, are more crucial for successful temporal memory performance compared to item recognition in a sample of 9-year-olds. These findings may provide insight into the developmental differences observed between item recognition and temporal memory, and suggests that the protracted development of temporal memory may be partially explained by developmental changes in inhibitory control and working memory abilities.

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