ABSTRACT

Title of Dissertation: DEVELOPMENT OF SUBJECTIVE AND OBJECTIVE RECOLLECTION: EVIDENCE FROM EVENT-RELATED POTENTIALS

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Memory, particularly memory for contextual details (i.e., recollection), undergoes significant development from middle childhood to young adulthood. This research examined the development of recollection utilizing participant's subjective reports as well as their objective accuracy for two contextual details (i.e., the color of the item and a semantic judgment made during encoding). The aims of the present studies were to examine age-related differences in subjective and objective recollection, the correspondence between these abilities, and their neural correlates. Participants included 6- to 8-year-old children, 12- to 13-year-old adolescents, and young adults. Event-related potentials (ERPs) were recorded during the encoding (Study 1) and retrieval (Study 2) portions of a memory paradigm. Age-related improvements in objective and subjective recollection were found in both studies. At encoding, ERP indices of recollection were present when recollection was indexed subjectively or by accuracy for the semantic judgment made during encoding. In

contrast, ERP responses were not sensitive to recollection when memory for color was used as the measure of recollection. ERP effects associated with recollection at encoding were not influenced by age. This finding suggests that children, adolescents, and adults process items similarly at the encoding stage. During retrieval, a recollection effect was only present when recollection was indexed by subjective judgments. Further, this effect was influenced by participant age. The effect was absent in children, topographically widespread in adolescents, and, consistent with previous literature (for review see Rugg & Curran, 2007), maximal over left centro-parietal leads in adults. Collectively, these findings suggest that ERP effects associated with recollection may be more apparent using subjective versus objective measures and that improvement in memory performance from middle childhood to adulthood is primarily attributable to the development of consolidation, storage, or retrieval processes.

DEVELOPMENT OF SUBJECTIVE AND OBJECTIVE RECOLLECTION:

EVIDENCE FROM EVENT-RELATED POTENTIALS

by

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Chapter 1: Introduction

Remembering events from our past involves not only recognizing that specific events occurred but also retrieving contextual details about those experiences and subjectively *reliving* them. Research on the development of the subjective experience that accompanies recollection has lagged behind studies on the development of memory for specific contextual details. This has occurred primarily because of methodological challenges associated with administering subjective tasks to young children. However, investigations on the development of subjective remembering are important because this ability is a critical component of episodic memory (Tulving, 1985). Further, the subjective experience of remembering is hypothesized to motivate action and support the development of self-identity by providing continuity of the self throughout the past, present, and future (Rajaram & Roediger, 1997). Thus, research on the development of subjective recollection will be able to shed light on multiple aspects of cognition including how and why children remember, memory phenomena observed across the lifespan (e.g., infantile and childhood amnesia), the emergence of self-recognition (Howe & Courage, 1997), and the construction of a personal timeline (Buckner & Carroll, 2007). The goal of this dissertation was to investigate the development of subjective and objective recollection using a developmental cognitive neuroscience framework. Specifically, the aims were to a) examine developmental differences in subjective and objective recollection, b) explore the correspondence between subjective and objective measures of recollection, and c) evaluate neural responses (via event-related potentials) associated with subjective and objective recollection at encoding and retrieval.

Two relatively separate bodies of literature served as the foundation for this investigation. The first includes the methods used to assess subjective and objective recollection in adults as well as the neural correlates of these abilities. The second includes studies on the development of subjective and objective recollection at the behavioral and neural levels of analysis. This dissertation aims to bridge the gap between these literatures by providing critical information regarding the cognitive and neural development of subjective and objective recollection.

Assessment of Recollection in Adults

In order to study how people *"relive"* their experiences, Tulving (1985) developed the remember/know paradigm. During this procedure, participants encode a series of stimuli (e.g., pictures or words), and are asked at retrieval whether they "remember" the item or if they merely "know" they previously saw it. Participants are instructed to state that they "remember" an item when they can recollect contextual information associated with it (e.g., what they thought of or how they felt when they saw the item). For example, if a participant remembered that the picture of a dog was the first he saw or that the dog reminded him of the neighbor's dog, he should provide a "remember" response. In contrast, if he was certain he saw the dog but could not recollect any contextual information associated with it, he should provide a "know" response.

Verifying that participants understand the distinction between "remembering" and "knowing" is critical for using this methodology as an assessment of distinct mental states (Geraci, McCabe, & Guillory, 2009; Rajaram & Roediger, 1997). Researchers were initially concerned that participants may not be capable of introspecting about the contents of their memory or that they would interpret directions differently. However, these concerns have faded in studies of adults (Yonelinas, 2002), because of the consistency of results across studies and laboratories and convergence between the remember/know methodology and memory for specific contextual details (e.g., Dudukovic & Knowlton, 2006; Friedman & Trott, 2000). For example of the relation between remember/know performance and memory for specific contextual details, one study showed that the list a word was studied from was more likely to be recollected for words given a “remember” judgment rather than those given a “know” judgment (Friedman & Trott, 2000). Another concern about the remember/know paradigm was that performance would reflect response confidence rather than differentiable states of memory. However, research has shown that remember/know judgments and confidence ratings are distinct constructs (as discussed by Yonelinas, 2002). For example, although amnesic patients perform similarly to controls in their provision of confidence ratings, they differ in their attribution of remember/know judgments (Rajaram, Hamilton, & Bolton, 2002). This work has collectively shown that adults do have conscious access to their memories and do use objectively recalled details in order to make subjective judgments of “remembering.”

Others have built upon Tulving’s work by suggesting that performance on the remember/know paradigm reflects two independent memory states that underlie recognition memory, recollection and familiarity (Yonelinas & Jacoby, 1995).

Recollection refers to memory for specific contextual details whereas familiarity refers to overall memory strength. For example, while taking a road trip you may first notice that your surroundings are *familiar* but be unable to remember having ever been there before. When you suddenly remember that you drove on this road on your way to a friend's wedding on a hot day in July and that you were miserable because the air condition was broken, that is *recollection*.

The processes of recollection and familiarity can be assessed in multiple ways. One method is to utilize subjective assessments of recollection and familiarity such as the remember/know paradigm (Tulving, 1985). Recollection is indexed by the proportion of "remember" responses because participants are asked to respond that they "remember" the item when it is retrieved along with contextual information. Because items given a "remember" judgment may also be familiar, familiarity cannot be directly indexed by the proportion of "know" responses (Yonelinas & Jacoby, 1995). In the example above, I was first capable of identifying that the road was familiar and then subsequently recollected when I was last on it, where I was going, and my emotional state during that trip. For this reason, familiarity is indexed by the proportion of "known" items relative to the number of previously viewed items that were not recollected (i.e., K/(1-R); Yonelinas & Jacoby, 1995). In the subsequent text, "remember" responses are referred to a measure of *subjective recollection*. The benefit of using the remember/know paradigm to assess recollection is that any contextual detail participants are capable of recollecting would lead to a "remember" judgment.

Recollection can also be indexed by accuracy for specific contextual details. Participants study items associated with contextual details and at retrieval are asked whether they have viewed the individual items before and, if so, which contextual detail was associated with them. For example, participants could study words that appear either at the top or bottom of the screen. At retrieval they would be asked whether they had seen the word before and, if so, where on the screen it appeared. Examples of details that have been utilized include color (i.e., was the item red or green?; e.g., Dudukovic & Knowlton, 2006), the gender of the person who originally spoke the word (i.e., was the word spoken by a male or female voice?; e.g., Wilding & Rugg, 1996), the question previously answered about the item (i.e., did you make a judgment about the item's animacy or size?; e.g., Duarte, Ranganath, Winward, Hayward, & Knight, 2004), which list the word was a member of (i.e., was the word in List A or List B?; e.g., Friedman & Trott, 2000), and which word was paired with it (i.e., was the word "apple" paired with the word "table"?; e.g., Donaldson & Rugg, 1998). Accuracy for contextual details that can be objectively validated by the experimenters is subsequently referred to a measure of *objective recollection.*

Two primary concerns have been raised about objective recollection tasks. First, given the forced-choice nature of the memory prompt, participants may be accurately guessing the contextual detail correctly as opposed to accurately recollecting the experience. Second, participants may recollect information about the item that is not associated with the contextual detail of interest (i.e., noncriterial recollection; Yonelinas & Jacoby, 1996). For example, the participant may have remembered that the word "apple" came before the word "crayon" but not that the word “apple” was paired with the word “table.” Despite these limitations, the benefit of objective recollection paradigms is that performance is not dependent upon subjective memory judgments.

Neural Correlates of Recollection in Adults

The neural correlates of subjective and objective recollection have been examined in adults using several methodological approaches, including neuropsychological investigations of lesion patients, ERPs, and functional magnetic resonance imaging (fMRI). Studies of patients with brain lesions suggest that whereas hippocampal lesions influence performance on both subjective and objective recollection (for review see Yonelinas, 2002), lesions to the prefrontal cortex (PFC) are specifically detrimental to the recollection of objective details (Duarte, Ranganath, & Knight, 2005; Kopelman, Stanhope, & Kingsley, 1997; Swick, Senkfor, & Van Petten, 2006). Duarte and colleagues (2005) argued that the PFC may be specifically recruited during objective assessments of recollection due to the processing demands of those tasks. Although a subjective assessment of an item as “remembered” may arise when any contextual detail is retrieved, performance on the objective assessment requires the retrieval of a specific contextual detail. The ability to recollect specific contextual details requires strategic search, maintenance, and evaluation of information acquired from the medial temporal regions, functions hypothesized to be carried out by the PFC (Dobbins & Han, 2006; Fletcher & Henson, 2001; Simons & Spiers, 2003). ERP and fMRI studies have examined neural activity associated with recollection and familiarity at encoding, when information is learned, and retrieval, when information is being recovered. These studies show that subjective and objective recollection rely on partially overlapping yet dissociable neural networks, underscoring the importance of assessing both subjective and objective measures of recollection.

Encoding. ERP methodology has shown that, at encoding, components of the ERP waveform are sensitive to subjective but not objective recollection. Encoding studies have shown that neural activity differentiates performance on Tulving's (1985) remember/know paradigm. Items that are subsequently given a "remember" judgment elicit a more positive-going waveform in comparison to items given a "know" judgment during the 400-1000 ms epoch (Duarte et al., 2004; Friedman & Trott, 2000; Mangels, Picton, & Craik, 2001; Yovel & Paller, 2004; c.f. Smith, 1993). Further, amplitude elicited to "remembered" items differs from the amplitude elicited to "missed" items, whereas the amplitude to "known" items does not. In contrast, ERPs at encoding do not differentiate whether participants accurately identify objective contextual details associated with items or not (Duarte et al., 2004; Friedman & Trott, 2000; Guo, Duan, Li, & Paller, 2006; Rollins & Riggins, 2013). The best evidence for this dissociation comes from a study that used a within-subjects design (Friedman & Trott, 2000). Friedman and Trott (2000) reported differences in ERP amplitude between items subsequently given "remember" and "know" judgments but not between items for which the list membership was or was not recollected. These findings suggest that subjective and objective recollection may be neurally dissociable constructs at the encoding phase.

fMRI studies of encoding have shown that subsequently recollected items show enhanced activation of the medial temporal lobes, PFC, and parietal cortex compared to items that are given a "know" judgment or identified without objective contextual details (Achim & Lepage, 2005; Brewer, Zhao, Desmond, Glover, & Gabrieli, 1998; Cansino, Maquet, Dolan, & Rugg, 2002; Chua, Rand-Giovannetti, Schacter, Albert, & Sperling, 2004; Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Uncapher, Otten, & Rugg, 2006). Too few studies of memory encoding have been conducted to directly compare neural regions involved in subjective and objective recollection, and, to my knowledge, no investigations have included both measures of objective and subjective recollection in the same study.

Retrieval. Studies using ERPs to examine memory retrieval have demonstrated reliable recollection effects (i.e., neural activity that differentiates recollected from familiar items) for subjective and objective assessments (for reviews see Friedman & Johnson, 2000; Rugg & Curran, 2007). Consistent with dual process models of memory, which propose that familiarity and recollection are dissociable processes that rely on different brain networks (e.g., Yonelinas, 2002), the processes of recollection and familiarity have been related to distinct components of the ERP waveform at retrieval. Familiarity is associated with the mid-frontal old/new effect which occurs 300-500 ms poststimulus onset (Curran, 2000; Rugg et al., 1998; Trott, Friedman, Ritter, Fabiani, & Snodgrass, 1999; Woodruff, Hayama, & Rugg, 2006). This activity distinguishes "old" from "new" items but does not differentiate "remembered" and "known" items (Rugg et al., 1998; Trott et al., 1999). In contrast, recollection is associated with the left parietal old/new effect which occurs 400-800 ms poststimulus onset (for reviews see Friedman & Johnson, 2000; Rugg & Curran, 2007). The amplitude of the response elicited to items recollected is larger than the response to familiar items. This pattern of results has been shown using both subjective and objective paradigms. However, consistent with ERP studies of encoding, the magnitude of the parietal old/new effect at retrieval is larger using the subjective remember/know paradigm versus a measure of objective recollection (e.g., Trott et al., 1999). Differences in the magnitude of the effect may reflect differences in the degree to which neural regions or networks that underlie this response are involved in subjective and objective recollection.

fMRI methodology has confirmed evidence by ERP studies which suggested partially overlapping yet dissociable neural involvement in subjective and objective recollection at retrieval. A recent meta-analysis suggests that at retrieval the regions involved in subjective and objective recollection, although partially overlapping, are dissociable (Spaniol et al., 2009). Studies of objective recollection were more likely to recruit the ventrolateral PFC, dorsolateral PFC, anterior cingulate cortex, and intraparietal sulcus. In contrast, studies of subjective recollection were more likely to recruit the medial anterior PFC, inferior parietal cortex, parahippocampal gyrus, and hippocampus.

Conclusions. Collectively, studies in lesion patients and investigations using ERP and fMRI methodologies suggest that although objective and subjective recollection are related constructs, they recruit partially dissociable neural networks. It is currently unclear whether this difference is primarily due to methodological differences across paradigms, differences in the neural substrates that underlie subjective and objective recollection, differences in other cognitive processes that accompany these forms of memory (i.e., controlled search operations carried out by the PFC), or a combination of these factors. These findings highlight the importance of examining both objective and subjective recollection. Developmental research may be able to shed light on the relations between subjective and objective recollection and their neural correlates.

Assessment of Recollection in Developmental Populations

Developmental studies of memory are important because they can inform knowledge about the constructs of recollection and familiarity, including the neural mechanisms that underlie these abilities and the cognitive operations that support them. For example, whether the PFC is differentially involved in subjective and objective recollection may be a question with particular utility for a developmental approach given the prolonged developmental trajectory of this neural region (Gogtay et al., 2004). Relative to the body of literature in adults on recollection and familiarity, substantially fewer studies have been conducted in developmental populations. Of the research that does exist, most developmental studies have examined objective recollection due to concerns about children's ability to perform introspective tasks (see Appendix A for a review of the development of metacognition with a focus on metamemory; Cycowicz, 2000; Cycowicz, Friedman, & Duff, 2003; Cycowicz, Friedman, & Snodgrass, 2001; Czernochowski, Mecklinger, Johansson, & Brinkmann, 2005; Drummey & Newcombe, 2002; Lloyd, Doydum, & Newcombe, 2009; Riggins, Rollins, & Graham, 2013; Rollins & Riggins, 2013; Sluzenski, Newcombe, & Kovacs, 2006). Only a few developmental studies have been conducted using subjective methods similar to those in adults, such as the remember/know paradigm (Billingsley, Smith, & McAndrews, 2002; Friedman, de

Chastelaine, Nessler, & Malcolm, 2010; Ghetti, Mirandola, Angelini, Cornoldi, & Ciaramelli, 2011; Hembacher & Ghetti, 2013; Ofen et al., 2007; Piolino et al., 2007) and the receiver operating characteristic (ROC) procedure (Ghetti & Angelini, 2008). Collectively, developmental studies of subjective and objective recollection suggest that recollection follows a prolonged developmental trajectory into adolescence, whereas familiarity develops by middle childhood and remains relatively stable.

An intensive behavioral investigation of subjective and objective recollection was recently conducted by Ghetti and colleagues (2011) with the following age groups: 6-7-year-olds, 9-10-year-olds, 12-13-year-olds, and 17-18-year-olds. This study will be described in detail because the design is similar to that of the current studies. Participant understanding of subjective memory states was assessed by the ability to classify statements as meeting the criteria for a “remember” or “familiar” judgment (i.e., the term “know” was changed to “familiar” to improve the youngest participants’ understanding of the distinction). For example, the statement “I know I saw a giraffe because it was red” should be given a “remember” judgment whereas “I know I saw a stapler but I can’t remember what question I answered about it” should be given a “familiar” judgment. Age-related improvements were present in the ability to classify statements; however, even 6- to 7-year-old participants were able to reliably classify statements.

Participants also performed a memory task that allowed for the examination of relations among old/new confidence ratings, subjective recollection, and objective recollection (Ghetti et al., 2011). Subjective recollection was indexed by remember/familiar judgments and objective recollection was indexed by memory for the item's original color and the semantic judgment made at encoding. Data on the memory task further supported that even young children understand subjective memory states. Across age groups, items that were given a "remember" judgment were judged as more confidently recognized and were more likely to be associated with accurate objective details (i.e., color and semantic judgment) than items given a "familiar" judgment. However, with age the difference in confidence ratings and objective accuracy between items given "remember" and "familiar" judgments increased. Findings from both the classification and memory tasks suggest that children as young as 6 years of age can reliably perform subjective recollection tasks, although age-related improvements are present. This was an important finding because of previous concerns about children's ability to perform subjective recollection tasks (e.g., Brainerd, Holliday, & Reyna, 2004; Brainerd, Payne, Wright, & Reyna, 2003; Ghetti, Qin, & Goodman, 2002).

Neural Correlates of Recollection in Developmental Populations

Developmental studies have contributed substantially to our knowledge about the neural mechanisms that underlie recollection. Studies of both encoding and retrieval are reviewed because improvements in memory performance may be due to the development of encoding processes, retrieval processes, or both. ERP methodology has demonstrated developmental differences in the timing, direction, and topography of memory effects at encoding and retrieval and that age-related differences may be present in the recruitment of familiarity and recollection. All developmental ERP studies have either used recognition or objective recollection memory paradigms; none have assessed ERP correlates of subjective recollection.

fMRI studies using subjective and objective recollection paradigms have shown age-related differences in the recruitment and specificity of neural regions involved in recollection.

Encoding. One developmental study has used the ERP methodology to examine encoding processes (Rollins & Riggins, 2013). This study found that the timing, direction, and topography of subsequent recognition effects differed between 6-year-old children and adults. However, consistent with adult studies reviewed above (Duarte et al., 2004; Friedman & Trott, 2000; Guo et al., 2006), ERP effects did not differentiate items subsequently recollected along with an objective detail in either children or adults.

Developmental fMRI studies suggest that neural regions supporting recollection undergo substantial age-related differences by becoming more specific for recollection-based processing. To date, two developmental fMRI studies of memory encoding have utilized objective recollection paradigms (Ghetti, DeMaster, Yonelinas, & Bunge, 2010; Güler & Thomas, 2013), and one has employed a subjective recollection paradigm (i.e., the remember/know paradigm, Ofen et al., 2007). Studies using objective paradigms have suggested age-related differences in the activation of medial temporal and prefrontal cortices. The activation of the hippocampus during encoding becomes increasingly specialized for recollection with age (Ghetti et al., 2010). The hippocampal activation of 8-year-olds did not differentiate items later recalled with and without contextual details; in contrast, hippocampal activation of 14-year-olds and adults was larger for items subsequently recollected along with the contextual detail of color than items recognized without the contextual detail of color and subsequently forgotten items (Ghetti et al., 2010). Another study using an objective recollection paradigm revealed increased encoding efficiency with age in PFC regions (Güler & Thomas, 2013). Güler & Thomas (2013) reported that 8-year-old children recruited regions of the DLPFC and temporal cortex in order to remember word pairs that 12-13-year-olds did not. This finding is interesting because Ofen and colleagues (2007), who used a subjective recollection paradigm, reported that the recruitment of the DLPFC for “remembered,” in comparison to “familiar” items, increased with age. Taken together, these findings suggest development of the neural regions that support encoding processes during middle to late childhood.

Retrieval. Multiple ERP studies of memory retrieval have examined the development of objective recollection during middle childhood (Cycowicz et al., 2003; Czernochowski, Mecklinger, & Johansson, 2009; Czernochowski et al., 2005; Mecklinger, Brunnemann, & Kipp, 2011; Sprondel, Kipp, & Mecklinger, 2011, 2012). All studies reveal that the processes that support memory performance change with age. However, research findings on the developmental progression of recollection and the relative contributions of recollection and familiarity to memory performance differ. One study suggested that ERP effects associated with recollection demonstrate a prolonged developmental trajectory (Cycowicz et al., 2003). Using an objective recollection task, this study found that adults, but not children or adolescents, demonstrated a reliable parietal old/new effect (i.e., the putative ERP correlate of recollection). In contrast, other studies have found that children, like adults, show the parietal old/new effect but not the earlier occurring frontal effect that has been associated with familiarity (Czernochowski et al., 2005; Friedman et al., 2010; Sprondel et al., 2011). Because of this pattern of findings, some researchers have suggested that children predominantly rely on recollection rather than familiarity (Czernochowski et al., 2005; Friedman et al., 2010). This is puzzling because it stands in opposition to behavioral data suggesting a smaller age-related change in familiarity than recollection (Ghetti & Angelini, 2008). This discrepancy across studies may be due to multiple factors, including methodological differences. Lastly, one study showed that children and adults both utilize the processes of familiarity and recollection, however, do so differentially based on task demands (Mecklinger et al., 2011). When timing demands were imposed during a recollection task, both children and adults demonstrated the frontal old/new effect (i.e., the ERP correlate of familiarity) whereas neither group demonstrated the parietal old/new effect associated with recollection. When timing demands were not present, only adults showed the frontal old/new effect and both children and adults showed the parietal old/new effect. Taken together, these studies raise more questions than they answer. Full understanding of the development of recollection will require studies, such as the present dissertation, that utilize methodologies more widely employed in the adult literature on recollection.

Two developmental fMRI studies have examined retrieval processes associated with objective recollection (DeMaster & Ghetti, 2013; Güler & Thomas, 2013). One study revealed age-related differences in the recruitment of the hippocampus, parietal cortex, and prefrontal cortex (DeMaster & Ghetti, 2013). Whereas children (i.e., 8- to 11-years-old) recruited the posterior region of the hippocampus to successfully recollect item color, adults recruited the anterior regions. In adults, the posterior parietal cortex was sensitive to item recognition (i.e., the activation was larger for items recognized either with or without the border color correct compared to novel items). Activation in children was larger for items recollected with the color correct than the color incorrect and novel items. Lastly, left anterior PFC in adults, but not children, was sensitive to memory. Similarly, Güler and Thomas (2013) found that neural activity was greater for recalled than forgotten information in medial temporal, parietal, and frontal cortices in 12- and 13-year-old but not 8- to 9-year-old children. Because prefrontal and parietal cortices are commonly recruited during successful objective recollection tasks in adults (Spaniol et al., 2009), this age-related difference may underlie children's poorer performance on objective recollection tasks.

Conclusions. In summary, ERP and fMRI studies have demonstrated that the timing of recollective processes and the neural regions that support them demonstrate substantial change from middle childhood through adolescence. However, a number of gaps are present in the current literature. No developmental study has examined the development of subjective recollection at either encoding or retrieval using ERPs, and no fMRI study has examined the development of subjective recollection at retrieval. Furthermore, no studies have assessed the development of objective and subjective recollection using a within-subject design at encoding or retrieval using either ERP or fMRI methodologies. These gaps are problematic because of the importance of memory capacities and evidence suggesting that objective and subjective recollection rely on partially overlapping yet dissociable neural regions. Thus, the current studies fill a substantial gap in the current literature by investigating ERP responses associated with subjective and objective recollection at encoding and retrieval in children, adolescents, and adults.

The Present Study

The aims of the present studies were to 1) examine the behavioral development of subjective and objective recollection, 2) explore age-related differences in the correspondence between subjective and objective recollection, and 3) evaluate neural responses associated with subjective and objective recollection at encoding and retrieval (see Table 1 for a summary of the aims, hypotheses, and research questions). To achieve this goal, ERPs were recorded as children, adolescents, and adults performed encoding (Study 1) and retrieval (Study 2) phases of a memory paradigm. Participants made color and semantic judgments about each item at encoding. At retrieval participants made recognition (i.e., old/new), subjective recollection (i.e., remember/familiar), and objective recollection judgments for each item (i.e., color and semantic judgments; for a similar design see Ghetti et al., 2011). Understanding of the subjective recollection judgments was examined using a classification task (Ghetti et al., 2011).

Table 1

Aims, Hypotheses, and Research Questions

Hypotheses/Research Questions	Supported/ Not Supported
Aim 1: Examine developmental differences in subjective and objective recollection	
Study 1: Encoding	
H1a: Reports of subjective remembering associated with accurately recognized items will decrease with age (i.e., because adults will use the “remember” judgment more selectively).	Not Supported
H1b: Reports of subjective remembering associated with falsely recognized items will decrease with age.	Supported
H1c: All age groups will be able to classify statements as meeting the criteria for a “remember” or “familiar” judgment above chance levels.	Supported
H1d: Participants will more accurately classify statements as meeting the criteria for a “remember” or “familiar” judgment with age.	Supported
H1e: Memory for the original color of the item will improve with age.	Supported
H1f: Memory for the semantic judgment made at encoding will improve with age.	Supported
Study 2: Retrieval	
H1g: Reports of subjective remembering associated with accurately recognized items will decrease with age.	Not Supported
H1h: Reports of subjective remembering associated with falsely recognized items will decrease with age.	Not Supported
H1i: All age groups will be able to classify statements as meeting the criteria for a “remember” or “familiar” judgment above chance levels.	Supported
H1j: Participants will more accurately classify statements as meeting the criteria for a “remember” or “familiar” judgment with age.	Supported
H1k: Memory for the original color of the item will improve with age.	Not Supported
H1l: Memory for the semantic judgment made at encoding will improve with age.	Supported

(continued)

Table 1 Continued

Hypotheses/Research Questions	Supported/ Not Supported
Aim 2: Explore the correspondence between subjective and objective measures of recollection	
Study 1: Encoding	
H2a: With age, accurate memory for objective details will increasingly be associated with “remember” rather than “familiar” judgments.	Not Supported
Study 2: Retrieval	
H2b: With age, accurate memory for objective details will increasingly be associated with “remember” rather than “familiar” judgments.	Supported
Aim 3: Evaluate ERP responses of subjective and objective recollection during memory encoding and retrieval.	
Study 1: Encoding	
H3a: ERP amplitude elicited to items subsequently given a “remember” judgment will be more positive than the amplitude to “familiar” and missed items (i.e., Remembered > Familiar = Missed).	Supported 700-900 ms
RQ1: Will age-related differences be present in the timing, topography, and/or direction of this effect?	No
H3b: ERP amplitude elicited to subsequently recognized items will be greater than missed items but similar regardless of whether the original item color is recollected or not (i.e., Color-correct = Color-incorrect > Missed).	Not Supported 700-900 ms C-C > M
H3c: ERP amplitude elicited to subsequently recognized items will be greater than missed items but similar regardless of whether the semantic judgment made at encoding is recollected or not (i.e., Task-correct = Task-incorrect > Missed).	Not Supported 700-900 ms T-C > T-I = M

(continued)

Table 1 Continued

Hypotheses/Research Questions	Supported/ Not Supported
Study 2: Retrieval	
H3d: ERP amplitude will be more positive for items given a “remember” judgment than items given a “familiar” judgment and correctly rejected novel items (i.e., Remembered > Familiar = Correct rejections).	Supported 500-700 ms
RQ2: Will age-related differences be present in the timing, topography, and/or direction of this effect?	Yes, presence and topography
H3e: ERP amplitude will be more positive to items recollected along with the contextual detail of color relative to recognized items for which that details is forgotten and correctly rejected novel items (i.e., Color-correct > Color-incorrect = Correct rejections).	Not Supported
RQ3: Will age-related differences be present in the timing, topography, and/or direction of this effect?	N/A
H3f: ERP amplitude will be more positive to items recollected along with the semantic judgment made at encoding relative to recognized items for which that detail is forgotten and correctly rejected novel items (i.e., Task-correct > Task-incorrect = Correct rejections).	Not Supported
RQ4: Will age-related differences be present in the timing, topography, and/or direction of this effect?	N/A

Note. H = Hypothesis, RQ = Research Question

Chapter 2: Study 1

Method

Participants. A total of 124 participants provided complete behavioral data for this study, 55 children (mean age = 7.63 years, *SD* = .75, 32 females, 23 males), 32 adolescents (mean age = 12.79 years, *SD* = .61, 18 females, 14 males), and 37 adults (mean age = 20.22[1] years, *SD* = 2.26, 20 females, 17 males). An additional 9 participants came in for the study but were excluded due to noncompliance (1 child) or equipment failure (2 children, 6 adults). Two participants (1 child, 1 adolescent) were excluded from subjective recollection analyses because they verbally indicated using the judgments incorrectly (i.e., both believed they should only use the "remember" judgment when both contextual details were recalled). Three participants (1 child, 1 adolescent, 1 adult) were excluded from the analysis examining the correspondence between objective and subjective recollection because they provided exclusively "remember" or "familiar" judgments for all recognized stimuli.

Materials.

Pictorial stimuli. Stimuli included 194 images of items that could be classified as living/non-living and big/small (i.e., of animals, plants, and common objects). The images came from a colored version of the Snodgrass and Vanderwart line drawings (Rossion & Pourtois, 2004) and external sources. Images obtained from external sources were matched for object complexity with the Rossion and Pourtois (2004) images. Fourteen images were used as practice stimuli to ensure participants understood the task. The remaining 180 images were used as test stimuli. Participants

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[1] Two adult participants did not provide their exact birthdate. However, they fell within the range of tested participants.

saw 120 of the test stimuli at encoding and all 180 stimuli at retrieval. To ensure that stimulus characteristics did not influence memory performance, the stimuli were sorted into three sets of 60 pictures. Each set included 15 stimuli in each of the following categories which were relevant for the task (see memory paradigm procedure below): large/living, large/non-living, small/living, and small/non-living. Once sorted into sets, the images were altered to be shades of red or green for the encoding phase and gray for the retrieval phase using Microsoft Powerpoint software. Coloration was approximately distributed across the four categories. For the stimuli that are typically red (e.g., lobster) or green (e.g., alligator), half of them remained their typical color and the other half were changed to the atypical color. For each set of pictures, 30 were red and 30 were green. See Appendix B for examples of four stimuli.

Classification task. The classification task examined participant understanding of the distinction between the subjective memory terms “remember” and “familiar” (Tulving, 1985). This task was modeled after the assessment used by Ghetti and colleagues (2011; see Appendix C for the script and body of the classification task). Participants classified 36 subjective memory statements (18 remember, 18 familiar). Six “remember” statements were associated with memory for each of the following: color, the semantic judgment made, and memory for both the color and semantic judgment (e.g., “I saw sunglasses, I can picture them in red and I said they were not living”). Six “familiar” statements were associated with the absence of memory for color, the semantic judgment, and memory for both the color and the semantic judgment (e.g., “I saw a pelican, but I can’t tell if it was red or green"). To ensure participants were not relying on confidence to distinguish subjective recollection states, 12 of the statements were high in confidence (6 remember, 6 familiar; e.g., "I definitely saw a panther but I can't tell you what question you asked me."). Each of the stimulus categories described above (e.g., living/big) were represented in 9 statements. To decrease the likelihood that participants could confuse the statements from the classification task with the memory task, the stimuli used in the memory and classifications task did not overlap.

Procedures. The University of Maryland Institutional Review Board approved all procedures prior to the beginning of the study (see Appendix D for the approval letters). Child and adolescent participants were recruited from a database maintained by the Infant and Child Studies Consortium at the University of Maryland, College Park or by announcements sent to local parent groups. Child participants received a small gift for participating and adolescents received either a small gift or $10. Adult participants were recruited from the Psychology Department's electronic database used to provide students with course credit for participation. Informed assent/consent and parental consent, when applicable, was obtained at the beginning of each session.

Memory paradigm. The present study was modeled after previous ERP studies of encoding processes in children (Rollins & Riggins, 2013) and adults (e.g., Duarte et al., 2004) as well as Ghetti and colleagues' (2011) behavioral study on the development of subjective and objective recollection.

First, participants were fitted with a stretchy Lycra cap appropriate for their head size for EEG collection. Participants were seated approximately 90 cm in front of a computer screen in a dimly lit room. During encoding, participants made judgments about the color and a semantic feature (i.e., animacy or size) of each stimulus. Participants performed a practice phase to ensure they were able to distinguish the color of the object and accurately make the semantic judgments. All participants were asked to first report the stimulus color followed by the semantic judgment. During practice, the experimenter gave feedback if these judgments were made inaccurately. Participants were instructed to only provide their verbal responses after the stimulus went off of the screen to avoid the inclusion of movement artifact during the recording epoch. The experimenter recorded all participants' verbal responses via a button press. This procedure was used to decrease movement artifact typically associated with a button press, particularly for the youngest age group (DeBoer, Scott, & Nelson, 2007).

During encoding, participants were aware their memory would be subsequently examined. However, they did not know they would be subsequently asked to make subjective or objective recollection judgments. ERPs and behavioral responses were collected during the encoding portion of the study, and behavioral responses were recorded during the retrieval portion. Participants' semantic judgments about animacy and size were alternated in blocks of 30 stimuli (i.e., ABAB) to decrease executive function demands associated with switching (see Rollins & Riggins, 2013, and Ghetti et al., 2011, for similar arguments). Four, rather than two, encoding blocks were selected to decrease the chance that participants could rely on familiarity when making subsequent recollective judgments about the task performed at encoding (see Rollins & Riggins, 2013, for additional information).

The semantic judgment made first and the stimulus sets that were associated with each encoding block were counterbalanced across participants. The presentation of individual stimuli within sets was randomly selected by E-Prime presentation software. A fixation cross was displayed on a white background for an inter-trial interval of 500 ms. Stimuli were presented for 1500 ms on a white background. Then, questions were presented on the screen and remained until the participants made a response (e.g., Red/Green?). If participants were unable to answer these questions because they failed to see a stimulus (i.e., they closed their eyes or looked away from the screen during stimulus presentation), that stimulus was excluded from behavioral and electrophysiological analysis. Between blocks the experimenter reminded participants about the judgments they would be making and that they would subsequently complete a memory task.

After encoding, participants were given a break of approximately 10 minutes during which time the Lycra cap was removed. Following the break, participants began the practice of the retrieval phase. The experimenter told participants they would see the same stimuli as before as well as new stimuli and that all of the images would be in grayscale. For each stimulus, participants made a recognition judgment (i.e., old/new), and, if they said the stimulus was "old," they were asked questions to assess recollection. First, they were asked to subjectively determine if they "remembered" the stimulus or whether it was "familiar." The experimenter explained the remember/familiar distinction to the participants. The instructions were similar to those used by Ghetti and colleagues (2011). Participants were told

> *"You should say you remember the drawing if you can think of when you first saw it. If you can think of specific details about when you saw the drawing before, then you remember it. For example, you should say remember it if you can clearly picture the color the picture was, the question you answered about it, or something else that you thought of when I showed it to you. However, sometimes you will feel like you have seen the drawing before, but you won't be able to think of the first time you saw it. You can't come up with details, but you know you've seen it. If you know you've seen the drawing before but you can't come up with any details, you should say the drawing is familiar. You can be very sure you saw the drawing, but, if you can't come up with any details, it's still familiar."*

To verify understanding, the researcher asked participants to define the terms "remember" and "familiar." Additional instruction and feedback were provided if participants showed a lack of understanding. Last, participants were told that they would be asked the original color of the stimulus and to state which semantic judgment (i.e., animacy or size) was made for that stimulus at encoding. Participants were shown nine practice stimuli (six were seen during encoding practice and three were novel). During the practice, participants were provided feedback about the accuracy of their responses.

During the test phase, participants viewed the grayscale version of the 120 stimuli previously viewed at encoding and 60 novel stimuli. Stimuli were presented in a random order. A 500 ms fixation cross was presented between each stimulus. Each stimulus remained on the screen until the participant verbally made the recognition judgment. If the participant responded that the item was “old,” a subjective recollection judgment and the two objective recollection judgments were made for that item. For each of these judgments, a written prompt was provided to remind the participants which question they were to answer (e.g., Remember/Familiar?). If the participant responded that the item was “new,” the next stimulus was immediately presented. The experimenter sitting beside the participant recorded responses via a button press. Participants did not receive feedback during the test phase. See Table 2 for a list and description of dependent variables used for behavioral analysis and Table 3 for a list and description of conditions used for ERP analysis.

Table 2

Memory Paradigm Dependent Variables

Dependent Variable	Description
Remembered	Recognized items classified as remembered
Familiar	Recognized items classified as familiar
Color-correct	Recognized items with original color accurately identified
Remembered color-correct	Remembered items with original color accurately identified
Familiar color-correct	Familiar items with original color accurately identified
Task-correct	Recognized items with semantic judgment accurately identified
Remembered task-correct	Remembered items with semantic judgment accurately identified
Familiar task-correct	Familiar items with original task accurately identified
Falsely familiar	Novel items incorrectly classified as familiar
Falsely remembered	Novel items incorrectly classified as remembered

Note. All dependent variables will be assessed as percentages.

Table 3

ERP Conditions

Condition	Description
Remembered[1,2]	Recognized items classified as remembered
Familiar[1,2]	Recognized items classified as familiar
Color-correct[1,2]	Recognized items with original color accurately identified
Color-incorrect[1,2]	Recognized items with original color inaccurately identified
Task-correct[1,2]	Recognized items with semantic judgment accurately identified
Task-incorrect[1,2]	Recognized items with semantic judgment inaccurately identified
Missed[1]	Items viewed at encoding incorrectly classified as “new”
Correct Rejections[2]	Novel items correctly classified as “new”

Note. 1 = Analyzed for Study 1, 2 = Analyzed for Study 2

Classification task. After the memory task, participants performed the classification task. The experimenter explained that other participants had previously completed a memory study. They performed the same encoding task (i.e., identified item color and made a semantic judgment regarding animacy or size), but at retrieval they had to tell the experimenter what they remembered about the picture. An abridged description of the distinction between subjective judgments was provided (see Appendix C for the script associated with the classification task). During the task, the experimenter read one practice statement and 36 test statements to the participants and recorded whether the participants thought each statement met the criteria for a "remember" or "familiar" judgment. If necessary, the experimenter repeated the statement. The dependent variables from this task include the percentage of accurately classified remember and familiar statements.

ERP recording and analysis. EEG was continuously recorded during the encoding phase of the study with a sampling rate of 512 Hz (BioSemi Active 2) from 64 active Ag-AgCl scalp electrodes and two vertical and two horizontal electrooculogram (EOG) channels. Data were re-referenced offline using Brain Electrical Source Analysis (BESA) software (MEGIS Software GmbH, Gräfelfing, Germany) to an average mastoid configuration. Missing data from a maximum of 8 bad channels per participant was interpolated in accordance with recommendations provided by researchers using the ERP methodology in developmental populations (DeBoer, Scott, & Nelson, 2005). Consistent with prior ERP studies of memory development (e.g., Cycowicz et al., 2001; Marshall, Drummey, Fox, & Newcombe, 2002; Rollins & Riggins, 2013), trials containing ocular artifacts were corrected using the Ille, Berg, and Scherg (2002) algorithm. Data were high and low pass filtered at .1 and 80 Hz, respectively. Data were hand-edited to remove ocular artifacts that occurred at stimulus onset, movement-related artifact, and system-related artifact. ERPs were epoched with a 100 ms prestimulus baseline and extended to 1500 ms poststimulus onset. An automatic artifact rejection procedure was performed to remove trials that exceeded specified amplitude (250 μV), gradient (75 μV), and low-signal (.01 μV) criteria. ERPs for seven conditions (see Table 3) were averaged based on behavioral performance as described above (i.e., correct rejections were not applicable since EEG data was only collected during the encoding phase). Stimuli were included in multiple conditions (e.g., a recognized stimulus could be in the remembered, color-correct, and task-correct conditions).

A total of 90 participants provided ERP data for at least one analysis of interest. Participants were excluded from all analyses due to problems with the reference electrode(s) (15 children, 2 adolescents, 2 adults) or if they contributed fewer than 10 trials per condition due to movement-related artifact or behavioral performance (9 children, 2 adolescents, 4 adults; DeBoer et al., 2005; 2007).

For subjective recollection, participants were only included if they performed statistically above chance on the classification task (i.e., correctly classified 24 or more items correct out of 36). These criteria led to the inclusion of 17 children, 24 adolescents, and 26 adults. For children, the mean trial numbers (standard deviation and range) were 32 missed (11, 10-38), 33 remember (15, 10-62), and 23 familiar (8, 11-34). For adolescents, the mean trial numbers were 33 missed (11, 13-71), 33 remember (14, 12-58), and 31 familiar (15, 13-62). For adults, the mean trial numbers were 26 missed (11, 10-48), 31 remember (13, 14-59), and 34 familiar (14, 14-70). There were no age-related differences in trial numbers for missed, $F(2, 64) = 2.03$, $p = .14$, or remember conditions, $F(2, 64) = .24$, $p = .784$. However, adults had significantly more familiar trials than children, $F(2, 64) = .3.74$, $p = .029$.

For the objective recollection analyses, participants were included only if their accuracy for the contextual detail of interest (i.e., color or semantic judgment) was greater than 55%. Participants were omitted on the basis of behavioral performance because recollection effects may not emerge when participants are performing at chance. For example, one study of adults showed that high performing but not low performing participants demonstrated recollection effects (e.g., Curran & Cleary, 2003). The analysis of color recollection included 22 children, 18 adolescents, and 23 adults. For children, the mean trial numbers were 33 missed (14, 10-71), 35 color-correct (11, 15-55), and 21 color-incorrect (5, 12-30). For adolescents, the mean trial numbers were 36 missed (19, 13-71), 39 color-correct (13, 22-61), and 22 color-incorrect (9, 10-38). For adults, the mean trial numbers were 24 missed (11, 10-56), 43 color-correct (14, 21-71), and 25 color-incorrect (13, 10-70). Adults had significantly fewer missed trials than adolescents, $F(2, 60) = 3.8$, $p = .028$. The number of color-correct, $F(2, 60) = 2.15$, $p = .125$, and color-incorrect, $F(2, 60) = 1.23$, $p = .3$, trials did not differ between age groups.

The analysis of task recollection included 24 children, 25 adolescents, and 28 adults. For children, the mean trial numbers were 34 missed (14, 10-71), 39 task-correct (13, 14-63), and 17 task-incorrect (5, 10-26). For adolescents, the mean trial numbers were 34 missed (18, 13-71), 46 task-correct (12, 20-68), and 20 task-incorrect (8, 10-39). For adults, the mean trial numbers were 26 missed (12, 10-56), 49 task-correct (13, 21-73), and 19 task-incorrect (7, 10-42). There were no differences in the number of missed, $F(2, 74) = 1.95$, $p = .15$, or task-incorrect trials, $F(2, 74) = 1.52$, $p = .225$. However, adults had significantly more task-correct trials than children $F(2, 74) = 3.4$, $p = .039$.

Mean amplitudes, which are relatively unaffected by differences in trial numbers across conditions (Luck, 2005), were exported for analysis from 4 time windows that were selected based on previous literature (Duarte et al., 2004; Rollins & Riggins, 2013) and visual inspection. Mean amplitudes were exported for 150-300 ms, 300-450 ms, 500-700 ms, 700-900 ms time windows for children and adolescents and 125-250 ms, 250-350 ms, 500-700 ms, and 700-900 ms time windows for adults. Consistent with previous developmental ERP studies of memory, it is common for the timing and width of analysis windows to differ across age groups in order to capture the components of interest (Cycowicz et al., 2003; Czernochowski et al., 2005; Marshall et al., 2002; Mecklinger et al., 2011; Rollins & Riggins, 2013; Sprondel et al., 2011). All analyses were performed using IBM SPSS Statistics 20. ERP data was analyzed using an omnibus ANOVA with Age Group (Children, Adolescents, Adults) as the between-subjects factor and the following within-subjects factors: 4 Time Window x 3 Condition x 3 Coronal Plane (frontal, central, parietal) x 3 Sagittal Plane (left, midline, right) at the following leads, F3, Fz, F4, C3, Cz, C4, P3, Pz, P4. Analyses are identical in structure for subjective recollection (remember, familiar, missed) and objective recollection of color (color-correct, color-incorrect, missed) and task (task-correct, task-incorrect, missed). For all ERP analyses, only a main effect of or interaction with condition was reported. The Bonferroni correction was applied to correct for multiple comparisons within analyses, and the Greenhouse Geisser correction was applied to correct for violations in sphericity (i.e., sphericity violations are common with ERP data). An alpha level of .05 was used for all statistical analyses and, when necessary, follow-up analyses were conducted. Differences between conditions were assessed with Bonferroni-corrected pairwise comparisons and Bayes factors (BF). BFs provide the odds in support of the null hypothesis. BFs > 1.0 suggest evidence in favor of the null hypothesis with BF > 3 providing substantial support (Jeffreys, 1961). BFs < 1.0 suggest evidence in favor of the alternative hypothesis with BF < .33 indicating substantial support (Jeffreys, 1961). BFs were based on the *t*-statistic and obtained from the Bayes factor calculators provided on Dr. Jeffrey Rouder's website (http://pcl.missouri.edu/bayesfactor) using the Jeffrey-Zellner-Siow prior (Rouder, Speckman, Sun, Morey, & Iverson, 2009).

Results

Behavioral results.

Subjective recollection: Memory paradigm. A 3 Age Group (children, adolescents, adults) x 2 Subjective Judgment (remember, familiar) mixed-model ANOVA was conducted with the percentage of previously viewed items given each subjective judgment serving as the dependent variable. There was a significant age-related improvement in the ability to accurately recognize previously viewed items, $F(2, 119) = 9.74$, $p < .001$. For accurately recognized items, all age groups provided more “remember” than “familiar” judgments, $F(1, 119) = 11.34$, $p = .001$. Contrary to H1a, this effect did not interact with age $F(2, 119) = 1.73$, $p = .182$.

The same analysis was conducted using the percentage of falsely identified novel items as the dependent variable. There was a main effect of Subjective Judgment, $F(1, 119) = 22.96$, $p < .001$, that was qualified by an interaction between Age Group and Subjective Judgment, $F(2, 119) = 3.7$, $p = .028$. No age-related differences were present in false recognition rates associated with “remember” judgments, $F(2, 119) = .75$, $p = .476$. However, consistent with H1b, participants were more likely to provide “familiar” judgments to falsely recognized novel items with age, $F(2, 119) = 3.22$, $p = .043$ (see Figure 1).

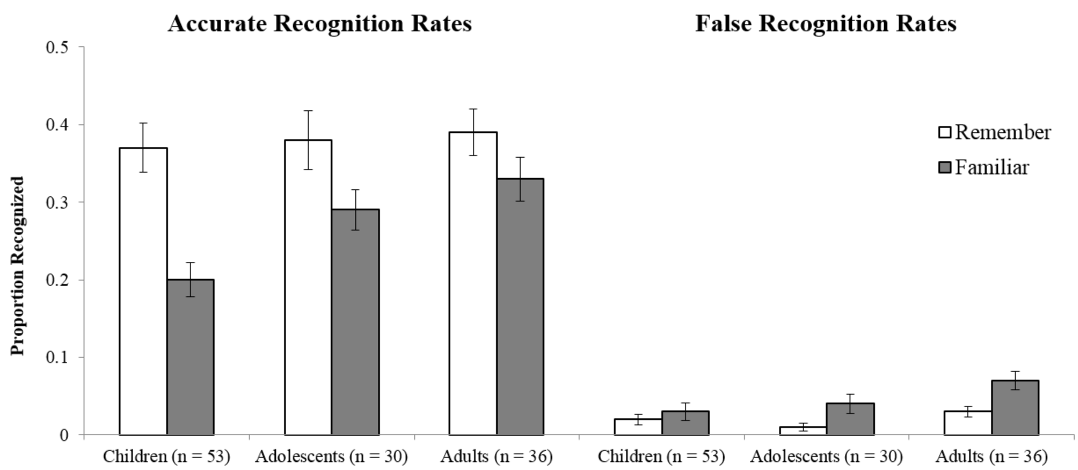

Figure 1. Mean accurate and false recognition rates for children, adolescents, and adults. Accurate recognition rates were higher in children than adolescents and adults, and more accurately recognized items were provided with “remember” than familiar judgments. Older participants were more likely to provide novel items falsely recognized with a “familiar” judgment. Error bars represent standard errors.

Subjective recollection: Classification task. To assess whether all age groups reliably classified subjective judgments, a one sample t-test was conducted on the proportion of correctly classified statements for each age group (i.e., the null hypothesis was set at .5). Consistent with H1c, children, $t(53) = 14.31$, $p < .001$; adolescents, $t(30) = 73.26$, $p < .001$; adults, $t(36) = 85.29$, $p < .001$, all reliably classified statements. Age-related differences in this task were assessed using a 3 Age Group x 2 Subjective Judgment mixed-model ANOVA where percent accuracy from the classification task was included as the dependent variable. Results revealed main effects of age group, $F(2, 119) = 7.19$, $p = .001$, and subjective judgment, $F(1, 119) = 14.05$, $p < .001$, as well as an interaction between age group and subjective judgment, $F(2, 119) = 7.75$, $p = .001$. Age-related improvements were larger in the classification of statements that should have received "remember", $F(2, 119) = 9.33$, $p < .001$, versus "familiar" judgments, $F(2, 119) = 2.51$, $p = .085$ (see Figure 2). These findings support H1d; there were age-related improvements in children's ability to classify subjective statements.

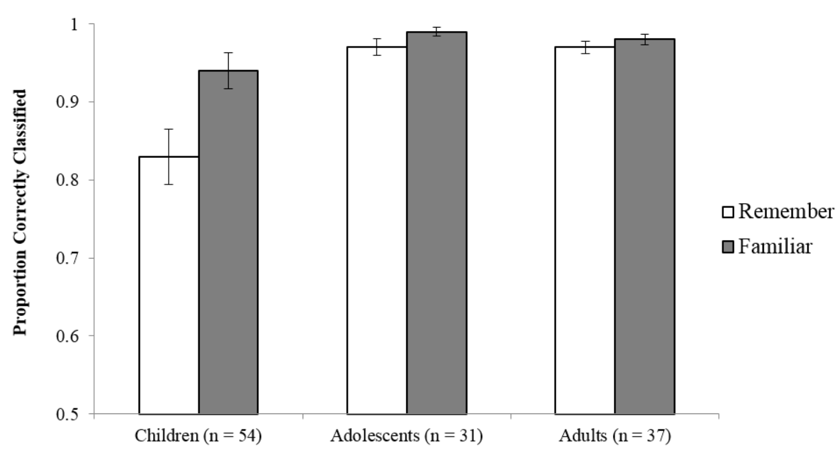

Figure 2. Accuracy rates for "remember" and "familiar" statements on the classification task. All age groups performed above chance. Children were less accurate at classifying "remember" statements than adolescents and adults. Error bars represent standard errors.

Objective recollection. Measures of objective recollection were analyzed separately because of differences in depth of processing (i.e., memory for the semantic judgment is expected to be higher than memory for the color of an item because semantic information is more deeply encoded; e.g., Ghetti et al., 2011). To assess hypotheses regarding age-related differences in objective recollection, a 3 Age Group x 2 Objective Judgment (color, semantic judgment) mixed-mixed model ANOVA was conducted. The percentage of items for which the contextual detail was accurately recollected relative to correctly recognized items served as the dependent variable. Participants more accurately remembered the semantic judgment made at encoding than the original color of the item, $F(1, 121) = 48.75$, $p < .001$. Consistent with hypotheses H1e and H1f, children performed more poorly on measures of objective recollection than adolescents and adults, $F(1, 121) = 4.61$, $p = .012$. No interaction was present between objective judgment type and age group, $F(1, 121) = 1.39$, $p = .253$.

Correspondence between subjective and objective recollection.. To examine age-related differences in the accurate use of subjective judgments, a 3 Age Group x 2 Subjective Judgment (remember, familiar) x 2 Objective Judgment (color, semantic) mixed-model ANOVA was conducted (see Figure 3). Accuracy for the objective details was higher when participants provided “remember” judgments than when they provided “familiar” judgments, $F(1, 116) = 41.77$, $p < .001$, and this effect did not interact with age, $F(2, 116) = 1.27$, $p = .286$. The finding that children, adolescents, and adults utilized the subjective judgments similarly when they were capable of recollecting objective contextual details does not support H2a.

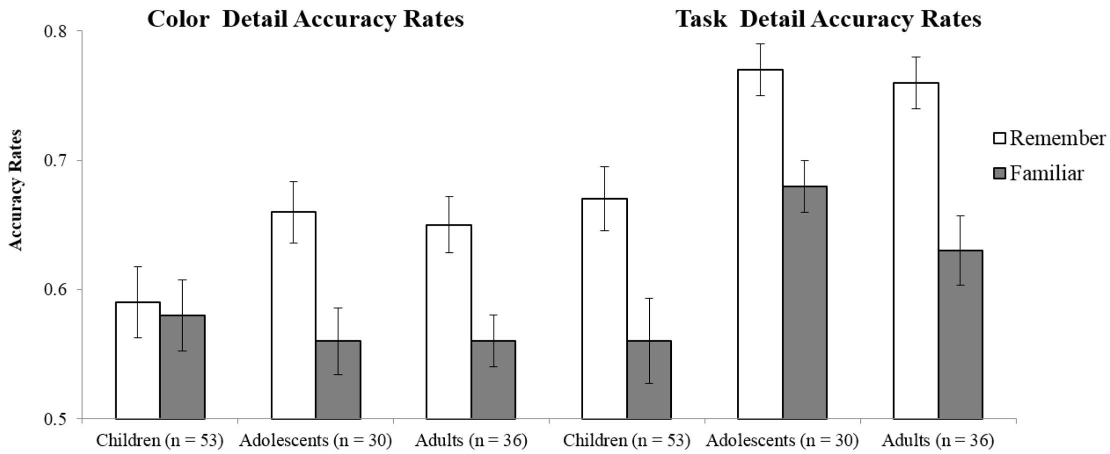

Figure 3. Mean accuracy rates for objective details as a function of subjective judgment. Memory for objective details was higher when participants provided "remember" versus "familiar" judgments. The judgment made at encoding was better remembered than the original color of the item. Overall, children had poorer memory for objective details than adolescents or adults. Error bars represent standard errors.

ERP results. Grand average waveforms depicting conditions included in the analyses of subjective recollection, color recollection, and task recollection are shown in Figures 4, 5, and 6, respectively. As described below, analyses of the subjective measure of recollection revealed that neural activity at encoding was sensitive to recollection (i.e., the amplitude of the response elicited to items later given "remember" judgments was more positive than items given "familiar" judgments or missed items). Further, this effect did not differ as a function of age. Subsequent recollection effects were also found when recollection was indexed by memory for the semantic judgment made at encoding. However, subsequent recollection effects were not found when recollection was indexed by memory for the item's color. Results below are for the 700-900 ms time window; analyses associated with the other three time windows are reported in Appendix E.

***Subsequent subjective recollection*[2].** Analysis of subjective recollection revealed a main effect of Condition, $F(2, 128) = 7.19$, $p = .001$. The results revealed a recollection effect with amplitude to items subsequently given "remember" judgments being more positive than items given "familiar" judgments ($t = 2.838$, $p = .018$, $BF = .245$) and missed items ($t = 3.828$, $p = .001$, $BF = .014$), which did not differ from one another ($t = .828$, $p = 1.0$, $BF = 7.434$; see Figure 4). This effect is consistent with H3a and does not support age-related differences in the timing, topography, or direction of the subsequent subjective recollection effect (RQ1).

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[2] Behavioral performance was comparable between participants included in the subjective recollection ERP analysis and the full sample. The task performed at encoding was better remembered than the color of the item, $F(1, 64) = 64.51$, $p < .001$, and participants were more accurate for objective details when they provided remember versus familiar judgments, $F(1, 64) = 53.33$, $p < .001$. However, memory for objective details did not differ as a function of Age Group in this subset of participants, $F(2, 64) = .79$, $p = .457$.

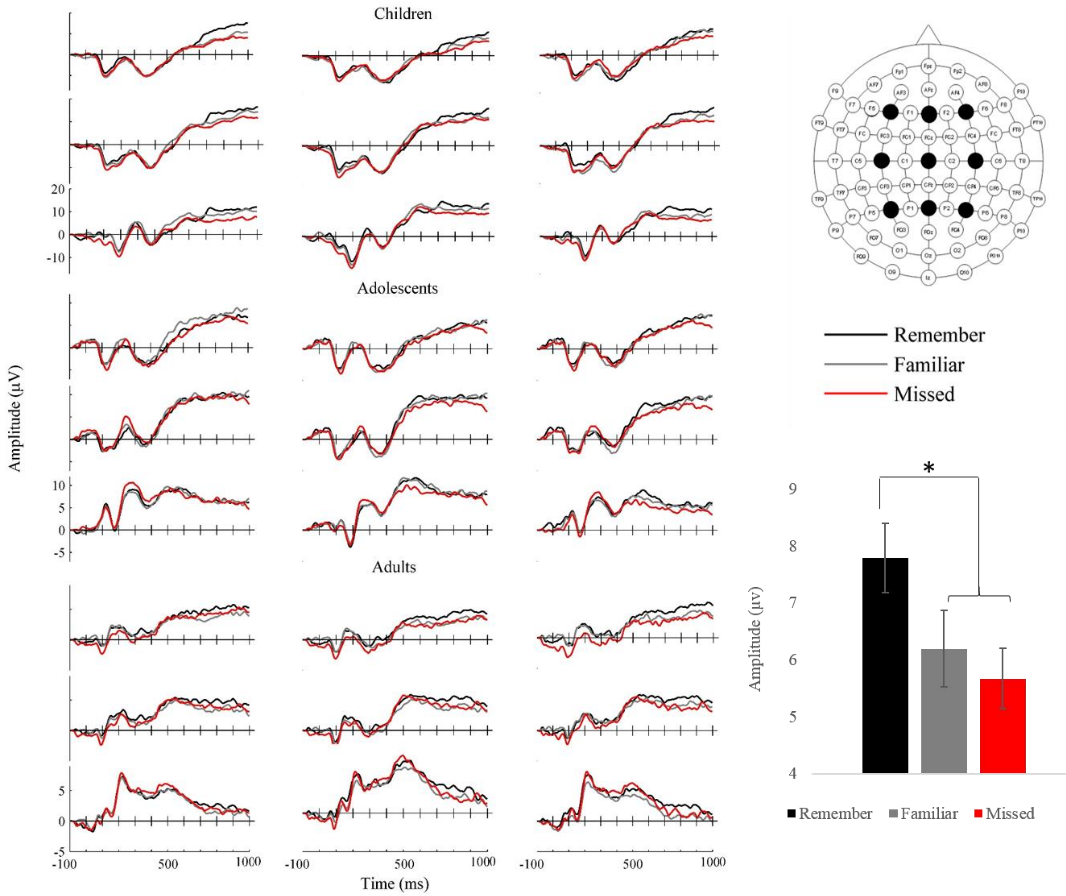


Figure 4. Grand average waveforms recorded at encoding illustrating ERPs to items subsequently classified as remembered, familiar, and missed. Bar graph represents mean amplitude in the 700-900 ms window collapsed across all analyzed electrodes and age groups. The mean amplitude elicited to remembered items was more positive than familiar and missed items. Error bars represent standard errors.

Subsequent color recollection. Analysis of color recollection revealed a main effect of Condition, $F(2, 120) = 3.27$, $p = .048$. The results revealed that items subsequently identified with the color-correct elicited a larger amplitude response than missed items ($t = 2.78$, $p = .022$, $BF = .279$); the amplitude of the response elicited to color-incorrect items was similar to color-correct ($t = .08$, $p = 1.0$, $BF = 10.069$) and missed items ($t = 1.921$, $p = .179$, $BF = 1.727$; see Figure 5). This effect partially supports H3b, which posited that the amplitude to color-correct and color-incorrect items would be larger than missed items.

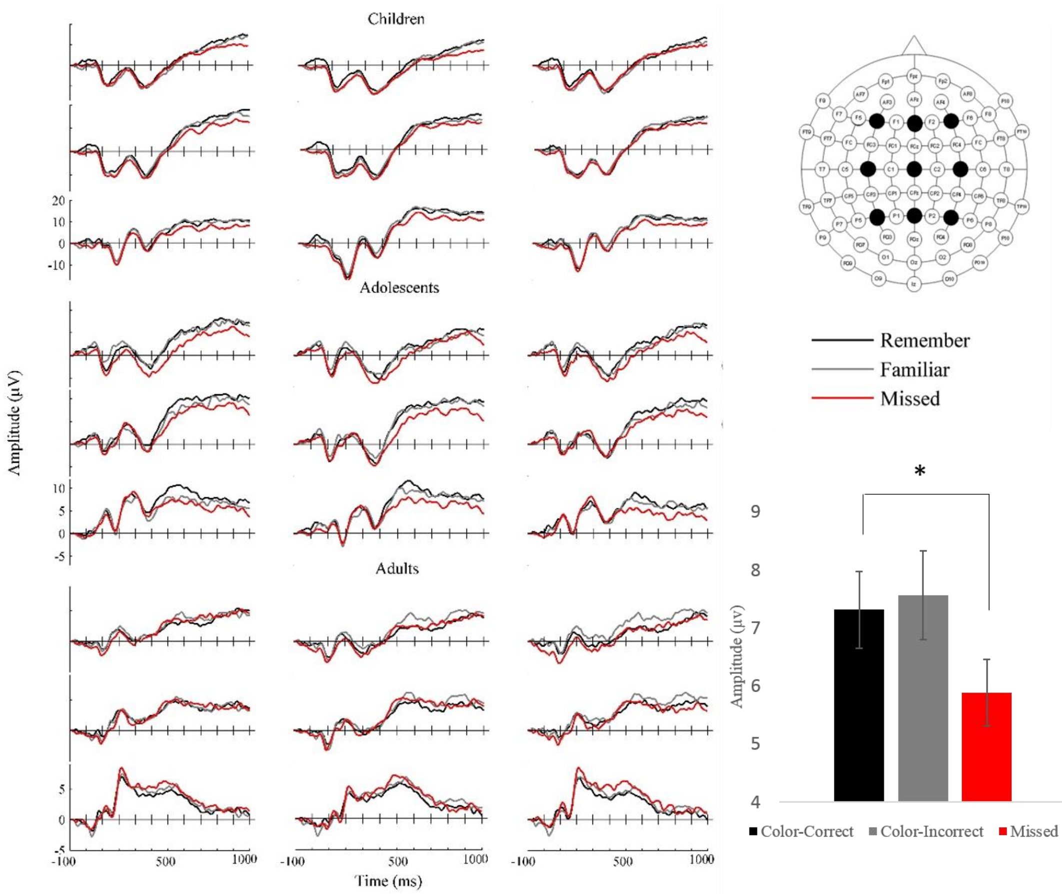


Figure 5. Grand average waveforms recorded at encoding illustrating ERPs to items subsequently classified as color-correct, color-incorrect, and missed. Bar graph represents mean amplitude in the 700-900 ms window collapsed across all analyzed electrodes and age groups. The mean amplitude elicited to color-correct items was more positive than missed items. Error bars represent standard errors.

Subsequent task recollection. When recollection was indexed by accurate memory for the semantic judgment made at encoding, there was a main effect of Condition, $F(4, 296) = 2.44$, $p = .012$. The results revealed a recollection effect with amplitude to subsequently task-correct items being more positive than task-incorrect ($t = 2.694$, $p = .026$, $BF = .362$) and missed items ($t = 2.767$, $p = .021$, $BF = .303$), which did not differ from one another ($t = .104$, $p = 1.0$, $BF = 11.078$; see Figure 6).This pattern of results does not support H3c, which posited a recognition effect (i.e., that the amplitude to task-correct and task-incorrect items would be larger than the amplitude of the response to missed items).

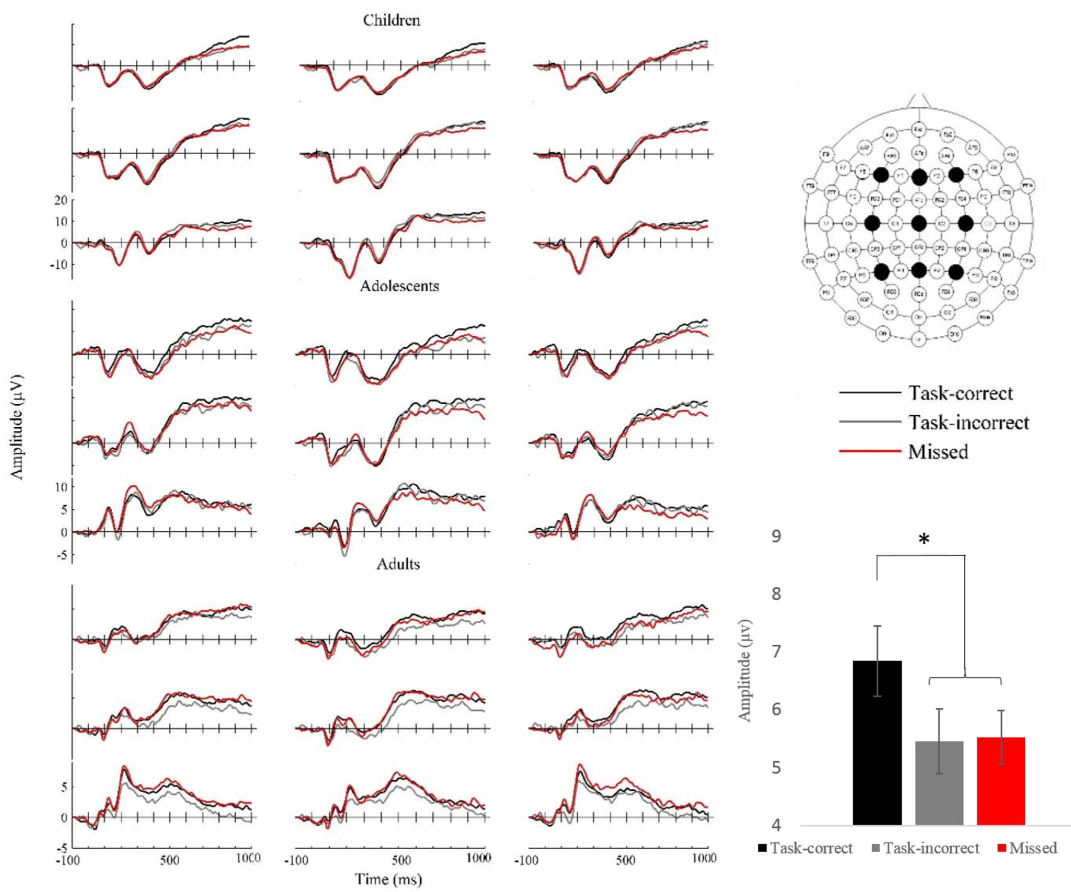


Figure 6. Grand average waveforms recorded at encoding illustrating ERPs to items subsequently classified as task-correct, task-incorrect, and missed. Bar graph represents mean amplitude in the 700-900 ms window collapsed across all analyzed

electrodes and age groups. The mean amplitude elicited to task-correct items was more positive than task-incorrect and missed items. Error bars represent standard errors.

Chapter 3: Study 2

Method

Participants. A total of 103 participants provided complete behavioral data for this study; 41 children (mean age = 7.44 years, *SD* = .56, 28 females, 13 males), 26 adolescents (mean age = 12.66 years, *SD* = .64, 18 females, 8 males), 36 adults (mean age = 20.23 years, *SD* = 2.3, 23 females, 13 males). An additional 5 participants came in for the study but were excluded due to equipment failure (1 adolescent, 2 adults), illness (1 adult), or noncompliance (1 child). One adult participant was excluded from subjective recollection analyses because she verbally indicated that she did not use the judgments correctly. One adult participant was excluded from the analysis examining the correspondence between objective and subjective recollection because he provided "familiar" judgments for all recognized stimuli.

Procedures. This design of this study is similar to Study 1; however, ERPs were recorded at the retrieval rather than the encoding portion of the study. The encoding portion was identical to Study 1. After encoding, the Lycra cap was applied resulting in a delay of approximately 15 minutes between encoding and retrieval. After the EEG cap was applied, participants were given instructions for the retrieval phase. To further clarify the distinction between remember/familiar judgments, the following exemplars were added to participant instructions:

"For example, you could remember the lamp because I asked you if it was living. You could remember seeing the owl/fire truck [depending on whether

the participant began with the animacy or size task] *because it was the first picture you saw. You could remember that you saw a ball because it was red, and I asked you if it could fit inside of the box. You could remember a sunflower because you thought of whether you would be taller than it. If you remember any detail about the picture, you should say you remember it."*

After receiving instructions, participants completed a practice phase to ensure they understood the task and that they needed to verbally respond only after the words "old/new" appeared on the screen. Each stimulus was presented for 1500 ms while ERPs were recorded. After 1500 ms elapsed, the words "old/new" appeared and participants were prompted to make a recognition judgment, subjective recollection judgment, and objective recollection judgments regarding the item's original color and the task performed at encoding. Following the memory paradigm, participants completed the classification task, and then the cap was removed.

ERP recording and analysis. The same procedures were used for ERP recording and analysis as for Study 1. A total of 84 participants provided ERP data for at least one analysis of interest. Participants were excluded from all analyses due to problems with the reference electrode(s) (2 children), poor quality EEG (2 children, 1 adolescent, 2 adults), failure to record the EEG data (1 child), or contributing fewer than 10 trials per condition due to movement-related artifact or behavioral performance (8 children, 1 adolescent, 2 adults).

For the analysis of subjective recollection, participants were only included if they performed statistically above chance on the classification task. These criteria led to the inclusion of 20 children, 19 adolescents, and 29 adults. For children, the mean trial numbers (standard deviation and range) were 38 correct rejections (8, 27-53), 24 remember (9, 11-39), and 19 familiar (8, 10-38). For adolescents, the mean trial numbers were 45 correct rejections (10, 29-58), 32 remember (16, 15-72), and 31 familiar (14, 11-54). For adults, the mean trial numbers were 46 correct rejections (7, 30-59), 34 remember (15, 13-70), and 30 familiar (16, 11-76). Children had fewer trials than adults and adolescents for all 3 conditions, $Fs(2, 65) = 3.58\text{-}6.52$ ps = .003-.033.

Participants were only included in ERP analyses of objective recollection if the contextual detail of interest (i.e., color or semantic judgment) was recollected accurately for greater than 55% of recognized items (see Methods for Study 1 for justification). These criteria led to the inclusion of 17 children, 16 adolescents, and 20 adults for the analysis of color recollection. The mean trial numbers (standard deviation and range) for children were as follows: 37 correct rejections (9, 18-47), 26 color-correct (9, 12-40), 17 color-incorrect (10-27). For adolescents, the mean trial numbers were 43 correct rejections (10, 28-56), 41 color-correct (11, 19-63), 25 color-incorrect (8, 11-37). For adults, the mean trial numbers were 46 correct rejections (8, 30-59), 46 color-correct (12, 15-65), and 22 color-incorrect (7, 14-40). Children had fewer trials than adults and adolescents for all 3 conditions, $Fs(2, 50) = 4.6\text{-}14.53$ ps = <.001-.015.

The analysis of task recollection included 17 children, 19 adolescents, and 28 adults. The mean trial numbers (standard deviation and range) for children were as follows: 37 correct rejections (10, 16-49), 29 task-correct (10, 15-47), 14 task-incorrect (10-24). For adolescents, the mean trial numbers were 45 correct rejections

(9, 30-58), 48 task-correct (10, 25-67), 20 task-incorrect (7, 10-35). For adults, the mean trial numbers were 45 correct rejections (7, 30-59), 46 task-correct (14, 26-76), and 20 task-incorrect (7, 10-39). Children had fewer trials than adults and adolescents for all 3 conditions, *Fs*(2, 61) = 4.35-13.34 *ps* = <.001-.017.

Mean amplitudes, which are relatively uninfluenced by differences in trial numbers across conditions (Luck, 2005), were exported from 4 time windows for analysis based on previous literature (e.g., Duarte et al., 2004) and visual inspection. Mean amplitudes were exported for 150-300 ms, 300-450 ms, 500-700 ms, 700-900 ms time windows for children and 125-250 ms, 250-450 ms, 500-700 ms, and 700-900 ms time windows for adolescents and adults.

Results

Behavioral results.

Subjective recollection: Memory paradigm. There was a significant age-related improvement in accurate recognition, $F(2, 99) = 14$, $p < .001$. Children correctly identified fewer items than adolescents and adults (see Figure 7). Contrary to H1g, age-related decreases in the provision of "remember" judgments were not present, $F(2, 99) = 2.43$, $p = .093$ (see Figure 7).

Participants were more likely to provide "familiar" than "remember" judgments for falsely recognized items, $F(1, 99) = 9.45$, $p = .003$ (see Figure 7). No age-related changes were present in false recognition, $F(2, 99) = .55$, $p = .581$, and, contrary to H1h, no interaction was present between age and subjective judgment type, $F(2, 99) = .44$, $p = .646$.

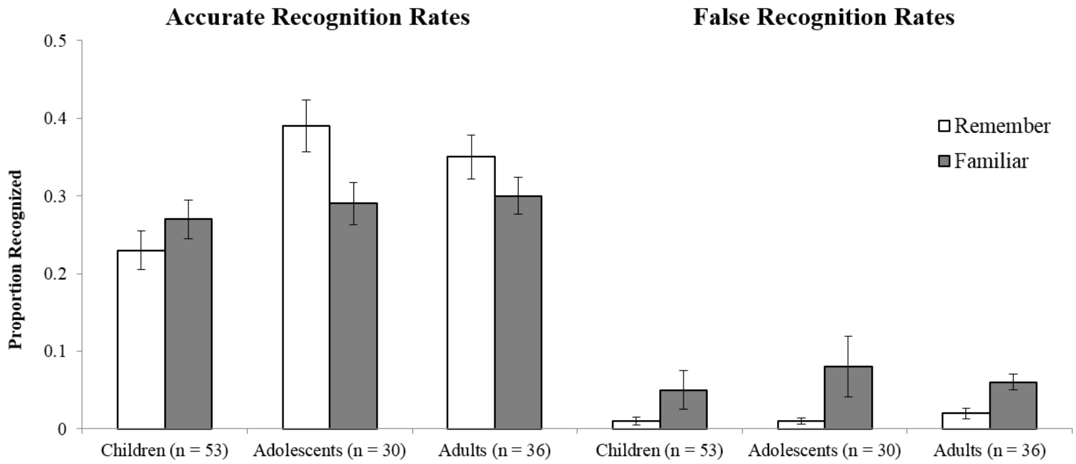


Figure 7. Mean accurate and false recognition rates for children, adolescents, and adults. Accurate recognition rates were higher in children than adolescents and adults, and more accurately recognized items were provided with "remember" than familiar judgments. Older participants were more likely to provide novel items falsely recognized with a "familiar" judgment. Error bars represent standard errors.

Subjective recollection: Classification task. All age groups reliably classified statements as meeting the criteria for a "remember" or "familiar" judgment, consistent with H1i; children, $t(39) = 21.08$, = $p < .001$; adolescents, $t(25) = 17.26$, = $p < .001$; adults, $t(34) = 51.83$, = $p < .001$. Performance on this task differed as a function of participant age, $F(2, 98) = 3.39$, $p = .038$, subjective judgment, $F(1, 98) = 6.13$, $p = .015$, and an interaction between age group and subjective judgment, $F(2, 98) = 4.1$, $p = .02$. In support of H1j, age-related improvements were present in the classification of statements that should have been associated "remember," $F(2, 98) = 5.53$, $p = .005$, but not "familiar" judgments, $F(2, 98) = .49$, $p = .61$ (see Figure 8).

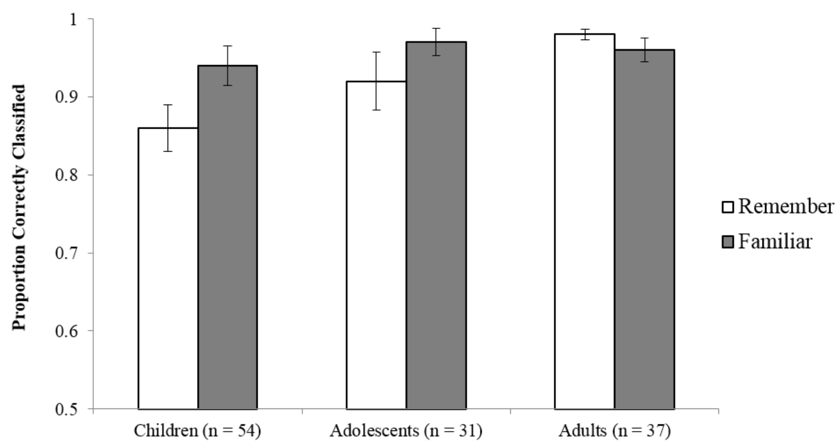


Figure 8. Accuracy rates for "remember" and "familiar" statements on the classification task. All age groups performed above chance. Children were less accurate at classifying "remember" statements than adolescents and adults. Error bars represent standard errors.

Objective recollection. Participants were more likely to remember the judgment made at encoding than the original color of the item, $F(1, 100) = 60.61$, $p < .001$. This effect was qualified by an interaction between age group and objective judgment, $F(2, 100) = 4.15$, $p = .019$. In contrast to H1k, memory for the original color of the item did not change with age, $F(2, 100) = .198$, $p = .821$. However, age-related improvements were present in memory for the judgment made at encoding, $F(2, 100) = 4.74$, $p = .011$, consistent with H1l. Children were less likely to recollect the task performed at encoding than adolescents or adults; adolescents and adults performed similarly. Thus, age-related changes were present in memory for task performed at encoding but not the original color of the item.

Correspondence between subjective and objective recollection. Across age groups, participants accurately used the subjective judgments; however, this ability improved with age (Figure 9). Memory for objective contextual details was higher when participants provided "remember" judgments than when they provided "familiar" judgments, $F(1, 98) = 36.48$, $p < .001$. However, this effect interacted with the type of objective judgment and age group, $F(2, 98) = 4.083$, $p = .02$. In children, there was a main effect of subjective judgment, $F(1, 40) = 8.16$, $p = .007$, and a marginal subjective judgment x objective judgment interaction, $F(1, 40) = 3.57$, $p = .066$. Children's "remember" judgments were associated with higher accuracy for the original color of the item, $t(40) = 3.281$, $p = .002$, $BF = .077$, but not the semantic judgment made at encoding, $t(40) = .546$, $p = .588$, $BF = 7.099$. In adolescents, there were main effects of objective judgment, $F(1, 25) = 17.02$, $p < .001$, and subjective judgment, $F(1, 25) = 13.04$, $p = .001$. Adolescents were more likely to remember the task performed at encoding than the original color of the item, and memory for the color and task judgments was higher when they made "remember" versus "familiar" judgments. Similarly, main effects of objective judgment, $F(1, 33) = 33.92$, $p < .001$, and subjective judgment, $F(1, 34) = 14.45$, $p = .001$, were present in adults. Memory was better for the task performed at encoding than the original color of the item, and adults were more accurate at identifying the color of and judgment made for items they reported "remembering" than for "familiar" items. The finding that accurate memory for objective details was increasingly associated with "remember" judgments with age is consistent with H2b.

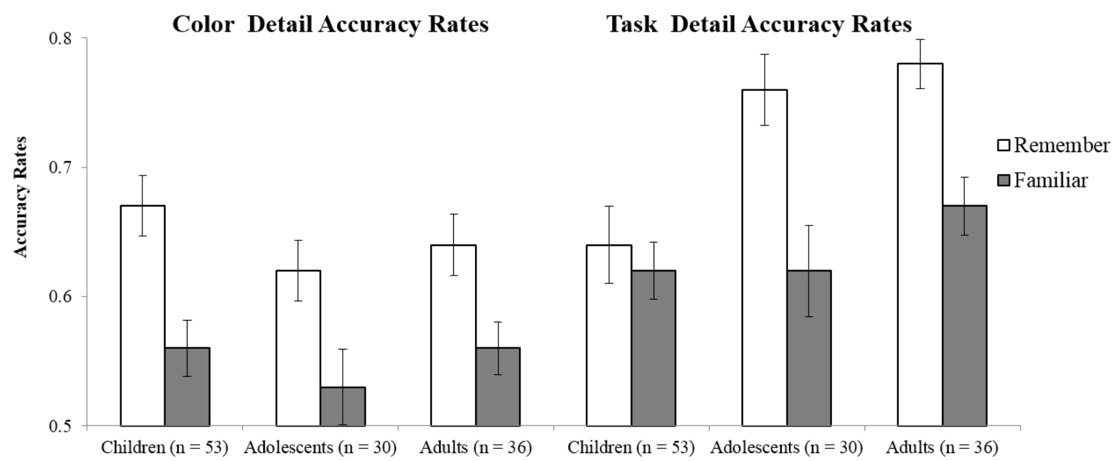


Figure 9. Mean accuracy rates for objective details as a function of subjective judgment. Memory for objective details was higher when participants provided "remember" versus "familiar" judgments. The judgment made at encoding was better remembered than the original color of the item. In children, "remember" and "familiar" judgments did not distinguish which items were recollected along with the task detail. Error bars represent standard errors.

ERP results. Grand average waveforms depicting conditions included in the analyses of subjective recollection, color recollection, and task recollection are shown in Figures 7, 8, and 9, respectively. Subjective recollection analyses revealed age-related differences in subjective recollection at retrieval. Consistent with previous literature (for review see Rugg & Curran, 2007), adults demonstrated a recollection effect (i.e., a more positive response to remembered than familiar and novel items) that was focused over left parietal leads in the 500-700 ms window. Adolescents also demonstrated a recollection effect; however, it was more widespread in topography. In contrast, children showed no evidence for either a recognition or recollection effect. Recollection effects were not found when either accurate memory for color or the task performed at encoding was used as an index of recollection. Results below are for the 500-700 ms time window; analyses from three additional time windows are reported in Appendix E.

Subjective recollection[3]. For the analysis of subjective recollection, there was an Age Group x Condition interaction, $F(4, 130) = 4.57$, $p = .002$, and an Age Group x Condition x Sagittal Plane interaction, $F(8, 260) = 2.86$, $p = .012$. Follow-up analyses were conducted separately for each age group. No main effect of or interaction with Condition was present in children. Bayes factors revealed no support in favor of differences in amplitude between items given remembered versus familiar items ($t = 1.525$, $p = .431$, $BF = 2.033$) or between correctly rejected novel items and either remembered ($t = 1.308$, $p = .619$, $BF = 2.656$) or familiar items ($t = .34$, $p = 1.0$, $BF = 5.544$). A significant main effect of Condition was present in adolescents, $F(2, 36) = 7.3$, $p = .002$. The results suggested a recollection effect with remembered items showing a trend of eliciting a more positive response than familiar items ($t = 2.36$, $p = .089$, $BF = .553$) and significantly eliciting a more positive response than correctly rejected items ($t = 4.447$, $p = .001$, $BF = .01$; see Figure 10). No difference was present between remembered and familiar items ($t = .86$, $p = 1.0$, $BF = 4.037$). In adults, there was a main effect of Condition, $F(2, 56) = 7.1$, $p = .002$, that was

[3] Participants included in the subjective recollection ERP analysis remembered the task performed at encoding better than the color of the item, $F(1, 65) = 45.52$, $p < .001$. No Objective Judgment x Age Group interaction was present, $F(2, 65) = .8$, $p = .45$. Although higher accuracy for objective details was associated with the use of remember judgments in all age groups, accurate use of subjective judgments improved with age, $F(2, 65) = 3.23$, $p = .046$. Further, a larger difference in accuracy between remembered and familiar item was present for the task versus the color detail, $F(1, 65) = 5.94$, $p = .018$. The Objective Judgment x Subjective Judgment x Age Group interaction was not significant in this subset of participants, $F(2, 65) = .51$, $p = .6$.

qualified by a Condition x Coronal Plane interaction, *F(*4, 112) = 4.09, *p* = .01, and a Condition x Sagittal Plane interaction, *F(*4, 112) = 4.44, *p* = .002. This pattern of results emerged because, consistent with previous studies, the recollection in effect in adults was maximal over left centro-parietal leads (see Figure 10). When follow-up analyses were conducted separately for each Sagittal Plane, a recollection effect was present across left leads (i.e., F3, C3, P3), *F(*2, 56) = 6.41, *p* = .003. Response amplitude was more positive to remembered than familiar (*t* = 2.968, *p* = .018, *BF* = .168) and correctly rejected novel items (*t* = 3.189, *p* = .011, *BF* = .103), which did not differ from one another (*t* = .058, *p* = 1.0, *BF* = 6.957). For midline leads, there was a main effect of Condition, *F(*2, 56) = 8.84, *p* < .001, and a Condition x Coronal Plane interaction, *F(*4, 112) = 5.11, *p* = .003. A main effect of condition was present at midline frontal, *F(*2, 56) = 3.24, *p* = .047, central, *F(*2, 56) = 8.82, *p* < .001, and parietal leads, *F(*2, 56) = 11.5, *p* < .001. At the midline frontal lead, no significant differences were present between remembered, familiar, and correctly rejected items (*t* = .646-2.208, *p* = .107-1.0, *BF* = .782-5.696). A significant recollection effect was present at the central midline lead; the response elicited to remembered items was more positive than familiar (*t* = 3.511, *p* = .005, *BF* = .049) and correctly rejected novel items (*t* = 3.37, *p* = .007, *BF* = .007), which did not differ from one another (*t* = .343, *p* = 1.0, *BF* = 6.581). At the parietal midline lead, the response amplitude to familiar items was less than correctly rejected (*t* = 2.54, *p* = .051, *BF* = .414) and remembered items (*t* = 4.944, *p* < .001, *BF* = .001), which did not differ from one another (*t* = 2.235, *p* = .101, *BF* = .744). For right leads, there was a there was a main effect of Condition, *F(*2, 56) = 5.12, *p* = .009, and a Condition x Coronal Plane interaction, $F(4, 112) = 3.98$, $p = .005$. No main effect of Condition was present at right frontal or central leads. A main effect of Condition was present at the right parietal lead, $F(2, 56) = 10.65$, $p < .001$. Similar to the effect at the midline parietal lead, the response amplitude to familiar items was less than correctly rejected ($t = 3.109$, $p = .013$, $BF = .122$) and remembered items ($t = 4.749$, $p < .001$, $BF = .002$), which did not differ from one another ($t = 1.525$, $p = .415$, $BF = 2.347$). Overall, this pattern of results is consistent with H3d. Adults and adolescents demonstrated a recollection effect. Further, in response to RQ2, the recollection effect at retrieval differed as a function of age; the effect was absent in children, widespread in adolescents, and focused over left centro-parietal leads in adults.

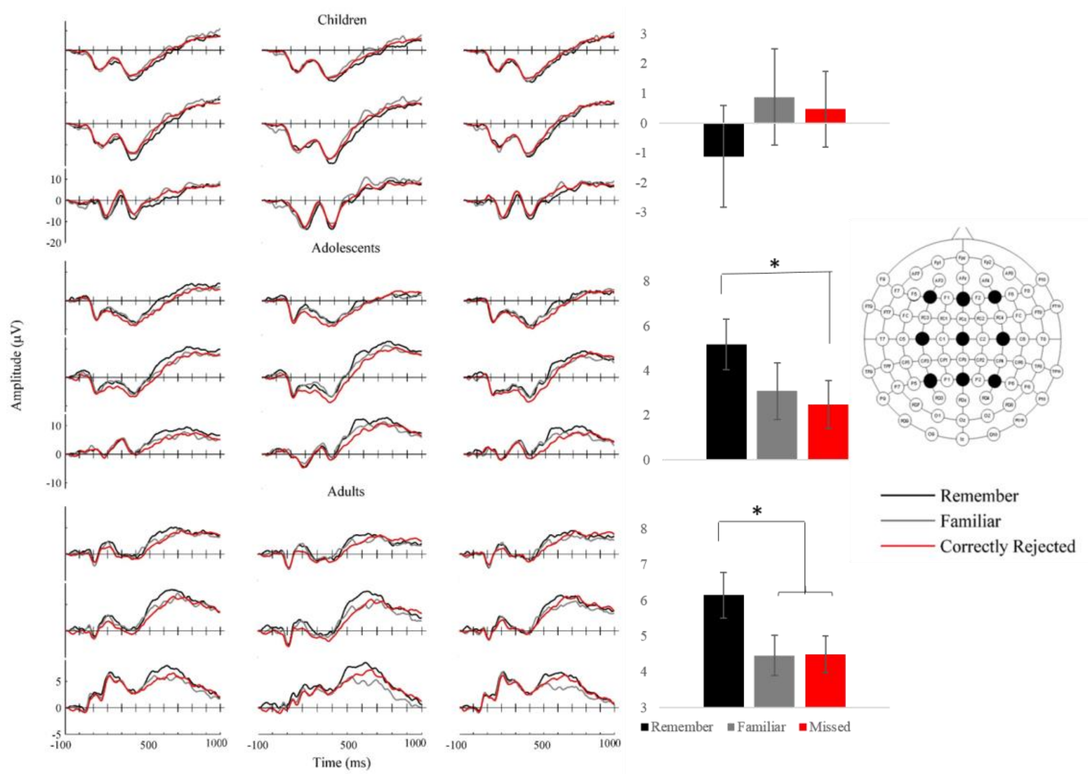


Figure 10. Grand average waveforms recorded at retrieval illustrating ERPs to items classified as remembered, familiar, and correctly rejected. Bar graph represents mean amplitude in the 500-700 ms window. For children and adolescents, mean amplitudes were collapsed across all analyzed electrodes. In adults, mean amplitudes were collapsed across left electrodes (F3, C3, P3). In adolescents, a recollection effect was widespread as indexed by a main effect of Condition whereas in adults the recollection effect was focused over left centro-parietal leads. Error bars represent standard errors.

Color recollection. In the third time window (500-700 ms) there was a significant Condition x Sagittal Plane interaction, $F(4, 200) = 3.06$, $p = .026$, and a Condition x Coronal Plane x Sagittal Plane interaction, $F(8, 400) = 2.26$, $p = .045$. However, no main effect of or interaction with condition was present in follow-up analyses conducted at each sagittal and coronal plane (see Figure 11). These findings do not lend support for the hypothesis that a recollection effect would be present when the color of the item was accurately identified (H3e; RQ3).

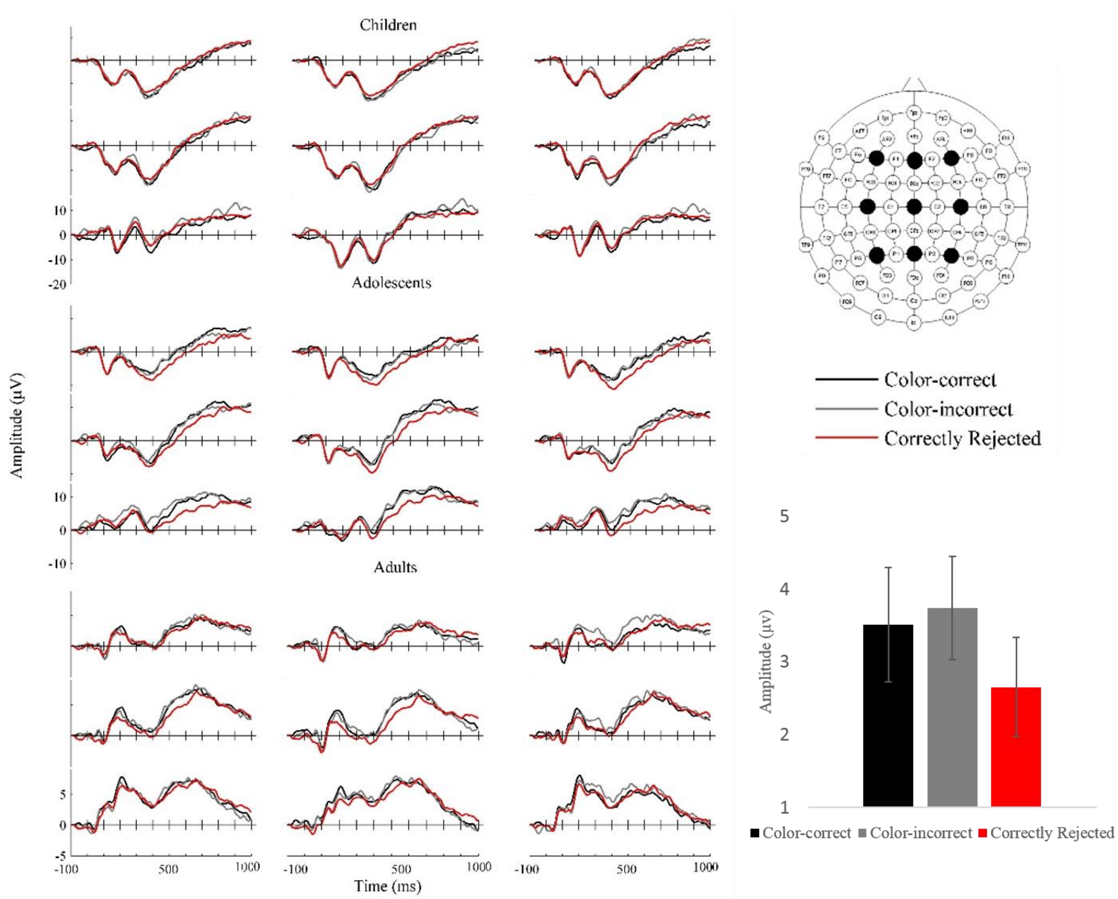


Figure 11. Grand average waveforms recorded at retrieval illustrating ERPs to items classified as color-correct, color-incorrect, and correctly rejected. Bar graph represents mean amplitude in the 500-700 ms window collapsed across all analyzed electrodes and age groups. No recognition or recollection effects were present. Error bars represent standard errors.

Task recollection. In the third time window (500-700 ms), there was a Condition x Coronal Plane interaction, $F(4, 244) = 5.53$, $p = .002$, and a Condition x Sagittal Plane interaction, $F(4, 244) = 5.32$, $p = .001$, that was qualified by Age Group, $F(8, 244) = 3.3$, $p = .002$. In children, there was a Condition x Sagittal Plane interaction, $F(4, 64) = 4.04$, $p = .006$. Follow-up analyses conducted at each sagittal plane revealed no main effect of or interaction with condition at left, midline, or right leads. In adolescents, there was a Condition x Coronal Plane interaction, $F(4, 72) = 5.33$, $p = .004$. At central leads there was a Condition x Sagittal Plane interaction, $F(4, 72) = 3.15$, $p = .036$. A main effect of Condition was present at the central midline lead, $F(2, 36) = 5.46$, $p = .008$. This effect was sensitive to item recognition; the amplitude of the response elicited to task-correct ($t = 3.162$, $p = .016$, $BF = .125$) and task-incorrect items ($t = 3.181$, $p = .016$, $BF = .121$) was more positive than the response to correctly rejected items (see Figure 12). No difference was present between task-correct and task-incorrect items ($t = .636$, $p = 1.0$, $BF = 4.721$). A recognition effect was also present across parietal leads, $F(2, 36) = 4.57$, $p = .017$. No main effect of or interaction with Condition was present in adults. These findings do not lend support for the hypothesis that a recollection effect would be present when the task performed at encoding was accurately identified (H3f; RQ4).

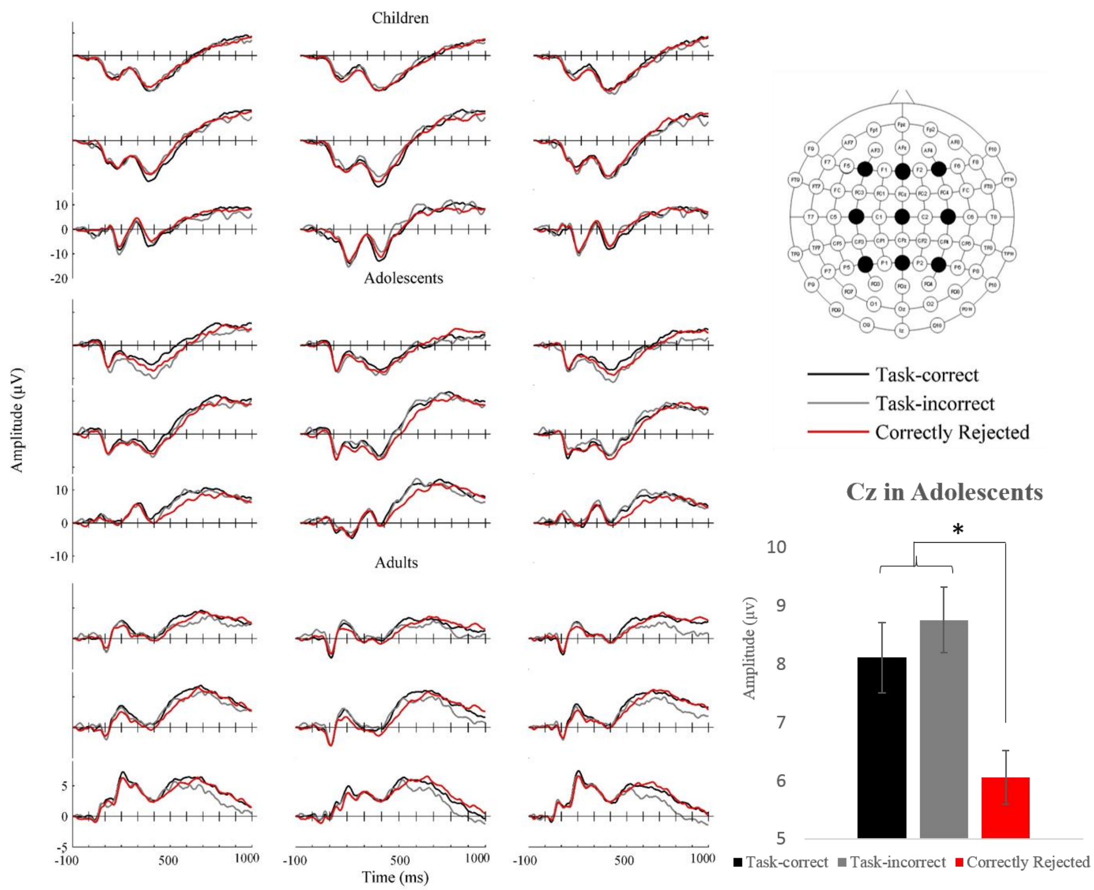


Figure 12. Grand average waveforms recorded at retrieval illustrating ERPs to items classified as task-correct, task-incorrect, and correctly rejected. Bar graph represents mean amplitude in the 500-700 ms window at Cz in adolescents who demonstrated a recollection effect. Error bars represent standard errors.

Chapter 4: Discussion

The present studies examined ERP correlates of subjective and objective recollection at encoding and retrieval in children, adolescents, and adults. Behavioral improvements in memory performance were demonstrated across both studies, and ERP results shed insight into the nature of these developmental differences at the neural level. During encoding, ERP responses were sensitive to recollection (i.e., responses were larger in amplitude to remembered than familiar or missed items) when recollection was indexed subjectively or by the task performed at encoding. No age-related differences were present in this response suggesting similarity of processing at encoding across age groups. At retrieval, ERP responses were only associated with recollection when recollection was indexed subjectively, and this effect differed as a function of age. A recollection effect was absent in children, widespread in adolescents, and maximal over left centro-parietal leads in adults. Collectively, these findings suggest that recollection effects may be more apparent using subjective versus objective measures of recollection and that improvement in recollection between middle childhood and adulthood is primarily attributable to the development of consolidation, storage, or retrieval processes.

ERP correlates of subjective recollection

ERPs recorded during encoding were sensitive to subjective recollection and recollection of the task performed at encoding. These effects did not differ between 6- to 8-year-old children, 12- to 13-year-old adolescents, and adults. The effect observed at encoding was widespread and present during the 700-900 ms time window, consistent with previous studies in adults (Duarte et al., 2004; Friedman & Trott, 2000; Mangels et al., 2001; Yovel & Paller, 2004). The similarity of this effect across age groups contributes to the current literature on the development of encoding processes that suggests improvement in encoding abilities between 6 and 8 years of age (Ghetti & Angelini, 2008; Rollins & Riggins, 2013). Less mature encoding abilities in 6-year-old children have been demonstrated by an ERP investigation that found age-related differences in the timing, direction, and topography of subsequent recognition effects between 6-year-old children and adults (Rollins & Riggins, 2013). Furthermore, a behavioral study showed that 6-year-old children only provided estimates of familiarity similar to 8- and 10-year-old children when they were given a longer duration of time to encode items (Ghetti & Angelini, 2008). However, the lack of age-related differences differs from fMRI studies of subjective and objective recollection in developmental populations which suggests developmental differences in the specificity of neural regions involved in encoding between middle childhood through adolescence (Ghetti et al., 2010; Güler & Thomas, 2013; Ofen et al., 2007). Methodological differences, such as the use of fMRI methodology and the paradigms utilized, likely contribute to differences in findings across investigations.

Results suggested that developmental differences in subjective recollection were present in ERP responses elicited during retrieval. ERPs in children did not differ as a function of memory. In adults, consistent with previous literature (for reviews see Friedman & Johnson, 2000; Rugg & Curran, 2007), the left parietal old/new effect in the 500-700 ms time window was sensitive to recollection. Adolescents demonstrated a similar, yet less localized, effect. Other studies using exclusion, speeded/nonspeeded recognition, or continuous recognition tasks have reported similar parietal old/new effects in children/adolescents and adults (Czernochowski et al., 2005; Mecklinger et al., 2011; Spondrel et al., 2011; 2012). These authors argue that the ERP correlate of recollection is present in children and that memory development is primarily due to improvements strategic recollection and post-retrieval evaluation of retrieved information (e.g., Sprondel et al., 2012). However, none of the paradigms utilized by those researchers examine the ability to engage in subjective recollection, an ability that could also be undergoing development across childhood and adolescence.

The present study found that neural activity at retrieval associated with subjective recollection was localized over left centro-parietal leads in adults but widespread in adolescents. Within the field of developmental cognitive neuroscience, age-related increases in the localization and specialization of neural activity is common and has been associated with the development of neural regions and their connectivity (e.g., Johnson, 2001). This pattern of results has been demonstrated in research on language (e.g., Mills, Coffey-Corina, & Neville, 1997), face processing (e.g., Halit, de Haan, & Johnson, 2003), and memory (e.g., Ghetti et al., 2010; Güler & Thomas, 2013). Within the memory literature, hippocampal activity at encoding becomes increasingly specialized for recollection between 8- and 14 years of age (Ghetti et al., 2010). Furthermore, at retrieval, 8- to 9-year-old children were less likely to recruit regions of left ventrolateral prefrontal cortex and left inferior parietal cortex than 12- and 13-year-old children (Güler & Thomas, 2013). Thus, it is possible that the increased development of and connectivity between neural regions that support recollection in adults (i.e., medial temporal lobes, prefrontal cortex, parietal cortex) led to the developmental differences in ERP correlates of subjective recollection observed in the present study.

ERP correlates of objective recollection

Although behavioral results demonstrated that participants' subjective judgments aligned with their accuracy for objective contextual details, few ERP correlates of objective recollection were present. When recollection was indexed by memory for the original color of the item, ERP responses were not sensitive to recollection at either encoding or retrieval. However, when memory for the task performed at encoding was used as the index of recollection, ERPs at encoding, but not retrieval, were indicative of recollection. This finding is consistent with within-subject studies of adults that have reported larger ERP recollection effects for subjective versus objective assessments of recollection (Duarte et al., 2004; Friedman & Trott, 2000; Trott et al., 1999). However, many published studies do report recollection effects at retrieval when using objective measures of recollection (Curran, 2000; Rugg, Schloerscheidt, Doyle, Cox, & Patching, 1996; Trott, Friedman, Ritter, & Fabiani, 1997; Wilding, 1999; Wilding, Doyle, & Rugg, 1995; Wilding & Rugg, 1996, 1997a, 1997b). The discrepancy between the present and previous studies cannot be accounted for by accuracy rates or the delay between encoding and retrieval. One difference between the current studies and previous investigations is that the perceptual characteristics of stimuli were altered between encoding and retrieval. During encoding, stimuli were presented as red or green, and, at retrieval, they were viewed in grayscale. A recent study showed that the parietal old/new effect was attenuated when perceptual characteristics of stimuli were altered at retrieval (Groh-Bordin, Zimmer, & Ecker, 2006). Thus, it is possible that this methodological decision attenuated and masked the influence of objective recollection on the parietal old/new effect.

Behavioral improvements in objective and subjective recollection

The behavioral results demonstrated age-related improvements in memory for objective contextual details, consistent with previous investigations (Cycowicz et al., 2001; Cycowicz et al., 2003 Ghetti & Angelini, 2008; Ghetti et al., 2010; Ghetti et al., 2011; Ofen et al., 2007; Rollins & Riggins, 2013). Similar to the findings by Ghetti and colleagues (2011), both studies suggest that memory for the task performed at encoding surpassed memory for the original color of the item. This finding is consistent with the rich literature on deep versus shallow encoding conditions (e.g., Craik & Lockhart, 1972). Making a semantic judgment about an item's animacy or size requires conceptual processing resulting in a deeper and more salient encoding experience than providing the color of the item. Memory for these objective contextual details also differed in their developmental trajectories. Memory for the original color of the item was similar across age groups whereas memory for the task performed at encoding was lower in children than in adolescents and adults. The stability of memory for color across age groups could be explained by the fact that it is a perceptual characteristic that it is capable of being unitized with the item. A recent theory suggests that contextual details that can be unitized with the item (e.g., item color) can be supported by different neural regions within the MTL than contextual details that must be bound to items (e.g., memory for the task performed at encoding; Diana, Yonelinas, & Ranganath, 2007). Future research is needed to investigate the developmental trajectory of memory for unitized and non-unitized contextual details.

Children, adolescents, and adults were capable of making subjective memory judgments. Memory for objective contextual details was higher when participants provided remember versus familiar judgments. This pattern of results is consistent with previous studies employing the modified remember/know paradigm in children (Ghetti et al., 2011; Hembacher & Ghetti, 2013). Ghetti and colleagues have suggested that children's judgments of remembering are more likely to be supported by memory for color than older age groups (Ghetti et al., 2011; Hembacher & Ghetti, 2013). The present studies provide mixed support for this hypothesis. In Study 1 remember judgments in children were associated with better memory for the task performed at encoding but not the color of the item. For Study 2, analysis of all children showed the opposite pattern; remember judgments were associated with better memory for color but not the task performed at encoding. However, remember judgments in children included in the ERP analysis of subjective recollection for Study 2, which required that participants contribute a minimum of 10 ERP trials associated with remember and familiar judgments and perform above chance performance on the classification task, were associated with better memory for the task performed at encoding but not the color of the item. Thus, while it is possible that children differentially rely on perceptual versus semantic information when making subjective judgments of recollection, the children included in the present ERP analyses show the more mature pattern where subjective recollection is predominantly associated with memory for semantic information.

Future directions

The present studies serve as the foundation for multiple avenues of future research. Evidence from ERP and behavioral investigations suggest age-related changes in encoding processes (or other abilities associated with encoding processes, such as processing speed) between 6 and 8 years of age and stability thereafter (Ghetti & Angelini, 2008; Rollins & Riggins, 2013), highlighting early childhood as an interesting period of investigation for the development of encoding processes. Future research could examine the effect of behavioral manipulations at encoding (e.g., stimulus exposure) as well as the contribution of structural and functional brain development to encoding efficiency. The current findings also suggest that the development of subjective recollection between middle childhood and adulthood is primarily due to the development of storage, consolidation, or retrieval operations. One limitation of the present study is the inability to determine whether age-related differences are specifically due to storage, consolidation, or retrieval operations. Storage and consolidation are continuous processes and thus less amenable to investigation utilizing the ERP methodology which requires the time-locking of events. Future studies are needed to dissociate the developmental trajectories of storage, consolidation, and retrieval processes.

Another topic of current interest within the field of memory research is whether the development of retrieval is related to the improvement of processes specific to memory or those that support memory (e.g., executive functioning). Specifically, recollection is theoretically related to executive functioning because, in order to accurately recollect contextual details from memory, those details must be strategically searched for, maintained in working memory for evaluation, and selected from competing details (Dobbins & Han, 2006; Fletcher & Henson, 2001; Simons & Spiers, 2003). Some data suggests that objective recollection, which requires the recollection of specific contextual details, may be more sensitive to executive functioning than subjective recollection (Duarte et al., 2005). However, no studies have examined these relations in developmental populations.

Only recently have developmental researchers begun to examine children's ability to subjectively reflect upon the contents of their memories, an aspect of episodic memory considered core by Tulving (1985). This is an important area for future research because of the hypothesized relations between subjective remembering and emergence of the self (Buckner & Carroll, 2007; Howe & Courage, 1997; Rajaram & Roediger, 1997). Future research is needed to understand the relation between subjective recollection and other cognitive abilities, such as executive functioning, as discussed above, and theory of mind. Theory of mind, the ability to understand the thoughts and desires of others, has been theoretically related to the ability recall personal memories (e.g., Perner, Kloo, & Stöttinger, 2007). However, few studies have empirically examined relations between these abilities.

Conclusions

In summary, the present dissertation suggests that the development of recollection between middle childhood and young adulthood is primarily due to improvement in processes associated with consolidation, storage, or retrieval since neural activity at encoding was similar between children, adolescents, and adult. Further, ERP effects differed based on whether recollection was indexed using the modified remember/know paradigm or as accuracy for the color of the item or the semantic judgment made at encoding, a finding that has important implications for future research.

Appendix A

Development of metamemory: Implications for investigations of episodic remembering

When thinking about our past we experience a subjective state called *remembering*. Remembering has been defined as the phenomenological experience of reliving events and tying them to our personal past (Tulving, 1985). For example, when reflecting upon your recent birthday you may remember the sound of your family and friends singing you “Happy Birthday”, the flickering of the candles on your birthday cake, and how happy you felt in that moment. Remembering is a complex cognitive enterprise and has been theorized to support many higher order cognitive abilities, including our understanding of the causal and temporal structure of events, consideration of the perspectives of others, perception of ourselves as continuous across time, and our ability to envision future events (e.g., Buckner & Carroll, 2007; Rajaram & Roediger, 1997; Schacter, Addis, & Buckner, 2007). The most widely utilized tool to investigate remembering in adults is the remember/know paradigm, an introspective memory task (Tulving, 1985). During this task participants must decide whether each item is “remembered” along with contextual detail(s) or whether they merely “know” it was previously encountered. Because of concerns regarding children’s introspective capacities (Brainerd et al., 2003, 2004; Ghetti et al., 2002), relatively few studies have examined the development of memory introspection in children.

The aim of this literature review is to consider current evidence about the presence and development of children's ability to think about their own and others' cognitive abilities (i.e., metacognition), which is a prerequisite to reliable performance on introspective memory tasks, such as the remember/know task. First, I will briefly discuss the construct of metacognition and John Flavell's (1979) theory about components that comprise metacognition. Then, I will describe the development of metacognition generally and review in detail the current literature on the development of metamemory (the most relevant component of metacognition). I conclude by describing how the remember/know paradigm fits within Flavell's framework and current research that has investigated children's competence at completing this paradigm.

Metacognition

Reflecting upon cognition is vital because of the role it plays in supporting goal accomplishment before, during, and after a cognitive enterprise. Prior to engagement in a cognitive activity, a strategy can be selected based on prior effectiveness. During the cognitive activity progress can be monitored to decide whether the current strategy should be maintained or abandoned for an alternative approach. Following completion overall performance success can be evaluated to improve future cognitions. For example, when trying to remember my grocery store list from memory I could order the items in a number of ways (e.g., the order I thought of them, alphabetical order, order of importance, or the store's layout). I may initially decide to use the store's layout to order the items. However, if I kept forgetting one of my most important items because it was in the middle of the list, I could abandon that strategy and instead try to rehearse items by order of importance. Then, based on how successful I am at remembering all of the items on my list, I may either keep using that strategy or choose an alternative strategy in the future.

The ability to monitor and evaluate cognitive processes was coined metacognition by Flavell (1979). Flavell (1979) suggested that four components underlie metacognitive monitoring, (a) knowledge about cognition, (b) metacognitive experiences, (c) goals, and (d) strategies that support the achievement of cognitive goals. Metacognitive knowledge includes information about the cognitive abilities of yourself and others (e.g., people can forget information they currently know), how task demands influence cognition (e.g., learning information for an exam is easier with more extensive prior knowledge), and the impact of strategies (e.g., rehearsal) on cognition. Metacognitive experiences refer to instances where one is consciously evaluating cognition. For example, determining whether you are prepared for an exam is an example of a metacognitive experience because you are assessing the quality of your knowledge in order to determine whether to feel confident or anxious about the impending exam. Goals and strategies can each be either cognitive or metacognitive. Considering the examination example, a cognitive goal is to obtain knowledge about a subject in order to pass the exam whereas a metacognitive goal is to assess your understanding of the concepts. A cognitive strategy improves progress toward the goal (e.g., making flash cards) whereas a metacognitive strategy evaluates the progress is being made toward that goal (e.g., flipping through flashcards and identifying how well you know the information).

Flavell's (1979) theory of metacognition applies to a wide variety of cognitive abilities. Metacognition encompasses reflections about memory, decision making, reading and oral comprehension, attention, problem solving, affective processing, and social cognition (e.g., intention understanding). This list demonstrates that metacognition encompasses the ability to reflect upon personal cognitions (i.e., introspection) as well as the cognitions of others (i.e., mentalising). How introspection and mentalising are related remains a highly debated topic by researchers and philosophers (Carruthers, 2009; Frith & Happe, 1999; Nichols & Stich, 2003; Shanton & Goldman, 2010). Although some theorize that introspection and mentalising are two forms of one metacognitive ability (Frith & Happe, 1999), others contend introspection and mentalising are independent abilities (Nichols & Stich, 2003). Additional views suggest that the understanding of the self and others are closely related abilities. For example, Shanton and Goldman (2010) argue that mentalising arises from simulation of internal mental states, whereas Carruthers (2009) proposes that mentalising, which is used to understand how others are thinking, is used to understand personal cognitions. Because the goal of this review is to examine the development of metacognition, and, in particular introspection about memories, further discussion of these theories is beyond the scope of the current review. However, the multifaceted nature of metacognition has important implications for the development of metacognition because the subcomponents that comprise metacognition likely develop at varying rates.

Development of Metacognition

The current literature on the development of metacognition shows that although some metacognitive abilities emerge as early as infancy, development continues throughout the school-aged years. For this section I discuss metacognitive abilities chronologically. Overall, evidence in infancy and toddlerhood shows that children have an early understanding others' actions and desires. During the preschool years children's linguistic utterances provide us a window into their understanding of their own and others' cognitive abilities, which improve with age. During the school-aged years children demonstrate more advanced introspective and mentalising capacities such as greater metacognitive monitoring and perspective tasking abilities, respectively.

The earliest metacognitive ability demonstrated is infants' understanding the actions of others as intentional and goal-directed (for a review see Woodward, 2009). For example, Woodward (1998) habituated 6- and 9-month-old infants to an experimenter reaching toward an object. During the test phase the experimenter either reached toward a novel object positioned in the same location as the habituated object or toward the habituated object in a novel location. Both 6- and 9-month-old infants looked longer when the researcher reached toward the novel object. This finding suggests that infants metacognitively represented the intentions of the experimenter's reaching behavior and expected the experimenter to continue to reach for the same object.

At approximately 18 months of age infants display an understanding that desires and emotions of others are subjective and can differ from one's own

(Repacholi & Gopnik, 1997). For example, Rapacholi and Gopnik (1997) had 14- and 18-month-old infants observe an experimenter make an expression of disgust when eating goldfish crackers and an expression of happiness when eating broccoli. Then, the experimenter asked the child for a snack while pushing a tray containing both the goldfish crackers and broccoli. If children understood that emotions are subjective and that the experimenter's desire for broccoli may not match their own preference for the crackers, they should give the experimenter the broccoli. Eighteen-month-old children, but not 14-month-old children, showed this ability to reflect upon the experimenter's preference.

Children begin to describe their own emotional and cognitive states during the toddler and preschool years. During the latter half of the second year children begin to use words such as "happy", "sad", "scared", "mad", and "tired" to describe their emotional experiences (Bretherton, McNew, & Beeghly-Smith, 1981). During the third year children begin to use mental verbs such as "think" and "know" (see Bartsch & Wellman, 1995 for a review of the development of how children discuss the content of their and others' minds; Brown & Dunn, 1991). However, one study suggests that children's use of these mental terms does not imply complete understanding of them (Wellman & Johnson, 1979). Wellman and Johnson (1979) investigated 3- to 7-year-old children's understanding of the terms "remember" and "forget" by reading stories that varied a character's prior knowledge and current performance. Although both remembering and forgetting require prior knowledge (i.e., you can neither remember nor forget something you never learned), remembering is associated with retrieval success whereas forgetting is associated with retrieval failure. For example, one story children were read was about a child who visited a friend's house. He either observed which closet his coat was hung in or did not (i.e., leading to prior knowledge or not). Later, he went to retrieve his coat and looked either in the closet that did or did not house his coat (i.e., leading to performance success or not). Then, children were asked if the child remembered the location his coat was and if he forgot the location his coat was. Four-year-olds understood that retrieval success (i.e., choosing the correct closet) was necessary for remembering but only 5- and 7-year-old children understood that prior knowledge was also necessary for remembering and forgetting. These studies demonstrate how children's linguistic utterances can be useful measures of children's metacognitive awareness but that production does not necessarily reflect competency.

Children also begin to demonstrate more advanced understanding of other people's minds during the early childhood period. This ability has primarily been assessed by children's understanding of false beliefs. Three forms of false belief tasks are prevalently employed in the current literature, (a) location tasks, (b) content tasks, and (c) identity tasks. For example, during the Sally-Anne location task children see Sally place a doll in one location (e.g., under the bed) and leaves the room; Baron-Cohen, Leslie, & Frith, 1985). Then, Anne comes and moves the doll to another location (e.g., in the closet). To assess theory of mind, children are asked where Sally will look for the doll when she returns. If children are relying on theory of mind, they should report that Sally will search for the doll in the location she believes it to be in rather than the location where the doll has been moved. For content tasks, such as the Smarties task, children are shown a box that says "Smarties" and are asked what is inside (Hogrefe, Wimmer, & Perner, 1986). Then, they are shown that in reality that pencils, not Smarties, are contained within the box. Theory of mind is assessed by their ability to say that someone else will think there are Smarties, not pencils, inside of the box. Similarly, on the sponge-rock identity task children are shown an object that looks like a rock and asked what it is (Flavell, Flavell, & Green, 1983). Then, they are shown that it is actually a sponge. Theory of mind is assessed by their ability to say that another person thinks the object is a rock rather than a sponge. These tasks are all indicators of how well children are capable of reflecting upon mental content because the correct response requires that children use metacognition to think about how others would be thinking rather than relying on physical evidence or merely focusing on their own thoughts and knowledge. A meta-analysis of 178 studies showed that, across task variations, children begin to reliably perform theory of mind tasks after 44 months of age (Wellman, Cross, & Watson, 2001).

During middle childhood and adolescence introspection and mentalising capacities continue to be refined. For example, introspection improves through increased acknowledgement of thoughts as continuous and insuppressible (Flavell, Green, & Flavell, 1993, 1997, 2000; Flavell, Green, Flavell, Harris, & Astington, 1995), monitoring whether current knowledge is sufficient for task demands (Markman, 1977), awareness and use of strategies (e.g., Estes, 1998; Flavell, Friedrichs, & Hoyt, 1970), reading comprehension monitoring (Kolić-Vehovec, Bajšanski, & Zubković, 2010), and confidence-task accuracy correspondence (Weil et al., 2013). Mentalising also undergoes age-related change with older children demonstrating greater empathetic accuracy (i.e., accuracy in one's ability to infer the thoughts and emotions of others; Eisenberg, Murphy, & Shepard, 1997), understanding of second-order mental states (e.g., Sarah thinks that Matt knows; Perner & Wimmer, 1985), perspective taking (for a review of the neural development of perspective taking see Crone & Dahl, 2012), and sarcasm comprehension (e.g., Glenwright & Pexman, 2010).

These findings collectively demonstrate that the many facets of metacognition undergo a prolonged developmental trajectory. However, it is also important to note that metacognitive abilities are not flawless even in adults. Adults frequently misinterpret the cues of others, fail to engage in efficient study behaviors, and are unaware of strategies they use to solve problems. Flavell (1979, p. 910) acknowledged this failure when he noted that "I am absolutely convinced that there is, overall, far too little rather than enough or too much cognitive monitoring in this world. This is true for adults as well as children, but it is especially true for children."

Development of Metamemory

Four decades ago Flavell asked the question "what is memory development the development of (1971, p. 272)?" His response was that memory development is primarily the development of metamemory, the "intelligent structuring and storage of input, of intelligent search and retrieval operations, and of intelligent monitoring and knowledge of these storage and retrieval operations" (Flavell, 1971, p. 277). The focus of this section is on the development of metamemory from early childhood throughout adulthood. First, I review evidence regarding children's knowledge about memory. For example, what do children know about memory properties (e.g., it is possible to remember something now and forget it later as well as forget something now you will remember later), differences in memory ability across individuals, the influence of task demands on memory performance (e.g., it is easier to remember a shorter versus a longer list of items), and the efficacy of various memorization strategies? Then, because strategy knowledge is not synonymous with strategy use, I discuss the effective use of memorization strategies across development. I next describe children's ability to reflect upon the contents of their memories and, when evidence is available, use that introspection to control their behavior. For example, I consider how well children's judgments about confidence align with encoding experiences and whether these judgments influence trial skipping and subjective judgments of memory. I conclude by discussing, based on the literature reviewed, how reliable children may be at performing introspective memory tasks, such as the remember/know task, which are widely utilized to examine the subjective state of remembering in adults. This question is of importance because, if children can reliably perform these types of tasks, great advances may be made toward understanding the lifespan development of memory as well as the role of subjective remembering in the development of the self, understanding of others, processing of previously experienced events, and future imagination (e.g., Buckner & Carroll, 2007; Rajaram & Roediger, 1997; Schacter et al., 2007).

Knowledge about Metamemory

Metacognitive knowledge refers to children's understanding of factors that influence memory. Although not widely discussed, most researchers are in agreement that this knowledge is acquired through children's personal experiences with memory (i.e., although it is possible that very young children's knowledge may not benefit from such experiences; Flavell, 1979; Karably & Zabrucky, 2009; Moynahan, 1973). Some support for this notion comes from a study finding that children who performed a categorization memory task prior to predicting the effect of categorization on memory were more likely to say that categorization improves memory than children who performed the prediction task first (Moynahan, 1973). However, it is also possible that children's knowledge about memory could come from other people. For example, children could learn that the period of time between encoding and retrieval influences retrieval probability from parents making statements such as "Take your truck to your room right now. If you wait, you might forget." Many of the studies below focus not on how metamemory knowledge is acquired but rather the content of that knowledge. Three categories of metamemory knowledge are discussed: person-oriented, task-oriented, and strategy-oriented.

Person-oriented metamemory knowledge. Person-oriented metacognitive knowledge includes information about attributes internal to individuals that influence memory performance. The domain of person-oriented metacognitive knowledge can be further separated into factors that influence memory within an individual person (i.e., intra-individual differences), differences across individuals (i.e., inter-individual differences), and general properties of memory

Intra-individual differences. Research on children's understanding of intra-individual factors suggests that children develop an understanding that emotions, attentional states, and goals influence memory early in development. Preschool-aged children have been shown to understand that some emotions and mood states influence memory (Hayes, Scott, Chemelski, & Johnson, 1987). Three- to 5-year-old children expected that they and others would remember more information when happy versus sad and when alert versus tired (Hayes et al., 1987). However, they did not predict differences in memory performance when someone was fearful versus calm. Whereas even kindergarteners knew that someone is more likely to remember information if inherently interested in it, they did not understand that cognitive goals and attention would influence memory performance until 2nd grade (Miller & Weiss, 1982). Kindergarten, 2nd grade, 5th grade, and adult participants expected people to be more likely to remember information when their interest is high than when it is low (Miller & Weiss, 1982). However, only 2nd graders, 5th graders, and adults recognized that attentiveness (i.e., the degree to which thoughts were focused on the task versus the room contents) and goals (i.e., the degree to which the child's goal is to complete the memory task versus listen to what is occurring in the next room) influence subsequent memory performance.

Inter-individual differences. Studies on inter-individual differences have examined children's understanding of relevant (i.e., age, individual differences) and irrelevant (e.g., clothing) factors. The most widely investigated inter-individual factor is age (Kreutzer, Leonard, Flavell, & Hagen, 1975; Miller & Weiss, 1982; Schneider & Pressley, 1997; Wellman, 1977b; Yussen & Bird, 1979). Collectively, these studies show that whereas preschool children do not understand that older people are more likely to remember information, school-aged children do, with the ability becoming more reliable between 4 and 6 years of age. For example, whereas in one study only 33% of 4-year-old children indicated that age would influence memory performance (Schneider & Pressley, 1997), other studies showed the majority of 5-year-olds and kindergarteners considered age as an important indicator of memory (Miller & Weiss, 1982; Wellman, 1977b). Furthermore, children’s explanations about memory suggest that they are aware that age influences memory and that overall memory accuracy across individuals differs (e.g., one child stated “Sometimes I remember better than them and sometimes they remember better than I–I’ve got one older friend and that’s all–he’d probably remember more than me” and another said “Well, some of my friends would get about all of them, some of them wouldn’t get any, and some would get about the same as me”; Kreutzer et al., 1975, p. 6).

As important as it is for children to understand factors that do influence memory performance, it is equally important for them to acknowledge factors that are unrelated to memory. Knowledge of irrelevant inter-individual factors has predominantly been studied in 3- to 5-year-old children (Hayes et al., 1987; see Schneider & Pressley, 1997 for a discussion of Munich Longitudinal Study findings; Wellman, 1977b). These studies show that with age children are less likely to endorse weight (Hayes et al., 1987; Wellman, 1977b), hair color (Schneider & Pressley, 1997; Wellman 1977), and clothing (Wellman, 1977b) as factors that influence memory performance. In summary, throughout early childhood there is a significant increase in children’s ability to acknowledge valid and ignore irrelevant sources of inter-individual differences in memory performance.

General knowledge about memory. As children utilize their memory capacities and observe other’s engaging in memory-related activities, they gradually acquire general knowledge about the form and function of memory. For example, Flavell (1979) argued that children “learn that there are various degrees and kinds of understanding (attending, remembering, communicating, problem solving, etc.). You may not understand some person or thing you hear, see, or read about if you do not attend closely, and also, sometimes, even if you do attend closely" (p. 907). Flavell's contemporaries and successors agreed that children's understanding of memory is an interesting research topic and have investigated children's understanding of remembering, forgetting, and memory errors. As such, the focus of this section is on children's developing knowledge about different memory states, principles of memory, and memory errors.

Differentiating memory states. During their third year children begin to use terms related to memory such as "remember" and "forget" (Limber, 1973). Four-year-old children appropriately understand the term "forget" refers to an absence of memory (Macnamara, Baker, & Olson, 1976). Macnamara and colleagues (1976) showed that 4-year-old children expected a friend in a narrative to be disappointed when her friend "forgot" to bring a toy along with her. Further, children expected that if she "forgot" the toy it would not be with her. Despite this early understanding, more complete knowledge of the meaning of the terms "remember" and "forget" is not obtained until the elementary school years. For example, Wellman and Johnson (1979) found that children did not fully appreciate that prior knowledge is necessary for the use of the terms "remember" and "forget" until they were 5- to 7-years-old (e.g., John did not know that his dad went to the grocery store he could neither remember nor forget that his father was there).

Throughout early childhood school children also develop an understanding of the terms "know" and "guess." Evidence suggests that children go through four stages of development when learning the difference between "know" and "guess" (Johnson & Wellman, 1980; Miscione, Marvin, O'Brien, & Greenberg, 1978). Initially children do not conceptualize the difference between these terms. Following this stage children focus on the outcome of the action to determine whether the appropriate mental state is "know" or "guess" (i.e., if correct, they "knew" the response but if incorrect it was a "guess"). Then, children intermittently use the term guess accurately, and, eventually, demonstrate an adult-like understanding of their meaning (Johnson & Wellman, 1980; Miscione et al., 1978). Miscione and colleagues (1978) found substantial variability within age groups in the category of responses shown by 3- to 7-year-old children. However, an overall pattern of age-related improvements emerged.

A more recent study by Cherney (2003) showed that children's use of mental terms increasingly corresponds to their mental states. For example, 3- and 5-year-old children participated in a play-like task during which they had to assist an experimenter place animals back into their respective cages. Children's utterances of mental terms and accuracy for animal-cage placement were coded for a match between the mental state and objective memory performance. For example, the use of the term "know" and accurate cage placement as well as "forget" and inaccurate cage placement would each be coded as a match. The results showed age-related increases in performance matching with 45% of the 3-year-olds and 75% of the 5-year-olds demonstrating matching responses. These studies show that with age children increasingly understand the meaning of mental terms and apply them to their own behavior.

Principles of memory. In addition to an increased understanding and application of mental terms, the metamemory literature shows that children increasingly understand the processes of forgetting and conditions that facilitate learning. During the elementary school years children increasingly acknowledge that they can be forgetful and that they are more likely over time to remember gist (i.e., conceptually-consistent) versus verbatim (i.e., precise) information (Kreutzer et al., 1975). For example, after first hearing the story of *Little Red Riding Hood* children may remember that she explicitly comments on the size of her grandmother's ears, eyes, and hands. However, with time, they may forget that verbatim information and rather remember that she comments on the size of her grandmother's physical features. Children also know that it is easier for someone who has been exposed to information previously to re-learn it than it is for someone who is first being introduced. With age, children are better able to explain why this occurs (e.g., one child stated "because as soon as he heard the names, they would probably all come back to him; Kreutzer et al., 1975, p. 9)"

Memory errors. Children's understanding of two forms of memory errors, interference and suggestibility, develops during the elementary school years. Retroactive interference refers to novel information disrupting the maintenance of previously acquired information. For example, remembering the names of students from previous semesters is more difficult when a new semester begins. Proactive interference refers to prior information making it more challenging to learn present information. For example, one semester I had a hard time learning a student's name because she resembled an acquaintance of mine from college. Children's understanding of interference has been assessed by their responses to question about narratives (Kreutzer et al., 1975; O'Sullivan, Howe, & Marche, 1996). In one study preschoolers, 1^{st} graders, and 3^{rd} graders were read stories about children who went to a party and then had a friend come over to play (O'Sullivan et al., 1996). The 1^{st} and 3^{rd} graders but not the preschoolers expected the child to misremember the friend who came over to play as attending the birthday party. On a slightly more complex task, Kretuzer and colleagues (1975) demonstrated that that 3^{rd} and 5^{th} grade children but not kindergarten or 1^{st} grade children expected someone to experience retroactive interference. Children were asked whether a child who met 15 children at two events would have better or worse memory for the names of the children than a child who met 8 children at one event and went home. Only 3^{rd} and 5^{th} graders expected poorer memory in the child who learned more names at two events. To my knowledge no studies have investigated children's understanding of proactive interference.

Suggestibility refers to memory errors that are caused by information being introduced by a third party. Developmental research shows that children's awareness of suggestibility shows significant development during middle childhood (London, Bruck, Poole, & Melnyk, 2011; O'Sullivan et al., 1996). During a narrative task 3^{rd} graders but not preschoolers or 1^{st} graders expected a child's memory to be impacted by the mother having a false memory of the event (O'Sullivan et al., 1996). More recently, London and colleagues (2011) showed video clips of a child interacting with a fireman and his babysitter to 6- to 13-year-old children. During the video the fireman, who had previously left his hat with Jamie, returned to retrieve his hat while Jamie was playing with it. Later, participants saw Jamie talking to an interviewer who repeatedly asked whether the fireman had hit Jamie and his babysitter. Then, Jamie tells his mother that he was hit by the fireman. Understanding of suggestibility was assessed by asking participants "Why did Jamie tell the first adult that there was no hitting but then told the second adult that there was hitting (London et al., 2011, p. 150)?" The results showed significant and gradual age-related improvement in children's ability to identify suggestibility as the source of the error between 6 and 13 years of age with older participants showing performance at ceiling levels.

In conclusion, research shows that children's metamemory knowledge about person-oriented information undergoes significant development during childhood for the domains of intra-individual differences, inter-individual differences, and general knowledge about the function of memory. Most studies show substantial age-related differences in metamemory knowledge about person-oriented variables between 3 and 8 years of age. Next, I consider the development of understanding of task-related factors that can influence memory performance.

Task-oriented metamemory knowledge. Task-oriented metamemory knowledge refers to one's understanding of features of the encoding episode, retrieval conditions, or characteristics of the to-be-remembered information that influence subsequent retrieval. Multiple studies have examined the development of children's understanding of how these factors influence memory performance. These investigations collectively suggest that although children understand some task factors that influence memory relatively early in development understanding of other factors follows a more prolonged developmental trajectory.

Encoding conditions. Researchers have examined whether children understand the influence of three encoding conditions on memory performance: environmental distractions, study time, and contextualization. Within the domain of task-oriented metamemory knowledge, one of the first pieces of knowledge that children acquire is that memory encoding is compromised when information is learned in a noisy environment (Hayes et al., 1987; Miller & Weiss, 1982; Wellman, 1977b; Yussen & Bird, 1979). For example, Hayes and colleagues (1987) found that even 3- to 5-year-old children expected people to remember more when they were in a quiet versus a noisy room. Similarly, young children also understand that studying items for a longer period of time improves memory performance (Kreutzer et al., 1975; Yussen & Bird, 1979). Understanding of study duration as a factor that influences memory increases between 4 and 6 years of age (Yussen & Bird, 1979) but remains stable throughout the elementary school years (Kreutzer et al., 1975). Children also develop an understanding that information is more easily encoded when it is contextualized (Kreutzer et al., 1975). For example, 3rd and 5th graders were more likely than kindergarten and 1st graders to indicate that learning words within the context of a story would be easier than memorizing a list of words.

Retrieval conditions. Children also acquire an understanding that the duration of time between encoding and retrieval influences memory performance (Kreutzer et al., 1975; Lyon & Flavell, 1993). Lyon and Flavell (1993) asked 3- and 4-year-old children (a) whether characters who waited shorter versus longer periods of time between encoding and retrieval would be more likely to remember an object's location and (b) whether an object that was encountered a shorter or longer period of time ago would be more likely to be forgotten. Only 4-year-old children expected characters who viewed objects a longer time ago to have poorer memory for the object's location and for objects viewed longer ago to be forgotten while those viewed sooner ago remembered. Similarly, Kreutzer and colleagues (1975) demonstrated that, although the majority of kindergarten through 5th grade students indicated that a memorized phone number needed should be used immediately rather than after a delay, the frequency of this response increased with age.

Features of to-be-remembered items. In addition to children developing an understanding about factors that influence encoding and retrieval processes, children also learn that features of the to-be-remembered information influences memorability. During the preschool years children increasingly learn that it is more challenging to remember a larger number of items (Hayes et al., 1987; Wellman, 1977b; Yussen & Bird, 1979). Furthermore, some information is more easily recalled than other information. For example, 3rd but not 1st graders understand that details central to a story (e.g., Little Red Riding Hood's grandmother was replaced by a wolf) are more likely to be recalled than peripheral details (e.g., her grandmother was wearing a blue dress; O'Sullivan et al., 1996). Similarly, 3rd and 5th grade students but not 1st grade students understand that opposite pairs (e.g., boy-girl) are more easily recalled than arbitrarily associated pairs (e.g., Mary-walks) and that categorized information is easier to remember than non-categorized information (Kreutzer et al., 1975; Moynahan, 1973).

Recency, saliency, and plausibility also influence the memorability of events (Friedman, 2007; Ghetti & Alexander, 2004; Ghetti, Castelli, & Lyons, 2010). Ghetti and Alexander (2004) showed that children as young as 5-years-old expected events high in saliency (e.g., visiting the Grand Canyon) to be more memorable than events low in saliency (e.g., taking a craft class during the summer). However, only 9-year-olds and adults expected heightened memory for recent and low-plausible (e.g., meeting your favorite celebrity) events. Friedman (2007) recently provided additional evidence for the prolonged developmental trajectory of metamemory for temporal scale. Kindergarteners, in contrast to 2nd graders, 4th graders, 6th graders, and adults, failed to expect a decrement in memory for the time of day, day of the week, and month an event occurred. These results collectively suggest that although preschool-aged children have an elementary understanding of task-related factors that influence memory performance, their understanding of some of these elements (i.e., recency) continues to develop throughout middle childhood.

Strategy-oriented metamemory knowledge. The third component of metacognitive knowledge discussed by Flavell (1979) was knowledge about which strategies were optimal for meeting cognitive goals. This body of work began in the 1970s but was widely expanded during the 1980s by developmental and educational psychologists. Overall, children demonstrate age-related differences in (a) identifying which strategy they used to solve a task, (b) understanding why particular strategies are beneficial and (c) recognizing the most optimal strategy.

Strategy identification.Older children are more likely than younger children to state that they used a strategy while performing a task (Mathews & Fozard, 1970). For example, Mathews and Fozzard (1970) found that 25%, 56%, and 95% of 5-, 7-, and 12-year-old children, respectively, reported using a strategy to solve a temporal memory task. This pattern may either emerge either because younger children are not employing strategies or because they do not have metacognitive access to which strategies they used. A study by Bjorkland and Zeman (1982) suggests the latter. This study found that task performance suggested that 1^{st}, 3^{rd}, and 5^{th} graders' all used a clustering strategy to remember the names of children in their class (e.g., by sex). However, 5^{th} graders were significantly more likely to metacognitively identify this as the strategy used to recall names than the younger children (Bjorklund & Zeman, 1982).

Understanding why strategies are effective. With age children also have more accurate expectations of strategy effectiveness and better explanations for why strategies are effective (Miller & Weiss, 1982; Moynahan, 1973). For instance, when 1^{st}, 3^{rd}, and 5^{th} graders were asked "Why is it easier to remember things when there are all the same kinds of things together? (Moynahan, 1973, p. 240)", 1^{st} graders were less capable of providing comprehensive explanations than 5^{th} graders. A typical 1^{st} grader's response was non-specific (e.g., "It was easier to say") whereas a 5^{th} grader's response specifically referenced categories or associations as strengthening memory traces and aiding recall (e.g., "Because you can remember what group they are in, and it's easier to figure out what it is, like if you remember that it was a group of animals you wouldn't say kitchen sink"; Moynahan, 1973, p. 243-244).

Similarly, age-related differences are present in children's ability to understand components of strategies that improve performance. For example, leaving a reminder is potentially a good strategy for remembering to perform an act in the future (e.g., setting a timer to remind yourself to take the cookies out of the oven) or the location of an object (e.g., drawing a map to remember where you hid items for a scavenger hunt). However, if your reminder is insufficient (e.g., you wrote yourself a note saying “do something at 12pm” or a map without landmarks), you will burn your cookies and fail to find all of your hidden items during the scavenger hunt. Whereas kindergarten and 1st grade children acknowledged that cues should be related to the to-be-remembered information, visible, and available, 3rd grade children noted that they must also be unambiguous and noticeable, and only adults required that cues be sufficiently detailed (Beal, 1985).

Identifying the optimal strategy. In addition to understanding why strategies are effective, children must learn to prefer the most efficient strategy and determine which strategies are optimal for different tasks. Research suggests that this ability emerges later in the elementary school years and continues to develop into adolescence (Kreutzer et al., 1975; Lovett & Flavell, 1990; Schneider, 1986; Waters, 1982). Children initially demonstrate wide inter-individual variability in strategy preference but with age children converge to favor the optimal strategy. For example, Kreutzer and colleagues (1975) showed children cards that could be sorted into three categories (i.e., body parts, foods, and articles of clothing) and asked them what strategy they would use in order to remember the items. Responses were split into the following strategy categories: Categorization, Association, Rehearsal, External Storage, Looking, Random Rearrangement, and No Strategy. Whereas kindergarteners differed widely in their responses with association being the most common response (e.g., “a sock goes on your foot”, Kreutzer et al., 1975, p. 21), 72% of the 5th graders favored categorization. Simlarly, Schneider (1986) found that 4th graders' strategy preferences of are more similar to adults than are 2nd graders'. Demonstrating the prolonged developmental trajectory of optimal strategy selection, Waters (1982) found differences in strategy use between 8th and 10th graders. These studies demonstrate children's selection of strategies for a given task. However, different strategies are required for different cognitive tasks. For example, whereas rehearsal is a good strategy for preparing for a memory task, definition learning would be more beneficial than rehearsal for a reading comprehension task. Toward the end of elementary school, children begin to understand this principle. Third graders and adults are better at selecting strategies that would be useful for performing memory and comprehension tasks than 1st graders (Lovett & Flavell, 1990).

In conclusion, throughout the elementary school years children's knowledge about the impact of strategies on memory substantially increases. They are better able to identify strategies that they used to complete a task, describe these strategies in detail, and understand the effectiveness of strategies in a variety of situations. Because metamemory knowledge may precede or follow the children's application of strategies, the next section focuses on how efficiently children apply of strategies to complete memory tasks.

Employment of strategies to improve memory

Studies that have been conducted to assess children's application of strategies to improve memory performance show that (a) early in childhood children begin using strategies, (b) age-related differences are present in children's use of strategies and their ability to learn strategies from others, and (c) some of these age-related improvements in strategy application are due to abilities other than metamemory.

Multiple studies show that even young children apply some basic strategies to improve their memory performance. Elementary school children alter study behavior based on item relatedness (Dufrense & Kobasigawa, 1989), item familiarity (Kobasigawa & Metcalf-Haggert, 1993), and degree of prior learning (Masur, McIntyre, & Flavell, 1973). Specifically, children spend a longer period of time studying unrelated items than related items, unfamiliar than familiar items, and poorly-learned items than well-learned items. Children also differ their study duration based on task demands (Geis & Lange, 1976; Salatas & Flavell, 1976). For example, 1st grade children engage in increased categorization when told to “remember” versus “look” at items (Salatas & Flavell, 1976). Furthermore, they can use metacognitive knowledge about strategy effectiveness to influence their own behavior. Preschoolers both *state* that someone who is alert is better able to remember information than someone who is tired and *apply* this knowledge to their own behavior by delaying studying when tired (Hayes et al., 1987). To assess whether children would modulate their own behavior, one study had 3- to 5-year-old participate in feeding the class pigeon (Hayes et al., 1987). Prior to feeding the pigeon, children either engaged in high or low fatiguing activities. Children in the high-fatigue condition climbed four flights of stairs and carried a full bucket whereas children in the low-fatigue condition carried an empty bucket and helped clean the pigeon’s cage. Then, all children were asked if they would like to learn the rules for a new game now or later. Children in the high-fatigue conditions were significantly more likely to delay their learning.

Thus, children were capable of stating that someone who is tired is more likely to perform worse on a memory task than someone who is alert and deciding to delay their own learning when they are tired. This finding could be explained in at least two ways: a) children's metacognitive evaluation of their mental state led to their decision to delay learning or b) when children are tired, they delay learning.

Multiple age-related differences are present in the spontaneous application of strategies to improve memory performance. Older children are more likely to engage in the following behaviors than younger children: planful encoding (e.g., associating studied stimuli with related cues; Eskritt & Lee, 2002; Ritter, 1978; Schneider & Sodian, 1988), elaborative encoding (e.g., naming or contextualizing information "I put the dancer into the house with the comb because she needs to comb her hair very often"; Baker-Ward, Ornstein, & Holden, 1984; Schneider & Sodian, 1988, p. 217; Waters, 1982), and prolonged encoding of challenging versus easily acquired information (Dufresne & Kobasigawa, 1989; Lockl & Schneider, 2004). Waters (1982) demonstrated that the use of elaborative strategies continues to increase during adolescence with 8th graders less frequently employing elaboration than 10th graders. Furthermore, even when 8th graders utilized the elaborative strategy they were less efficient than 10th graders remembering 44% of the word pairs in comparison to the 61% remembered by 10th graders.

Although some increase in strategy use may be attributed to age-related improvements in metamemory, developmental improvements in general knowledge and working memory also contribute to increased memory performance. For example, Eskritt and McLeon (2008) recently investigated children's note taking abilities.

Older children's notes were more beneficial for task performance because they were better able to identify the important information while studying in comparison to younger children. Similarly, whereas 2nd graders were more likely to categorize strongly related items, 4th graders were equally as likely to categorize items that were strongly or weakly associated (Schneider, 1986).

In summary, children's knowledge about person, task, and strategy-oriented variables that influence memory emerges during the preschool years and develops significantly during the elementary school years. Generally, knowledge about and utilization of efficient strategies shows the longest developmental trajectory extending well into adolescence. Researchers speculate that children predominantly acquire metamemory knowledge by introspecting upon their own memory experiences memory (Flavell, 1979; Karably & Zabrucky, 2009; Moynahan, 1973). In order for this to be true, children must be able to accurately introspect about the contents of their memory. Thus, I turn my focus to the current literature on children's memory introspection.

Memory introspection

Whereas the majority of studies on metacognitive knowledge were conducted in the 1970s and 1980s, current research has focused on the development of memory introspection (e.g., for reviews see Ghetti, Hembacher, & Coughlin, 2013; Perner et al., 2007). This shift is related to a number of factors including interests in (a) using methods that bridge developmental and adult work (e.g., Ghetti & Angelini, 2008), (b) investigating how well children metacognitively control their behaviors (e.g., are children more likely to seek additional information when uncertain about the correct answer? Ghetti et al., 2013), and (c) determining the developmental trajectory of autobiographical remembering (i.e., the subjective state associating personal experience with retrieved memories; Perner et al., 2007).

Multiple bodies of work have assessed children's abilities to predict and introspect about the contents of their memory. I begin this section by describing studies investigating children's predictions of memory performance. Children are overall pretty poor at predicting future memory performance, particularly memory recall. However, children are much better at making introspective judgments about memory performance including judgments of learning (i.e., particularly when these judgments are delayed), feelings of knowing, and confidence ratings. I conclude by describing two studies that have empirically examined whether children are capable of reliably performing the remember/know task.

Memory predictions. Young children are notorious for overestimating their cognitive abilities (for review see Bjorklund, Periss, & Causey, 2009), and many systematic laboratory investigations have assessed children's ability to predict subsequent memory performance. Whereas no age-related improvements are present in predicting recognition performance across the elementary school years (Yussen & Berman, 1981), age-related differences are present in children's prediction of memory recall (Flavell et al., 1970; Lipko, Dunlosky, & Merriman, 2009). Children's overestimations of subsequent recall are present regardless of whether they are predicting their own behavior or the behavior of someone else and persist even after experiencing poor performance (Lipko et al., 2009). For example, Lipko and colleagues (2009) showed 4- and 5-year-old children 10 magnets and asked them how many they would subsequently be able to recall. Children consistently over predicted the number they would remember as well as how many another person would remember. Furthermore, even though children were relatively accurate at assessing how they performed on previous trials, across trials they continued to over predict the number of items they were capable of remembering. However, with age, children become more accurate at predicting the number of items they would subsequently recall (Flavell et al., 1970; Yussen & Berman, 1981).

Younger children's poor performance on prediction tasks could be due to a number of factors. First, overestimation could be due to a lack of metamemory experiences upon which to base the prediction. As argued by Kail (1990), children's propensity to overestimate memory performance could also be due to a lack of knowledge about factors that influence memory (i.e., such as person, task, or strategy variables discussed above). Another possibility is that even when children have experience with memory tasks and knowledge about factors that influence memory, they might not apply that knowledge to predict future performance.

Some researchers have speculated that skill overestimation may actually be beneficial early in development. For example, overestimation may facilitate ability acquisition by leading children to persist at challenging tasks (e.g., Bjorklund & Green, 1992; Bjorklund et al., 2009). For example, kindergarten to fifth grade children who showed the most skill overestimation performed better on a recall task across trials than children who more accurately judged their skills (Shin, Bjorklund, & Beck, 2007). However, it is also possible to view overestimation as a potential handicap. For example, consider two children who initially have similar amounts of knowledge about a subject. If one of them overestimates his knowledge and spends less time studying for a test whereas the other more accurately estimates his knowledge and spends more time studying, the latter will likely perform remember more content information the day of the test. Therefore, overestimation may be viewed either positively or negatively depending on the particular stage of development and task of interest.

Judgments of learning.A similar line of work has investigated children's judgments about how well they have learned material. Judgments of learning (JOLs) are obtained shortly after the encoding episode and require participants to reflect upon how likely they are to subsequently remember learned information. Developmental research suggests that, although age-related differences are present in the accuracy of JOLs, children as young as preschool-aged are capable of reflecting upon the contents of their memory and use the many of the same cues as adults when making JOLs (Flavell et al., 1970; Koriat, Ackerman, Lockl, & Schneider, 2009; Koriat & Shitzer-Reichert, 2002; Lipowski, Merriman, & Dunlosky, 2013; Roebers, von der Linden, Schneider, & Howie, 2007; Schneider, Visé, Lockl, & Nelson, 2000).

The earliest study of children's ability to judge how well they learned information was conducted by Flavell and his colleagues (1970). Experimenters asked preschool through 4th grade children to learn three sets of pictures until they were capable of remembering them all. The researchers found improvements in children's ability to accurately judge their learning. Whereas all 4th graders remembered all of the pictures for two or three of the sets, 78% of preschoolers and 50% of kindergarteners failed to completely recall any of the sets or only correctly recalled all items for one set. Although this study suggests age-related differences in JOLs, it is not clear why this result emerged. Differences between older and young children could have occurred because older children (a) are better at recall tasks, (b) more adequately evaluate the accuracy of their memories, (c) better understand the influence of study behavior on memory performance, or (d) are more motivated to study items in accordance with the experimenter's instructions. More recent studies have focused on assessing whether factors that influence JOLs in adults also do so in children.

Studies show that children's JOLs are affected by the duration of time that has elapsed since encoding, item repetition, the content of the information, and the amount of time participants study items (Koriat & Shitzer-Reichert, 2002; Koriat et al., 2009; Lipowski et al., 2013; Roebers et al., 2007; Schneider et al., 2000). Research in adults shows that JOLs more accurately predict performance when they are taken following a delay rather when they immediately follow encoding (Nelson & Dunlosky, 1991). Specifically, the gamma correlation (i.e., which ranges from -1.0 to 1.0 with 1.0 reflecting perfect correspondence between JOLs and memory performance) between JOLs and memory recall increases from .38 for immediate JOLs to .90 for delayed JOLs. Correspondence between immediate JOLs and recall performance is hypothesized to be lower because participants are initially over-confident in their ability to subsequently remember items. JOLs made directly after the item is encoded are affected by representations of the item in both short-term and long-term memory. In contrast, if JOLs are made after a delay, the short-term memory trace is no longer available. Thus, the correspondence between delayed JOLs and recall performance is higher because both measures are based solely on long-term memory traces.

Two developmental studies have demonstrated that children's JOLs are also more accurate when obtained following a delay versus immediately after encoding (i.e., the delayed-JOL effect; cf. Roebers et al., 2007; Lipowski et al., 2013; Schneider et al., 2000). The developmental assessment of JOLs began with Schneider and colleagues' (2000) assessment of school-aged children. Kindergarten, 2nd grade, and 4th grade students all demonstrated higher JOL-task performance correspondence when JOLs were obtained after a delay versus immediately after item encoding. Recently, Lipowski and colleagues (2013) assessed whether children as young as preschool-aged are capable of providing reliable JOLs. Preschool and 3rd grade children learned novel animal names and judged whether they would remember the names in the future. The number of children who expected to remember all of the animal names was larger when JOLs were made immediately after learning (i.e., 24 out of 29 preschoolers) than when they were made after a delay (i.e., 14 preschoolers). The gamma correlation for delayed JOLs and animal name recall was .42 for preschoolers and .96 for 3rd graders. The researchers argued that, although preschoolers' correlation was not significantly above zero, it was sufficiently high enough to suggest that even preschoolers can provide reliable assessments of their learning when these judgments are delayed.

In contrast to the studies just described, Roebers and colleagues (2007) failed to find differences in relations between JOLs and task performance when JOLs were obtained immediately after encoding compared to when they followed a delay. For this study, 8-year-olds, 10-year-olds, and adults watched a video. Either immediately after the video (i.e., immediate JOL condition) or the next day (i.e., delayed JOL condition) they were asked whether they would subsequently remember specific details about the video (e.g., "When the children come into the kitchen, what is the mother doing?" Roebers et al., 2007, p. 121). The delayed-JOL effect was likely not found in this study due to the timing of when the JOLs were acquired. Immediate JOLs were obtained after the entire video was watched. In the studies that found the delayed-JOL effect in children (i.e., Lipowski et al., 2013; Schneider et al., 2000) immediate JOLs were taken after each item was encoded whereas delayed JOLs were taken after all items had been encoded. Thus, the timing of the immediate JOLs in the study by Roebers and colleagues (2007) was similar to the delayed JOLs in the previous developmental studies (Lipowski et al., 2013; Schneider et al., 2000). This explanation is consistent with Nelson and Dunlosky's (1991) theory that immediate JOLs are overconfident because they rely on representations from long and short-term memory whereas delayed JOLs are more accurate because they merely rely on long-term memory. In the study by Roebers and colleagues (2007) the items would no longer have been active in short-term memory when participants made judgments after watching the entire movie.

One study demonstrated that children's JOLs are sensitive to item repetition (Koriat & Shitzer-Reichert, 2002). Researchers presented 2nd and 4th grade students with four repetitions of word pairs. Following the presentation of each word pair, children provided a JOL on a 5-point scale ranging from the child having "no chance to recall the response word" to "completely certain to recall the response word

(Koriat & Shitzer-Reichert, 2002, p. 7)." Both 2nd and 4th graders provided more confident JOLs across item repetitions. Furthermore, 2nd and 4th graders both decreased their JOLs for hard items from the first to the second presentation. This finding strands in contrast to the study of memory prediction described above which showed that preschool children did not adjust their predictions of the number items they would subsequently recall with practice (Lipko et al., 2009). The difference in findings between these two studies may be explained by differences in methodology; in one case children were asked to predict future memory recall whereas in the other they were required to judge whether individual items would be subsequently remembered.

Characteristics of stimuli also influence how well they are learned, and two studies suggest that children's JOLs are influenced by this factor. First through 4th graders all provide higher JOLs for more easily remembered word pairs in contrast to harder word pairs (Koriat & Shitzer-Reichert, 2002; Lockl & Schneider, 2002). However, age-related differences in JOLs were present in Koriat and Shitzer-Reichert's (2002) study. During the first block, 2nd and 4th graders provided similar JOLs for easy word pairs. The JOLs provided by 2nd graders were higher than those of 4th graders for harder word pairs suggesting that their learning expectations were more overconfident.

Lastly, the amount of time an item needs to be studied can be used as an indicator of how likely that item will be remembered in the future (Koriat et al., 2009; Son & Metcalfe, 2000). Specifically, items that are studied for a shorter period of time are associated with greater ease of processing and are expected to be more readily remembered than items that must be studied for longer durations. Current research suggests that during the elementary school years children develop an understanding of this concept. Koriat and colleagues (2009) found that the longer 3rd to 6th grade students studied the lower their JOLs. In contrast, 1st and 2nd grade students' JOLs were not influenced by study duration.

Collectively, these studies show that school-aged children are able to judge how well they have learned information. Their JOLs reliably predict subsequent memory recall and are influenced by the factors of timing, repetition, and stimulus characteristics in the same way as adults. Similar to adults, children's JOLs were better when they were made after a delay. This may explain why when introspective reports are taken at retrieval (i.e., feeling-of-knowing judgments, confidence judgments, and the remember/know judgments), as outlined below, children are relatively accurate.

Feelings-of-knowing. Similar to memory predictions and JOLs, feeling-of-knowing (FOK) judgments are subjective assessments about whether information will be retrievable later. Typically, participants engage in a free-recall task and FOKs are obtained following a failed recall attempt by asking participants if they will later recognize the information they were not able to freely recall. For example, one study examined FOKs in young 4- and 5-year-old children by showing them faces of people who varied in familiarity (Cultice, Somerville, & Wellman, 1983). Researchers initially asked the child to try and recall each person's name. Then, for people whose names they could not recall, feelings of knowing were indexed by children's response to the following question: "If I told you a lot of names, do you think you would recognize this person's name?" (Cultice et al., 1983). Both 4- and 5-year-old children demonstrated an ability to monitor the content of their memories by reporting feeling of knowing judgments when they were capable of subsequently recognizing the person's name. This finding suggests that, similar to findings above, young children are capable of introspecting about the content of their memories.

Within the FOK literature there is considerable debate about whether age-related differences are present in this ability. Wellman's (1977a) initial study suggested that FOK accuracy continues to develop throughout the elementary years. Kindergarten, 1st, and 3rd grade students were asked the names of items depicted as line drawings. For items children could not name correctly, children were asked if they would be able to recognize the name if provided with a list of possible names. Wellman (1977a) found age-related increases in concordance between FOKs and recognition accuracy. Brown and Lawton (1977) also reported increased FOK accuracy with age in a sample of children with developmental disabilities.

However, other research has failed to find developmental differences in the accuracy of FOK reports (Butterfield, Nelson, & Peck, 1988; Lockl & Schneider, 2002). One reason for this discrepancy may the methods used to examine FOK judgments (Butterfield et al., 1988). Some researchers have argued that dichotomous FOK judgments (i.e., yes/no judgments regarding whether an item will be subsequently recognized) may not be appropriate for examining developmental change in monitoring abilities because age-related differences may be present in the threshold participants set for accepting an item as "known" (Butterfield, Nelson, & Peck, 1988; Lockl & Schneider, 2002). For example, younger participants could be more conservative stating they will not later "know" the item from a list although they will or they could more liberally claim to later recognize items they will not. For this reason Butterfield and colleagues (1988) used a relative FOK assessment (Nelson & Narens, 1980). Relative FOKs are obtained by asking participants which item out of two they are more likely to subsequently recognize. Then, items are ranked based on how likely they are to be remembered. Using this methodology two studies failed to detect age-related increases FOK accuracy (Butterfield et al., 1988; Lockl & Schneider, 2002). In fact, one of these studies found that the FOKs of 6-year-olds were more accurate than those of adults (Butterfield et al., 1988). Despite the disagreement in the literature about whether accuracy for FOK judgments increase with age, all studies show that even young children are capable of making these judgments.

Memory confidence.A number of recent studies have aimed at assessing the development of introspection by asking children to rate their confidence about their memory for individual items and their contextual details. Although age-related improvements are present in the correspondence between children's confidence ratings and response accuracy (Lyons & Ghetti, 2011, 2013), event 3- to 5-year-old children's dichotomous confidence judgments have been shown to differentiate items accurately versus inaccurately identified (Lyons & Ghetti, 2011). Furthermore, children's confidence ratings distinguish items based on how they were encoded (Ghetti et al., 2010). For example, Ghetti and colleagues (2010) had 7- to 9-year-old children enact, imagine, and confabulate (i.e., imagine performing plus describe image to experimenter) common and odd actions. When asked to identify actions they had actually performed and their confidence regarding whether they had performed that action, all children were more confident when rejecting novel actions than imagined and confabulated actions. Similarly, another study found that 4th, 6th, and 8th grade children were equally as confident about whether they correctly answered a multiple-choice question about a story (Schneider & Körkel, 1989).

In addition to being able to provide accurate confidence judgments, even preschool aged children use memory confidence to influence their behavior (Balcomb & Gerken, 2008). One study allowed 3.5-year-old children to skip trials on an associative memory task. Compared to when children were required to provide responses, their memory performance was higher when they were allowed to skip trials. Further, the amount of time taken to recall a response has been shown to be associated with confidence in 2nd, 3rd, and 5th graders, and this relation increases with age (Koriat & Ackerman, 2010). These findings collectively suggest that even preschool-aged children are capable of monitoring their memory confidence and use this monitoring capacity to influence their behavior.

However, some age-related change is present in children's confidence ratings. Roderer and Roebers (2010) argue that there is a developmental dissociation between certainty monitoring and uncertainty monitoring. Whereas both children and adults assign high confidence ratings to items they have accurate memory for, children assign higher confidence ratings than adults to items they inaccurately remembered (e.g., Roebers, 2002). Similarly, one study of lifespan development suggests age-related differences in uncertainty may occur during the development as well as the decline of memory (Shing, Werkle-Bergner, Li, & Lindenberger, 2009). Shing and colleagues (2009) collected confidence ratings while 10-12-year-olds, 13-15-year-olds, 20-25-year-olds, and 70-75-year-olds performed an associative memory task. Whereas 10-12-year-old children provided proportionally fewer “confident” responses for accurately remembered items, 70-75-year-old adults reported proportionally more “confident” trials for false alarms (i.e., incorrectly recognized novel items) compared to the three younger age groups.

Remember/know paradigm. Tulving’s (1985) remember/know paradigm is arguably the most widely utilized metacognitive measures in the adult literature on memory. The remember/know paradigm induces what Flavell (1979) referred to as a metacognitive experience (i.e., a conscious evaluation of cognition). Participants are explicitly asked to reflect on the content and quality of their memory states to determine whether an item is “remembered” along with contextual details or merely “known.” Tulving initially developed the remember/know paradigm to assess autonoetic consciousness, a state of consciousness associated with episodic memory. Specifically Tulving argued that autonoetic consciousness “is necessary for the remembering of personally experienced events. When a person remembers such an event, he is aware of the event as a veridical part of his own past existence (Tulving, 1985, p. 3).” Since the development of the remember/know paradigm, this methodology has been used in hundreds of behavioral and neural investigations of memory.

Beyond the use of the remember/know paradigm as a measure of metacognition, researchers have argued that it can be used to dissociate the processes of recollection and familiarity which underlie recognition memory (e.g., Yonelinas, 2002). Recollection refers to memory for specific contextual details whereas familiarity refers to the overall assessment of the memory strength. To date, the assessment of the development of these processes has predominantly relied on objective measures of contextual details as an index of recollection. The reason behind this trend is that many researchers question young children's ability to introspect onto their memory states (Brainerd et al., 2003; 2004; Ghetti et al., 2002). Brainerd and colleagues (2004) were concerned (a) young children would be unable to comprehend instructions differentiating remembered and familiar items, (b) modifying instructions to a child-appropriate reading level would make the tasks incomparable, and (c) that children may not use the instructions the same way as adults even if they were able to comprehend them. However, given the findings above suggesting that children are reliable at performing introspective tasks, researchers have begun to empirically investigate whether children are capable of performing the remember/know paradigm.

A recent study investigated age-related differences in the ability to use this distinction (Ghetti et al., 2011). Participants (i.e., 6-7-year-olds, 9-10-year-olds, 12-13-year-olds, and 17-18-year-olds) completed a memory paradigm that included subjective and objective measures of memory performance. The subjective measures were old/new confidence ratings and a modified version of the remember/know paradigm. Rather than using the terms "remember" and "know" the terms "remember" and "familiar" were used due to pilot testing showing that children were better able to understand the term "familiar" than "know." Objective measures of recollection included memory for the original item color and for which semantic judgment was made at encoding. Participants also completed a classification task to verify that they were capable of understanding the distinction between the terms "remember" and "familiar." During the classification task participants were presented with some statements that should be given a "remember" judgment (e.g., "I know I saw a giraffe because it was red"), and others that should be given a "familiar" judgment ("I know I saw a stapler but I can't remember what question I answered about it"). For each statement participants were asked which judgment the statement should receive. A number of findings suggested that even the youngest participants were able to understand and use the remember/familiar distinction. First, all participants reliably and accurately classified the statements, although children improved with age. Further gave higher confidence ratings to "remembered" than "familiar" items and were more likely to state that the item was remembered when they accurately remembered the color and semantic judgment made at encoding.

These findings were replicated and extended by Hembacher and Ghetti (2013). As in the previous study, children (6-7-year-olds, 9-10-year-olds) and adults both provided relatively more remember judgments when items were retrieved along with objective contextual details (i.e., color and a semantic judgment). In this study participants were also asked to place bets on trials when they were certain their memory was accurate. Participants were told that accurate performance would lead to a better prize or more course credit at the end of the study. Although the youngest age group appeared to reliably understand the distinction between remembered and familiar items, they were not more likely to bet on those items although 9-10-year-olds and adults were.

Collectively, the studies by Ghetti and colleagues (Ghetti et al., 2011; Hembacher & Ghetti, 2013) suggest that children as young as 6 years of age can reliably distinguish between memory states in order to perform the remember/know paradigm. However, younger children may not be using the distinction between recollection and familiarity to alter their behavior (i.e., as demonstrated by their failure to bet larger amounts on items they "remember"). This finding that children can reliably perform this task paves the way for future studies on the development of recollection and familiarity using the remember/know paradigm in children greater than 6 years of age.

Conclusion

The phenomenological experience of remembering is important for the role it plays in the continuity of the self, perception of others' perspectives, understanding of previously experienced events, and our ability to imagine the future (e.g., Buckner & Carroll, 2007; Rajaram & Roediger, 1997; Schacter, Addis, & Buckner, 2007). Assessments of remembering require participants to metacognitively introspect about the contents of their memories, an ability that developmental memory researchers, until recently, were highly skeptical of in children. The current literature suggests that during the elementary school years children develop a substantial knowledge base about their memory capabilities. For complex tasks, such as the identification and efficient utilization of memory strategies, development continues well into adolescence. Memory introspection tasks (i.e., judgments of learning, feelings of knowing, confidence ratings, and the remember/know paradigm) that require children to make metacognitive judgments about the quality of their memories have consistently shown that, although age-related differences are present in these abilities, children can reliably perform them at a young age (i.e., as young as 3 years of age). These findings pave the way for more advanced studies of the development of children's memories and the processes that underlie these changes (e.g., investigations of properties associated with recollection and familiarity across development). Future research aimed at investigating the neural bases of remembering and developmental origins of autobiographical remembering will have important implications for our understanding of memory and the phenomenon of infantile amnesia.

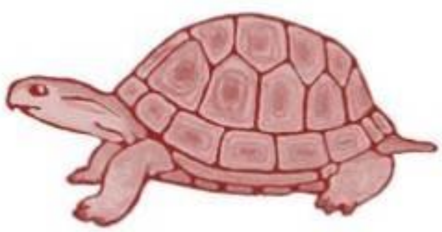
Appendix B

Sample Stimuli

Button

Motorcycle

Turtle



Giraffe

Appendix C

Remember/Familiar Classification Task

"*A group of children already looked at pictures like the ones you just saw. While they looked at drawings, they had to say what color the picture was, and say if the things in the drawings were living/not living or if they could fit inside of the box, the same as what you did.*

After that, we tested their memory for those drawings. We showed them the same drawings, but this time in black ink. They had to tell us if they had seen the drawings before, and what they remembered about them. For example, they could tell us the color of the picture, or the question we had asked them about it.

Now, I'm going to read you what the children said about the drawings. I want you to tell me if they remembered the drawings, or if they felt they were familiar. If the person could tell a detail about the drawing, that means it was remembered. If the person says she saw the drawing before, but can't tell any of the details about it, that means it's familiar.

Let's try with an example. One person said, "I know there was a dinosaur, because you asked me if it was living or not living." Is this a remember description or a familiar description?"

If the participant is correct say, *"Good. I'm going to read you more responses now. If you think it's a remember description, say 'remember.' If you think it's a familiar description, say 'familiar.'"*

If the participant is incorrect, read the difference between remember/familiar descriptions and dinosaur example again.

"Ok, let's start!"

1	You showed me a *carrot*, it was red and I said it could fit inside of the box.	R	
2	I saw a *moose*, but I can't tell if it was red or green.	F	
3	I think there was a *pear*, but I can't see what color it was.	F	
4	There was a drawing of a *stapler*, because I said it was not living.	R	
5	You showed me a *jungle gym* because you asked me whether it could fit inside the box and it was green.	R	
6	I'm sure you showed me a *rat*, it was green and I said it was living.	R	
7	I am sure there was a drawing of a *buffalo*, but I can't tell the color.	F	
8	You showed me a picture of a *globe*, but I don't remember the color or what you asked me.	F	
9	I am very sure that I saw a s*wing* but I can't remember what you asked me.	F	
10	I looked at a *pony*, it was red.	R	
11	I saw a *mailbox*, but I'm not sure what color it was.	F	
12	There was a drawing of an *painting*, but I can't tell whether it was red or green or what you asked me about it	F	

13	I think you showed me a *lightening bug*, but I'm not sure what question you asked me.	F	
14	You showed me a *phone*, but I can't tell if I said it was living or if it could fit in the box.	F	
15	You showed me a *camera*; you asked me if was living or not living.	R	
16	I am sure you showed me a *mosquito* because I said it was living.	R	
17	I saw a *pelican*, because I can picture that it was green.	R	
18	I think there was a *turkey*, because I can see it in green.	R	
19	I think there was a *snake*, but I'm not sure about the question you asked me.	F	
20	There was definitely a *picture frame*, but I don't know the color or what you asked me about it.	F	
21	I'm positive that you showed me a *coyote* because it was green and I said it could not fit inside of the box.	R	
22	I think that I saw *yarn*, but I'm not sure why.	F	
23	I am very sure that I saw a *crow* before, but I can't tell why	F	
24	I saw an *eagle*, because I said it was red.	R	
25	I saw an *eel*, but I'm not sure about the color.	F	
26	There was a *dump truck*, you asked me if it would fit inside of the box.	R	
27	There was definitely an *opossum*, it was green.	R	
28	I am sure there was a *clown fish* because it was red.	R	
29	I definitely saw a *panther*, but I can't tell you what question you asked me.	F	
30	I saw a drawing of a *lollipop*, but I can't tell what question you asked me.	F	
31	There was a drawing of a *swimming pool* for sure, because you asked me whether it would fit in the box.	R	
32	I saw *sunglasses*, I can picture them in red and I said they were not living.	R	
33	I saw a *porpoise*, I said it was living and I can picture it in green.	R	
34	There was a *weasel*, but I can't tell you the color or the question you asked me	F	
35	I think there was a *water bottle*, because I said it would fit in the box.	R	
36	I am sure I looked at *flag*, but I can't tell what color it was.	F	

Appendix D

IRB Approval

UNIVERSITY OF MARYLAND
INSTITUTIONAL REVIEW BOARD

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DATE:	September 10, 2012
TO:	Tracy Riggins
FROM:	University of Maryland College Park (UMCP) IRB
PROJECT TITLE:	[356056-2] Neurobehavioral investigation of memory development
REFERENCE #:	08-0612/2270
SUBMISSION TYPE:	Continuing Review/Progress Report
ACTION:	APPROVED
APPROVAL DATE:	September 10, 2012
EXPIRATION DATE:	October 19, 2013
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *4, 6, and 7*

Thank you for your submission of Continuing Review/Progress Report materials for this project. The University of Maryland College Park (UMCP) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this committee prior to initiation. Please use the appropriate revision forms for this procedure which are found on the IRBNet Forms and Templates Page.

All UNANTICIPATED PROBLEMS involving risks to subjects or others (UPIRSOs) and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this office.

This project has been determined to be a Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of October 19, 2013.

Please note that all research records must be retained for a minimum of three years after the completion of the project.

UNIVERSITY OF MARYLAND

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DATE:	April 30, 2013
TO:	Leslie Rollins, M.S.
FROM:	University of Maryland College Park (UMCP) IRB
PROJECT TITLE:	[439235-1] Electrophysiological investigation of subjective recollection
REFERENCE #:	
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	April 30, 2013
EXPIRATION DATE:	April 29, 2014
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *4, 6, & 7*

Thank you for your submission of New Project materials for this project. The University of Maryland College Park (UMCP) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this committee prior to initiation. Please use the appropriate revision forms for this procedure which are found on the IRBNet Forms and Templates Page.

All UNANTICIPATED PROBLEMS involving risks to subjects or others (UPIRSOs) and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this office.

This project has been determined to be a Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of April 29, 2014.

Please note that all research records must be retained for a minimum of three years after the completion of the project.

Appendix E

Additional ERP Analyses

Study 1: Encoding

Subsequent subjective recollection. In the early time window (150-300 ms for children and adolescents; 125-250 for adults), there was an Age Group x Condition x Coronal Plane interaction, $F(8, 256) = 2.69$, $p = .017$, and an Age Group x Condition x Coronal Plane x Sagittal Plane interaction, $F(16, 512) = 2.56$, $p = .002$. When follow-up analyses were conducted separately by age group, children demonstrated a Condition x Coronal Plane x Sagittal Plane interaction $F(8, 128) = 2.39$, $p = .019$. No main effect of or interaction with condition was present at frontal or parietal leads. At central leads there was a Condition x Sagittal Plane interaction, $F(4, 64) = 3.03$, $p = .024$. Although the conditions changed their relative positions across the coronal plane, no main effect of Condition was present at the right, midline, or left central lead. For adolescents, there was no significant main effect of or interaction with Condition. In adults there was a Condition x Coronal Plane interaction, $F(4, 100) = 3.61$, $p = .022$. Although the conditions changed their relative positions across the coronal plane, no main effect of condition was present at frontal, central, or parietal leads. In the second time window (150-300 ms for children and adolescents; 125-250 for adults), there was an Age Group x Condition x Coronal Plane x Sagittal Plane interaction, $F(16, 512) = 2.32$, $p = .006$. In children, there was a Condition x Coronal Plane x Sagittal Plane interaction, $F(8, 128) = 2.46$, $p = .027$. Main effects of condition or interactions with condition were not significant for follow-up analyses conducted at each coronal and sagittal plane. In adolescents and adults, there was no significant main effect of or interaction with Condition. In the third time window (500-700 ms), there was a Condition x Sagittal Plane interaction, $F(4, 256) = 2.85$, $p = .032$. Although the conditions changed their relative positions across the sagittal plane, no main effect of condition was present at left, central, or right leads.

Subsequent color recollection. In the early time window (150-300 ms for children and adolescents; 125-250 for adults), there was an Age Group x Condition x Coronal Plane interaction, $F(8, 240) = 4.22$, $p = .001$. When follow-up analyses were conducted separately by age group, a Condition x Coronal Plane interaction was present in all age groups, children, $F(4, 84) = 3.11$, $p = .04$, adolescents, $F(4, 68) = 3.09$, $p = .05$, and adults, $F(4, 88) = 5.04$, $p = .009$. However, there was no main effect of condition at frontal, central, or parietal leads in any age group. Condition and coronal plane interacted with age group because the relative positions of the conditions altered across the coronal plane differed across age groups. In the second time window (150-300 ms for children and adolescents; 125-250 for adults), there was an Age Group x Condition x Coronal Plane interaction, $F(8, 240) = 2.55$, $p = .024$. In children and adolescents, there was no significant main effect of or interaction with Condition. In adults, there was a significant Condition x Coronal Plane interaction, $F(4, 88) = 3.5$, $p = .033$. Although the conditions changed their relative positions across the coronal plane, no main effect of condition was present at frontal, central, or parietal leads. In the third time window (500-700 ms), there was an Age Group x Condition x Coronal Plane interaction, $F(8, 240) = 2.95$, $p = .009$. In children and adolescents there was no significant main effect of or interaction with

Condition. In adults, there was a Condition x Coronal Plane interaction, $F(2, 88) = 4.42$, $p = .003$. Follow-up analyses at frontal, central, and parietal leads, revealed no significant main effect of or interaction with Condition.

Subsequent task recollection. There was no main effect of or interaction within Condition in the first (150-300 ms for children and adolescents; 125-250 for adults) or second time windows (150-300 ms for children and adolescents; 125-250 for adults). In the third time window (500-700 ms), there was an Age Group x Condition x Coronal Plane interaction, $F(4, 296) = 2.44$, $p = .03$. No main effect of or interaction with condition was present in children or adolescents. Adults demonstrated a main effect of Condition, $F(2, 54) = 3.82$, $p = .028$, that was qualified by a Condition x Coronal Plane interaction, $F(4, 108) = 3.77$, $p = .011$. Follow-up analyses revealed a significant main effect of Condition at central, $F(2, 54) = 4.93$, $p = .01$, and parietal, $F(2, 54) = 4.7$, $p = .013$, but not frontal leads, $F(2, 54) = 2.3$, $p = .11$. At central leads, the amplitude elicited to items subsequently recollected with the task-correct was significantly larger than items with the task-incorrect, with missed items in-between (see Figure 6). At parietal leads, the amplitude elicited to task-correct and missed items was larger than task-incorrect items (see Figure 6).

Study 2: Retrieval

Subjective recollection. There was no main effect of or interaction with Condition in the first (150-300 ms for children; 125-250 for adolescents and adults) or second time windows (300-450 ms for children; 250-450 for adolescents and adults). In the later time window (700-900 ms), results revealed an Age Group x Condition x Sagittal Plane interaction, $F(8, 260) = 2.1$, $p = .036$. This interaction emerged from a change in the relative position of conditions across the coronal plane as a function of age group. However, follow-up analyses did not reveal significant memory effects in any age group during this time window.

Color recollection. For the earliest time window (150-300 ms for children; 125-250 for adolescents and adults) there was no main effect of or interaction with Condition. During the second time window (300-450 ms for children; 250-450 for adolescents and adults), there was a Condition x Sagittal Plane interaction, $F(4, 200) = 4.05$, $p = .004$. This interaction emerged from a change in the relative position of conditions across the sagittal plane. However, follow-up analyses did not reveal a significant main effect of or interaction with condition at any sagittal plane. For the last time window (700-900 ms), there was a Condition x Sagittal Plane interaction, $F(4, 200) = 3.55$, $p = .008$, and a Condition x Coronal Plane x Sagittal Plane interaction, $F(8, 400) = 2.86$, $p = .011$. Follow-up analyses were conducted separately for each Sagittal Plane. No main effect of or interaction with Condition was present at left or right leads. A Condition x Coronal Plane interaction was present at midline leads, $F(4, 200) = 4.27$, $p = .007$. This interaction emerged due to a change in the relative position of Conditions across the Coronal Plane. However, a main effect of condition was not present at frontal, central, or parietal midline leads.

Task recollection. In the earliest time window (150-300 ms for children; 125-250 for adolescents and adults) there was a Condition x Coronal Plane interaction, $F(4, 244) = 4.33$, $p = .008$, and a Condition x Sagittal Plane interaction, $F(4, 244) = 3.29$, $p = .021$. No main effect of or interaction with condition was present for follow-up analyses conducted at each coronal and sagittal plane.

During the second time window (300-450 ms for children; 250-450 for adolescents and adults), there was a Condition x Coronal Plane interaction, $F(4, 244) = 10.53$, $p < .001$, and a Condition x Sagittal Plane interaction, $F(4, 244) = 5.25$, $p = .001$, that was qualified by Age Group, $F(8, 244) = 3.93$, $p = .001$. In children, there was a significant Condition x Sagittal Plane interaction, $F(4, 64) = 5.39$, $p = .001$. At right leads there was a Condition x Coronal Plane interaction, $F(4, 64) = 3.17$, $p = .042$. Although leads changed relative position across the Coronal Plane, no significant main effect of Condition was present at right frontal, central, or parietal leads. In adolescents, there was a Condition x Coronal Plane interaction, $F(4, 72) = 7.97$, $p < .001$. At frontal and central leads, there was a main effect of Condition, $F(2, 36) = 4.49$, $p = .031$. The amplitude of the response elicited to task-correct items was less negative than task-incorrect items with correctly rejected items in-between (see Figure 6). No main effect of or interaction with Condition was present in adults.

Analysis of the last time window (700-900 ms) revealed a Condition x Sagittal Plane x Age Group interaction, $F(8, 244) = 2.16$, $p = .041$, and a Condition x Coronal Plane x Sagittal Plane interaction, $F(8, 488) = 2.27$, $p = .043$. No main effect of or interaction with condition was present in children. In adolescents, a Condition x Coronal Plane x Sagittal Plane interaction emerged, $F(8, 144) = 2.71$, $p = .048$. However, when follow-up analyses were conducted separately for each coronal and sagittal plane, no main effect of or interaction with Condition was present. No main effect of or interaction with Condition was present in adults.

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