EXPLORING THE ROLE OF LANGUAGE DEVELOPMENT AND VERBAL ENCODING IN SHORT-TERM RECOGNITION MEMORY IN EARLY CHILDHOOD

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(ABSTRACT)

There is evidence that language ability is related to a number of cognitive processes, including memory. As children become more proficient language-users, they develop the ability to use language as a memory attribute. This study used EEG coherence to investigate the extent to which verbal encoding strategies account for individual differences in two short-term recognition memory tasks in 50 3-year-olds. Children with better expressive and receptive language performed better on the picture memory task (which contains stimuli that can easily be labeled) but not the abstract memory task, indicating that language may support memory processes for some types of stimuli more than for others. Analyses of EEG coherence at the hypothesized electrode pairs (F7-T3 and F8-T4) at baseline and encoding were not significant, indicating that verbal encoding does not account for individual differences in short-term memory performance. When these electrode pairs were examined at baseline and retrieval for the picture memory task, EEG coherence analyses indicated that it may be the use of language as a retrieval cue rather than an encoding strategy that explains individual differences in short-term recognition memory.

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DEDICATION

I would like to dedicate this to my parents, James and Rashell Cardell, who have always loved and supported me unconditionally and who taught me to love learning; and to Fr. Samuel and Kh. Loretta, who provided immeasurable support throughout the writing process.

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Exploring the Role of Language Development and Verbal Encoding in Short-Term Recognition Memory in Early Childhood

Introduction and Background

It is difficult to imagine life without memory. Our memories are important because they help to define our sense of self. We can recall important events in our lives, including details about our behaviors over the course of our lives, giving us important information about what we are like and what the world is like. More importantly, we have the ability to communicate these memories to others, making memory a social process as well. Importantly, memory is highly integrated with other cognitive processes such as emotion, language, and attention.

Language, in particular, has been studied as a system that may enhance memory processes. Decades ago, Bruner (1966) proposed that as children develop the ability to use language as a conceptual tool, it transforms their thinking. Language serves as both a form of communication and a symbolic system that enables us to mentally represent complex concepts. As adults, many (though perhaps not all) of our memories are language-based memories. Even memories that consist almost entirely of images can easily be translated into linguistic terms. When we recall them, think through them, or communicate them to others, we often use language to do so. The linguistic nature of memory storage and retrieval is so much a part of our everyday lives that we are hardly aware of it.

At this point, it is necessary to distinguish between episodic and semantic memory because the two likely relate to language in different ways. Semantic memory is memory for facts. This includes our knowledge of word meaning. Semantic memory is a necessary part of language development in that it is required as children learn to map meaning onto symbols such as words. Episodic memory is memory for events, including autobiographical events. Although episodic memory is less important than semantic memory for language learning, as language is established as a system of symbolic thought, it has the potential to enhance episodic memory processes. This discussion is primarily focused on he relation of language to episodic memory.

Until children learn to use language as a representational system, it is likely that memories about the world consist largely of sensory images (tactile, visual, auditory, olfactory, or gustatory) (Piaget, 1965). As young children interact with others, they learn that words have meaning and can be used to represent objects, actions, and ideas. For young children, who are just beginning to become proficient in the use of language as a symbolic system, the process of encoding and retrieving memories in linguistic terms is probably less automatic than it is for adults (Simcock & Hayne, 2002). As their language ability improves, children become increasingly adept at encoding information and events in linguistic terms, which may help to explain some of the age-related changes in explicit memory (Hayne, 2004).

Whereas infants and children clearly have the capacity to form memories, most adults have few or no memories before about 3 and 4 years of age (Hayne, 2004; MacDonald, Uesiliana, & Hayne, 2000; Mullen, 1994; Nelson, 1993; Usher & Neisser, 1993; Wetzler & Sweeney, 1986). There is evidence that this may be because infants and toddlers mentally represent (or encode) events differently than older children and adults. The information that is available at the time the event was experienced affects how it is recalled. For example, a child's ability to describe an event seems to be dependent on that child's verbal ability at the time of the event rather than the time of retrieval (Bauer, Wenner, & Kroupina, 2002; Simcock & Hayne, 2002), indicating that language ability (the use of symbols to mentally represent the event) may help facilitate episodic memory and may be partly responsible for this shift.

A few studies have suggested that verbal ability may enhance short-term memory in children. In one study of children with Specific Language Impairment, verbal ability was more predictive of event memory than non-verbal IQ (Bishop & Donlan, 2005). Other researchers have found evidence that in children with SLI, deficits in verbal storage are at least partially responsible for the impaired performance on complex memory tasks (Archibald & Gathercole, 2007). Herbert and Hayne (2000) found that the use of verbal labels during demonstration in a deferred imitation task enhanced the ability of 24-month-old infants (but not 18-month-olds) to generalize to novel test stimuli. Perhaps the verbal labeling strengthened the memory enough that more complex information processing could occur upon retrieval. In another study using a bubble-machine task that required children to remember which color soap activated the bubble machine (Morris & Baker-Ward, 2007), children who already had a label for the color of the soap needed to activate the bubble machine during encoding were more likely to correctly identify the color (both verbally and nonverbally) at the time of testing. This provides further evidence that the use of a verbal label increases the strength and durability of a given memory representation.

Additional evidence for a link between language and memory comes from the observation that memory improves dramatically during the same time that children are becoming more adept at using language as a representational system. Whereas memory development is often referred to as a linear trend, the trend is not exactly linear. A recent study examined the development of the durability of visual recognition memory for a brightly colored animated stimulus in 1-, 2-, 3-, and 4-year-olds (Hayne, 2004). One-year-olds remembered only when immediately tested, 2-year-olds remembered for up to 1 day, 3-year-olds remembered for up to a week, and 4-year-olds remembered for up to a month. In fact, the slope of the function increased dramatically around the age of 3—at the same time children are becoming adept at language use. It could be that contemporaneous improvements in language and memory development at this age are the result of a generally more mature cerebral cortex. However, it is also possible that as children learn language, they are actually encoding information in a more efficient manner.

There is also considerable theoretical support for the idea that language may increase the efficiency of memory encoding. Hayne (2004) proposed that language serves as a memory attribute and suggests that encoding (and rehearsing) linguistically increases the quality and durability of a given representation and also allows children (and adults) to use language-based retrieval cues (rather than merely situation-specific cues). This could explain why children have trouble with episodic memory retrieval before their language abilities can support this process.

Fuzzy-trace theory and the distinction between gist and precise memory traces may also help to explain the process by which encoding an event based on a verbal label increases the quality and durability of that memory. According to fuzzy-trace theory, memory traces involving the “gist” of an event are less volatile than precise memory traces, which involve more specific details about a perceptual experience (Brainerd & Reyna, 1993, 2002, 2004; Harnishfeger & Brainerd, 1994). Leichtman and Ceci (1993) have proposed that as children age, the way that they store and represent information is changing. At some point in early childhood, children shift from using mostly verbatim memory traces to using mostly gist memory traces (although the shift is probably gradual and there are likely individual differences in the degree to which this shift occurs). Language ability is also developing during this time and may be partly responsible for the shift in memory strategies. Children are learning to use language as a representational system, allowing them to represent complex ideas with verbal labels (gist encoding). For example, when a child who is proficient in language sees a picture of an elephant, the memory of the picture might be encoded and retrieved more easily using the verbal label *elephant* rather than encoding and retrieving all of the specific details and curves of its visual composition. This is because an event that is based on a symbol such as a verbal label (or a sign in the case of non-hearing children) can be linked to and reconstructed from information that is already stored in declarative memory. A child who is less linguistically proficient may rely on more precise encoding and form a mental representation of the event based on specific details of its composition.

Further evidence that language development may play a strong role in the shift from verbatim to gist encoding comes from studies of split-brain patients, which indicate that the left hemisphere, which is known to be involved in verbal information processing, also tends to be involved in interpreting stimuli and using gist encoding whereas the right hemisphere, which is commonly implicated in the processing of spatial information has a greater tendency to process and encode more specific perceptual details about stimuli (Metcalfe, Funnell, & Gazzaniga, 1995).

The Importance of Verbal Labels

Verbal labels can provide an important link between an observed event and information that is already stored in long-term memory. The effect that labels have on how we encode and retrieve information about objects we see was demonstrated in a classic experiment with adults in which participants were shown ambiguous line drawings and were simultaneously presented with verbal labels. When asked to draw the object they had seen, participants distorted the drawings according to the labels associated with the drawings (Carmichael, Hogen, & Walter, 1932), suggesting that only the label for the event was encoded, and the memory was retrieved by reconstructing the image from declarative memory. This experiment illustrates the link between verbal labeling and the semantic encoding and retrieval of visual events. This is important because research overwhelmingly suggests that children (Nelson & Webb, 2003) and adults (Crowder, 1978; Hulme, Maughan, & Brown, 1991; Schweikert, 1993) who encode information semantically have better subsequent memory of that information than when it is not encoded semantically.

The codability effect provides additional evidence for the mnemonic benefit of semantic encoding. This has been demonstrated in both olfactory and visual domains. For example, the ability to apply a distinctive label to an odor influences subsequent recognition of that odor (Chrea, Ferdenzi, Valentin, & Abdi, 2007). The same is true for color. Several cross-cultural studies have indicated that the number of available color words in a given language might influence memory for color. For example, Brown and Lenneberg (1954) reported that Zuni Indians, who use a single term to describe both yellow and orange, are more likely than English-speaking participants to confuse these colors in a recognition memory task. This may be because having a label for a stimulus or event provides a framework for mental representation (Genter & Goldin-Meadow, 2003; Gumperz & Levinson, 1996) and also increases its distinctiveness from other stored representations, a feature that improves the strength and durability of memory (Howe, 2006). Perhaps this is because the simple act of applying labels to different objects or ideas increases our awareness of the differences between them. It may also be that without a symbolic system such as language that can be used to represent ideas about incoming perceptual information, the system may have no choice than to form verbatim memory representations that are based on specific perceptual details. As children gain more experience with language as a tool for communication and representation, processing an event semantically may become more automatic. If this is the case, it is likely that as language proficiency increases, memory will also be enhanced.

Simply finding that a child with better verbal ability has better recognition memory for images that can be labeled verbally is insufficient to clearly support the claim that language enhances memory for pictures *because* the child is using verbal encoding strategies. It is also possible that improvements in memory skills lead to improvements in language skills (e.g., being able to remember word meaning and being able to retain and execute syntactic rules). Furthermore, behavioral indicators of verbal encoding are likely to be unreliable. For example, if we were to operationally define verbal encoding by whether or not a child names a picture when shown, we may incorrectly categorize children who are so advanced that they normally engage covert labeling or children who are simply too behaviorally inhibited to name the pictures in a laboratory setting. In short, overt behavior is not necessarily an accurate indicator of underlying cognitive processes. If we wish to make some claim about the mechanisms involved (i.e., that a child is using verbal encoding strategies when looking at a given picture) then it is necessary for us to also examine physiological evidence that the child is using these strategies.

Physiological Correlates of Language and Memory

Cognitive neuroscience studies provide evidence of the neural basis for memory formation and retrieval. One fMRI study of children and adolescents (ages 11 to 19), activation and connectivity of the medial temporal lobes to other brain areas was examined while participants encoded visual images of outdoor scenes. While overall activation of the MTL decreased with age during this task, connectivity between the medial temporal lobes and the left dorsolateral prefrontal cortex increased, indicating that the maturation of the connection between the medial temporal lobes and the left dorsolateral prefrontal cortex plays an important role in memory encoding (Menon, Boyett-Anderson, & Reiss, 2005). Double dissociation and other studies of brain-injured patients also implicate both the frontal and medial temporal lobes in memory processes (Squire & Knowlton, 1995). This is consistent with other studies showing that patients with medial temporal lobe damage have trouble recognizing visual stimuli that were previously presented (Shimamura, Janowski, & Squire, 1990; Squire & Shimamura, 1986). Menon and colleagues (2005) have suggested that increased functional interactions between the medial temporal lobes and the prefrontal cortex may play a causal role in the development of effective encoding strategies.

The left hemisphere of the brain, particularly an area of the frontal lobe known as Broca's Area, is known to be involved in language and speech production, and a number of studies (in adults) have demonstrated that the left frontal cortex is active during tasks that require an individual to memorize verbal information (Fletcher, Frith, Grasby, Shallice, Frackokiak, & Dolan, 1995; Kapur, Tulving, Cabeza, McIntosh, Houle, & Craik, 1996; McDermott, Buckner, Petersen, Kelley, & Sanders, 1999). These same areas are also active during tasks in which the participant is able to remember words that he or she is not intentionally trying to memorize (Gabrieli, Poldrack, & Desmond, 1998; Kapur, Craik, Tulving, Wilson, Houle, & Brown, 1994). Furthermore, several fMRI studies have shown that left frontal activation is related to subsequent recognition of visually presented words (Buckner, Wheeler, & Sheridan, 2001; Wagner, Schacter, Rotte, Koustaal, Maril, Dale, et al., 1998b), indicating that this part of the brain is involved in verbal memory encoding, whether or not an individual is trying to memorize the information that is presented.

Pictures such as unfamiliar faces and patterns (which are not associated with a verbal label) are linked with right frontal activation in adults (Kelley et al., 1998; Wagner et al., 1998a). Although a search of the literature did not reveal any such studies involving children, left lateral frontal activation is closely associated with verbal encoding in adults, and most studies involve words presented visually or verbally. However, looking at pictures to which labels can be easily applied is also linked with left frontal activation, especially if participants are asked to silently name the object (Martin, Wiggs, Ungerleider, & Haxby, 1996).

Left frontal regions are likely not the only areas involved in the encoding process. According to Cabeza and Nyberg (2000), semantic memory retrieval at the time of an event is so closely related to incidental encoding that they can be viewed as two sides of the same coin. That is, most of the regions associated with semantic retrieval are also associated with episodic memory encoding. There is neurological evidence that the encoding process depends on the interaction between the frontal and temporal lobes. This may be because the application of a verbal label to an event depends largely on the retrieval of semantic information from declarative memory stores. Several studies with adults indicate that the left temporal lobes are activated during semantic retrieval tasks (Martin et al., 1996; Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996). As mentioned earlier, connections between the medial temporal lobes and the left dorsolateral prefrontal cortex play an important role in the encoding process (Menon, Boyett-Anderson, & Reiss, 2005). As is the case with the frontal lobes, studies of adults (Kanwisher, McDermott, & Chun, 1997; Lee, Simos, Sawrie, Martin, & Knowlton, 2005; McCarthy, Puce, Gore, & Allison, 1997; Passarotti, Paul, Bussiere, Buxton, Wong, & Stiles, 2003) and children (Passarotti et al., 2003) indicate greater right than left activation of the temporal lobes when looking at unfamiliar faces, providing further evidence of hemispheric differences in the processing of verbal and nonverbal stimuli. Therefore, it is also expected that activation of the left medial temporal lobes, particularly in concert with the frontal lobes, will also occur when verbal encoding strategies are used. The same areas in the right hemisphere are expected to be involved when predominantly nonverbal encoding strategies are used.

Notably, most of the studies mentioned above included only adults. Although children may be expected to have similar patterns, previous EEG research indicates that between the ages of 8 months and 4½ years, brain function is gradually becoming more localized (Bell & Wolfe, 2007). However, ERP research has demonstrated some degree of hemispheric specialization for language even in infants. For example, there are hemispheric differences in the amplitude of event-related potentials for known versus unknown words at 20 months but not at 13-17 months (Mills, Coffey-Corina, & Neville, 1997). Even in very young infants, the beginning of this pattern of specialization for language processing is observable. In 2- to 3-month-old infants, ERP changes have been detected in the left frontal and temporal lobes during detection of novel syllables (Dehaene-Lambertz & Dehaene, 1994). However, even by 4 months of age, there is no hemispheric distinction between the processing of phonemes and other sounds such as tones (Dehaene-Lambertz, 2000) although there is some evidence at this age for right hemispheric specialization for processing the prosody of speech (Homae, Watanabe, Nakano, Asakawa, & Taga, 2006). A study that is more relevant to language processing used optical topography to examine hemispheric differences in speech processing in neonates and found greater left hemisphere activation for speech than for backward speech or silence (Peña et al., 2003).

A recent study in our lab with 3-year-olds found that left frontal-temporal EEG coherence (specifically between F7 and T3) was linked to performance on a visual recognition memory task that involved pictures that can be labeled (Cardell & Bell, 2009), providing evidence that the brains of 3-year-olds are specialized enough to warrant specific hypotheses about which brain areas are expected to be involved in the verbal encoding process. Therefore, left frontal-temporal coherence can be considered evidence of the use of verbal encoding strategies.

Context for Current Study

Although there is some theoretical support for the idea that the ability to use language may enhance memory development, research directly investigating this claim is scarce, and research involving brain imaging is even rarer. Studies of memory are often confounded by the fact that behavioral measures of memory are entirely dependent on retrieval processes and therefore give little insight into the specific memory processes that might be involved. Failure to retrieve a given memory could be the result of encoding failure, storage failure, or problems with the retrieval process itself. The use of EEG coherence can provide researchers with insight into the relative importance of different stages of information processing.

Coherence is a measure of phase synchrony between two brain areas, and values are expressed as the frequency-dependent squared cross-correlation of electrical signals between two scalp electrode sites (Nunez, 1981; Thatcher, Krause, & Hrybyk, 1986). Whereas power values yield information about the electrical activation of a given brain area (Davidson, Jackson, & Larson, 2000), coherence values between two electrode sites are presumed to be a measure of the strength and number of active synaptic connections between the corresponding brain areas. Therefore, increased coherence indicates an increase in synchronized activity between two brain areas (Thatcher, 1994). There are cyclical developmental trends in general coherence patterns that arise from myelination, synaptogenesis, changes in neurotransmitters, and the cycles of blooming and pruning that occur in infancy and childhood (Thatcher, 1994). As the number of synaptic connections increases, coherence values go up across the cortex. As the brain specificity for various cognitive functions increases, connections are pruned, resulting in an overall decrease in coherence. Increased coherence between any two brain areas may or may not be adaptive for a given task. As the cortex matures, task-related increases in coherence become less general and more closely tied to specific brain areas that are involved in the processing demands of the particular task (Bell & Wolfe, 2007). Coherence is more relevant to the current research question than EEG power because memory encoding involves the integration of multiple brain areas, a process that cannot be fully evaluated using EEG power.

In a recent study from our research lab, children with the highest memory performance on a visual recognition memory task had higher language ability than children who performed less well, and EEG coherence data indicated that children in the high memory group had a greater tendency to use verbal encoding strategies than children in the low memory group, suggesting that perhaps their performance on the task was enhanced by the tendency to encode visual stimuli linguistically (Cardell & Bell, 2009). However, there are several issues in this study that need further attention.

First, this study failed to account for the fact that general mental ability (or some third variable) could be behind the language-memory link. This problem could be addressed by including a second recognition memory task involving stimuli that cannot be verbally labeled. If the language-memory relation is due (at least in part) to the fact that verbal encoding strategies enhance memory, we would expect to find that the correlation between language and memory for stimuli that can be verbally labeled would be stronger than the correlation between language and memory for stimuli that cannot be verbally labeled. If the relation between language and memory is the same in both situations, this may lend support to the possibility that general mental ability is a stronger indicator of individual differences in memory than is specific language ability. If the relation is stronger when verbal labels can be used, this would support the idea that language is functionally supporting memory to some degree. Also, the lack of a nonverbal baseline measure in the previous study made it impossible to reliably examine baseline-to-task changes in EEG coherence.

This study addresses these issues and uses EEG coherence to investigate individual differences in encoding strategies during a recognition memory task. Recognition memory was chosen because this type of task is easy to administer to 3-year-olds and requires only pointing and no verbal response. It is important to note that memory formation and retrieval are the result of multiple processes, and the relation between language and memory is almost certainly bi-directional. However, the current research relates only to the question of whether language ability can enhance memory.

Research Hypotheses

Behavioral Hypotheses. The first step in establishing a link between verbal encoding and memory is to find a positive relation between language ability and performance on a memory task. Several behavioral hypotheses were identified.

1) Children with higher expressive language will perform better on both a recognition memory task containing stimuli that can be verbally labeled and a recognition memory task containing stimuli that cannot be easily labeled than children with lower language ability.

2) Children with better receptive language will perform better on both a recognition memory task containing stimuli that can be verbally labeled and a recognition memory task containing stimuli that cannot be easily labeled than children with lower language ability.

3) For both receptive and expressive language, the relation between language and memory will be stronger if the memory task includes stimuli that can be verbally labeled than if the memory task includes only stimuli that cannot be easily verbally labeled because when stimuli can be easily labeled, it is more likely that language can serve as a memory attribute.

Physiological Hypotheses. A positive relation between language and memory in behavioral tasks is necessary but not sufficient to support a claim that verbal encoding enhances memory performance, so physiological indicators of encoding strategies will also be examined. Left hemisphere coherence can be viewed as an indicator of verbal (gist) encoding, and right hemisphere coherence can be viewed as an indicator of nonverbal (verbatim) encoding. Coherence will be used instead of power because it is presumed to yield information about active connections between multiple brain areas (Thatcher, 1994). Communication between the frontal and temporal lobes is theoretically more specific to the verbal encoding process than activation of individual brain areas. Based on this premise, several physiological hypotheses were identified.

1) On a memory task that includes items which can be verbally labeled (pictures), children who encode items verbally (i.e., who use gist encoding) will perform better than

children who use less verbal encoding strategies; specifically, children who perform better on the picture recognition memory task will have greater left lateral frontal (F7) and left anterior temporal (T3) EEG coherence during the encoding phase of the task (i.e., while looking at the picture) than children who perform less well on the task.

2) On a memory task that includes items which do not have an obvious verbal label (abstract images), children who use verbatim (nonverbal) encoding will perform best; specifically, children who perform better on the abstract recognition memory task will have greater right lateral frontal (F8) and right anterior temporal (T4) EEG coherence during the encoding phase of the task (i.e., while looking at the abstract image) than children who perform less well.

Exploratory Analyses

In addition to the above hypotheses, several additional questions were identified. A search of the literature did not suggest any specific hypotheses; however, the answers to these questions can potentially lead to an increased understanding of how language and brain physiology relate to memory development.

1) Do expressive and receptive language relate to memory performance in the same way, or is one of these more strongly correlated with short-term recognition memory than the other?

2) What variables will be most useful in predicting performance on both the picture and abstract memory tasks? EEG coherence, receptive and expressive language performance, gender, and age are considered.

Method

Participants

Participants were 50 children (25 male; 25 female) between 36 and 40 months of age, who were recruited from the Blacksburg area. Of the 50 children who participated, 47 were White (not Hispanic), 2 were Asian, and 1 was African American. All children who participated wore the EEG cap during baseline and memory tasks and completed at least one language measure. All children completed the PPVT-III, but only 33 completed the EVT. EVT data are not available on the remaining 17 children for various reasons. Some refused to answer the questions and others were not given the measure because the other procedures had taken so long that the children became tired, and the researcher chose to eliminate the task. All but one child completed both memory tasks. This child completed the entire picture task and a portion of the abstract memory task, but because percentage scores were used, his data were included in the analyses.

Procedures

When they arrived, parents and children were greeted, and an experimenter explained all procedures and obtained the parent's written consent and the child's verbal assent. After playing a warm-up game, children were seated in a chair and entertained with various toys while a researcher applied the EEG cap. Physiological data were recorded at baseline while the child quietly looked at a video of a Microsoft Windows screensaver (mystify). This baseline task was selected because, unlike the picture version of the short-term memory task described below, it is less likely to directly involve language or language processing. Also, unlike the abstract version of the short-term memory task described below, it involves continuous processing of a single stimulus that moves around the screen instead of a series of rapidly changing images. EEG recordings were obtained during the two memory tasks. A parent was present in the room at all times during the study.

EEG Recordings. EEG data were collected, examined, and analyzed according to the procedure described by Pivik and colleagues (1993). EEG was recorded using an Electro-Cap from eight left and eight right scalp sites: Frontal pole (Fp1, Fp2), medial frontal (F3, F4), lateral frontal (F7, F8), central (C3, C4), anterior temporal (T3, T4), posterior temporal (T7, T8), parietal, (P3, P4), and occipital (O1, O2), referenced to Cz. NuPrep and EEG Gel conductor were inserted into each recording site, and the scalp was lightly rubbed. Electrode impedances were measured and accepted if they were below 5,000 ohms. The electrical activity from each lead was amplified using separate SA Instrumentation Bioamps, bands passed from 1 to 100 Hz, and digitized online at 512 samples per second to prevent aliasing. Activity for each lead was displayed on a Pentium computer using Snap/Shot acquisition software.

The EEG data were examined using EEG Analysis System Software (James Long Company, Canoga Lake, NY). The data were referenced to an average reference using the software and were visually examined and scored for artifact (eye, muscle, and gross motor movements). Average reference is considered the optimal configuration when computing coherence between spatially distinct electrodes (Fein, Raz, Brown, & Merrin, 1988). Any artifact was rejected and excluded from analyses. Remaining data were analyzed using a discrete Fourier transform (DFT) using a Hanning window of 1-s width and 50% overlap.

Coherence was computed for the 6- to 9-Hz frequency band using the algorithm developed by Saltzberg and colleagues (Saltzberg, Burton, Burch, Fletcher, & Michaels, 1986). The 6-9 Hz frequency band was selected because it is the dominant frequency band for preschool children (Marshall, Bar-Haim, & Fox, 2002) and has shown associations with memory processing in preschool children (Bell & Wolfe, 2007) . Coherence values are expressed as the frequency-dependent squared cross-correlation of electrical signals between two scalp electrode sites (Nunez, 1981; Thatcher, Krause, & Hrybyk, 1986) and vary from 0 to 1. Coherence values closer to 1 indicate greater coupling between the two electrode sites. Unlike EEG power values, EEG coherence is not affected by arousal, opening or closing of eyes, or changes in state (Thatcher, 1994)

Short-term Recognition Memory Tasks. Short-term memory was assessed using 2 variations of the Corsi-Milner test of recognition memory (Corsi, 1972, cited in Milner, 1972). One consisted of simple monochromatic drawings of everyday objects, which can easily be verbally labeled, and the other consisted of monochromatic abstract images, which cannot be easily verbally labeled. The tasks were administered in succession, and the order was counterbalanced across participants. During each of these tasks, the children were shown 40 cards, each depicting a monochromatic image (a simple line drawing of an everyday object for the "picture" task and an abstract image for the "abstract" task), and 10 question cards (one presented after every fourth trial), each depicting one image that was previously presented and one image that was not previously presented. Some of the images on the question cards (4 in each task) came from the set immediately preceding the question card and the rest were drawn from earlier sets. The task was administered as it is described by Diamond and colleagues (1997).

The recognition memory task requires the child to distinguish an image that has been shown from an image that has not been shown. During the practice trials, the child was shown a single picture card immediately followed by a question card depicting two images. The child was asked, "Which of these two pictures have you already seen?" For results to be considered valid, the child will be required to demonstrate that he or she understands the meaning of the words *already seen* by correctly identifying which card was "already seen" in at least two of three practice trials. All of the children were able to demonstrate that they understood the rules. The experimenter explained any errors to the child and praised and explained any correct responses during practice trials only. After the practice trials, the experimenter said, “That’s how we play this picture game! Are you ready to play?” The experimenter then began the task by placing the laminated cards, one at a time, in front of the child. Each card was presented for approximately 5 seconds. After cards 4, 8, 12, 16, 20, 24, 28, 32, 36, and 40, a question card depicting two images (one of which was previously presented) was shown. The child was asked, “Which of these two pictures have you already seen?” No feedback was given during the administration of the test. Children received 1 point for each correct response and 0 points for each incorrect response. Scores were then converted to percentages and could range from 0 to 100 percent. For the one child who partially completed a task, scores were calculated based on a percent of total items attempted. See Table 1 for descriptive statistics on these tasks. Girls (*M* = 86.40, *SD* = 13.19) performed better than boys (*M* = 75.20, *SD* = 21.04) on the picture memory task; *t*(48) = 2.26, *p* = .03. Girls (*M* = 60.00, *SD* = 17.80) and boys (*M* = 62.20, *SD* = 12.42) did not differ in their performance on the abstract memory task; *t*(48) = .51, *p* = .62. Scores on the two memory tasks were not correlated, *r*(48) = .09, *p* = .53.

During the administration of each task, a research assistant sat at a computer in the control room and entered an event mark on the EEG record at the beginning of the task (as soon as the first card was placed in front of the child). Additional events were later reconstructed from the video event and added at the beginning and end of each set of stimuli, as soon as each question card was presented to the child, and immediately after the child’s response to each question. This allowed the encoding phase of the task (when the child is looking at the stimuli) to be separated from the retrieval phase (when the child is looking at the question cards) in the EEG file.

Language Measures. The Peabody Picture Vocabulary Test-III (PPVT-III; Dunn & Dunn, 1997) was also administered to assess each child’s receptive vocabulary. The Expressive Vocabulary Test (EVT; Williams, 1997) was administered to assess each child’s expressive vocabulary. These tests were selected because they are age appropriate and are widely accepted and nationally standardized instruments. For both language measures, raw scores were used in all calculations because absolute language ability is more relevant to the research question than age-related performance. See Table 1 for descriptive statistics on these measures. Boys (*M* = 51.08, *SD* = 15.59) and girls (*M* = 55.48, *SD* = 13.99) did not differ in their performance on the PPVT-III; *t*(48) = 1.05, *p* = .30. Boys (*M* = 41.21, *SD* = 3.42) and girls (*M* = 43.89, *SD* = 6.28) also did not differ in their performance on the EVT; *t*(31) = 1.44, *p* = .16. The EVT and PPVT-III were moderately correlated, *r*(31) = .48, *p* = .005.

Results

Hypothesis Testing

Behavioral hypotheses. To test the hypothesis that children with higher expressive language will perform better on both picture and abstract short-term recognition memory tasks than children with lower language ability, a Pearson product-moment correlation of EVT scores and scores on each of the two memory tasks was conducted. As predicted, the EVT was positively correlated with performance on the picture memory task, *r*(31) = .41, *p* = .02. However, the EVT was not correlated with performance on the abstract memory task, *r*(31) = .06, *p* = .76.

To test the hypothesis that children with better receptive language will perform better on both the picture and abstract recognition memory tasks than children with lower language ability, a Pearson product-moment correlation of PPVT-III scores and scores on each of the two memory tasks was conducted. As predicted, the PPVT-III was positively correlated with performance on the picture memory task, *r*(48) = .34, *p* = .02. However, the PPVT-III was not correlated with the abstract memory task, *r*(48) = .04, *p* = .80.

The final behavioral hypothesis was that (for both receptive and expressive language) the relation between language and memory will be stronger if the memory task includes stimuli that can be verbally labeled. The test for the receptive language correlations (PPVT & picture memory task, *r* = .34; PPVT & abstract memory task, *r* = .04) showed a trend for a difference between the two correlations; *t*(47) = 1.64; *p* = .05 (1-tailed test). The test for the expressive language correlations (EVT & picture memory task, *r* = .41; EVT & abstract memory task, *r* = .06) likewise showed a trend for a difference between the two correlations; *t*(30) = 1.53, *p* = .07 (1-tailed test).

Physiological hypotheses. Children were divided into groups based on their performance on each of the recognition memory tasks. Groups for each memory task were determined by median split. For the picture recognition memory task, the median score was 80 percent. Children who scored above 80 percent were in the high performance group, and children who scored at or below 80 percent were in the low performance group. Based on these criteria, there were 27 children in the low memory group (*M* = 66.67, SD = 12.71) and 23 children in the high memory group (*M* = 97.39, SD = 4.49). For the abstract recognition memory task, the median score was 60 percent. Children who scored above 60 percent were in the high memory group, and children who scored at or below 60 percent were in the low memory group. Based on these criteria, there were 29 children in the low memory group (*M* = 51.03, SD = 10.81) and 21 children in the high memory group (*M* = 75.00, SD = 7.42).

Because age was a potential source of variance in the memory tasks, a Pearson product-moment correlation between age and performance on the picture and abstract memory tasks was performed. Age was not correlated with performance on either task; for the picture memory task, *r*(48) = .21, *p* = .14, and for the abstract memory task, *r*(48) = -.19, *p* = .18. Because age was not correlated with performance on either of the memory tasks, MANOVAs were used in subsequent analyses instead of MANCOVAs.

To test the hypothesis that children who perform better on the picture recognition memory task will have greater left lateral frontal (F7) and left anterior temporal (T3) EEG coherence during encoding than children who perform less well, a repeated measures MANOVA was conducted on the coherence values between F7 (left frontal) and T3 (left temporal), and between F8 (right frontal) and T4 (right temporal). The within subjects factors were hemisphere (left, right) and condition (baseline, encoding), and the between subjects factor was group (determined by high or low performance on the picture recognition memory task).

To support this hypothesis, there should have been a Group by Hemisphere by Condition interaction in which the high performing group had greater left hemisphere coherence during the encoding phase relative to baseline. However, the hypothesis was not supported (MANOVA results are shown in Table 2). There were no main effects or interactions involving performance group.

To test the hypothesis that children who perform better on an abstract recognition memory task will have greater right lateral frontal (F8) and right anterior temporal (T4) EEG coherence during encoding than children who perform less well, a repeated measures MANOVA was conducted on the coherence values between F7 (left frontal) and T3 (left temporal), and between F8 (right frontal) and T4 (right temporal). The within subjects factors were hemisphere (left, right) and condition (baseline, encoding), and the between subjects factor was group (determined by high or low performance on the abstract recognition memory task).

To support the hypothesis, there should have been a Group by Hemisphere by Condition interaction in which the high performing group has greater right hemisphere coherence during the encoding phase relative to baseline. This hypothesis was not supported (MANOVA results are shown in Table 2). There were no main effects or interactions involving performance group.

Post hoc Analyses

Because encoding and retrieval processes are so intricately linked (Cabeza & Nyberg, 2000) and because they likely depend on the same brain areas, coherence at the hypothesized electrode sites (F7-T3 and F8-T4) was also examined at baseline and during the retrieval portion of both memory tasks. For the picture memory task (see Figure 1), there was a Group by Hemisphere by Condition interaction, $\eta^2 = .10$, in which children in the low performance group had greater right hemisphere coherence during retrieval (*M* = .38, *S.E* = .04) than at baseline (*M* = .29, *S.E.* = .02), *t*(22) = 2.13, *p* = .04. In the high performance group, although visual inspection of the data suggested a trend toward greater left hemisphere coherence during retrieval (*M* = .30, *S.E.* = .03) than at baseline (*M* = .25, *S.E.* = .02), the simple effects testing was not significant, *t*(20) = 1.55, *p* = .14. For the abstract memory task, there were no main effects or interactions involving performance group. MANOVA results for both tasks are shown in Table 2.

To examine the possibility of group differences in coherence at the hypothesized electrode sites (F7-T3 and F8-T4) among children who performed either the same or differently on the two memory tasks, four groups were created based on a comparison of performance on the two memory tasks. Fifteen children were in the low performance group on both memory tasks, 10 children were in the high performance group on both memory tasks, 13 were in the low abstract/high picture group, and 11 were in the high abstract/low picture group. Baseline to encoding change scores were computed for both electrode pairs for both memory tasks (scores were computed by subtracting coherence at baseline from coherence during the encoding phase of each task). A repeated measures MANOVA was conducted on baseline to encoding change scores (for both tasks) for coherence between F7 (left frontal) and T3 (left temporal), and between F8 (right frontal) and T4 (right temporal). The within subjects factors were hemisphere (left, right) and condition (picture, abstract), and the between subjects factor was group (determined by performance on the two memory tasks). There were no main effects or interactions involving group; all F's < 1.31, all *p*'s > .28).

Exploratory Analyses

To address the question of whether expressive and receptive language relate to memory performance in the same way, or whether one of these more strongly correlated with short-term recognition memory than the other, a test of the difference between correlations was performed. The test for the difference in correlations between the language measures and the picture memory task (PPVT & picture task $r = .34$; EVT & picture task, $r = .41$) showed no difference between the two correlations; $t\ (30) = .29$; $p = .61$. The test for the abstract drawing correlations (PPVT & abstract task $r = .04$; EVT & abstract task, $r = .06$) likewise showed no difference between the two correlations; $t\ (30) = .08$, $p = .53$.

To address the question of which variables would be most useful in predicting performance on both the picture and abstract tasks, a series of regression equations were computed. The following variables were considered: age, gender, expressive and receptive language, EEG coherence during encoding, and EEG coherence during retrieval. Multiple regression equations were considered using the variables mentioned above. The regression equation reported here explained the most variance and includes only significant predictors of task performance. The regression equation for predicting scores on the picture memory task included EEG coherence at F7-T3 and F8-T4 during retrieval, performance on the PPVT-III, and gender. This model accounted for 29 percent of variance in task performance, $F(4, 40) = 4.06$, $p = .007$. Beta weights for this model are presented in Table 3. The beta weight for left hemisphere coherence at retrieval was positive and the beta weight for right hemisphere coherence at retrieval was negative. The beta weight for gender was positive, indicating that being female was predictive of higher performance. Performance on the abstract memory task was not correlated with any of the variables considered here, so a regression equation was not computed.

Discussion

Verbal Encoding

The goal of this research was to examine verbal encoding as a source of individual differences in short-term recognition memory in young children. To accomplish this, the first step was to establish a relation between language ability and performance on a memory task for which stimuli can easily be labeled or encoded verbally. It was hypothesized that receptive and expressive language would be positively correlated with performance on both the picture memory task (which consisted of images that could easily be labeled) and the abstract memory task (which consisted of abstract images). To support the idea that verbal encoding accounts for individual differences in memory, there should be a stronger relation between language and performance on the picture memory task than between language and performance on the abstract memory task. Both expressive and receptive language were positively correlated with performance on the picture memory task. This finding is consistent with previous research that has established a positive relation between language and memory (Cardell & Bell, 2009; Morris & Baker-Ward, 2007). However, there was no relation between language and performance on the abstract memory task. This suggests that the observed relation between language and memory is not due simply to differences in general mental ability. Rather, it is likely that language in some way differentially supports memory processes for some stimuli more than for others. That is, language is more likely to be related to memory when it can serve as a retrieval cue (such as when the memory involves stimuli that can be verbally labeled). This is consistent with the idea that the development of a symbolic representation system such as language enhances memory by altering the way stimuli are encoded and retrieved.

Expressive and receptive language did not differ in their relation to performance on either of the memory measures. This is not surprising given that these two measures are positively correlated with each other. To fully examine the differential relation that expressive and receptive language may have to memory, a population with divergent expressive and receptive language scores would need to be examined.

Although the above findings are consistent with the idea that the use of language supports memory processes, these associations do little to explain the source of individual differences in short-term memory and do not address the question of *how* language might support memory processes. To test the idea that language accounts for individual differences by enhancing verbal encoding, EEG coherence was examined at baseline and during the encoding phase of the two short-term memory tasks. Based on previous research linking left lateral frontal (F7) and anterior temporal (T3) regions to language and memory processing (Fletcher et al., 1995; Kapur et al, 1996; Martin et al., 1996; Menon et al. 2005; McDermott et al., 1999; Vandenberghe et al., 1996) coherence between these two electrode sites was taken as evidence of verbal encoding. The corresponding sites in the right hemisphere (F8 and T4) were expected to be more involved in nonverbal memory processes (Kanwisher et al., 1997; Kelley et al., 1998; Lee et al., 2005;

McCarthy et al., 1997; Passarotti et al., 2003; Wagner et al., 1998a). Children who use more verbal encoding strategies should have more coherence in the left hemisphere while children who use less verbal encoding strategies should exhibit increased coherence in the right hemisphere. As with the relation between language and memory, performance on the picture and abstract memory tasks was expected to relate to different patterns of EEG coherence.

The hypothesis that (for the picture memory task) children in the high memory group would have greater coherence between left lateral frontal (F7) and left anterior temporal (T3) areas than children in the low memory group during the encoding phase of the task was not supported. In fact, there were no group differences at the hypothesized electrode sites, indicating that the tendency to encode stimuli verbally is not a source of individual differences in task performance. Similarly, coherence (at F8 and T4) was not related to group differences in performance on the abstract memory task. This finding is inconsistent with previous research in our lab indicating that higher left hemisphere (F7-T3) coherence during a film clip and during the encoding phase of a short-term recognition memory task (in which stimuli can be easily labeled) is associated with better performance on the recognition memory task (Cardell and Bell, 2009).

An attempt to examine group differences between children who performed the same (High-High, Low-Low) or differently (High-Low, Low-High) on the two memory measures was not informative. Given the small size of the four groups (ranging from 10 to 15), more children would be needed to reasonably examine trends related to group differences. Interestingly, although it may seem logical to expect children who do well or poorly on one memory task to perform similarly well or poorly on the other, the four groups were nearly the same size. Future studies focused on differences in processing by high and low performers on these tasks could benefit from a larger sample size (at least double what was used in this study).

Verbal Retrieval

Retrieval and encoding processes are intricately linked (Cabeza & Nyberg, 2000), and additional research has suggested that brain patterns during a surprise retrieval task for visually presented words are the same as those observed during intentional encoding (Buckner, Wheeler, & Sheridan, 2001). Because no evidence was found that verbal encoding (as signified by F7-T3 EEG coherence) is a source of individual differences in performance on the memory task, EEG coherence during the retrieval phase of the task was also examined. For the picture memory task, there was a Group by Hemisphere by Condition interaction at the hypothesized electrode sites. Children who performed more poorly on the task showed an increase in right hemisphere coherence between baseline and retrieval, indicating that children who perform more poorly also tend to use less verbal retrieval strategies. There was also a trend toward an increase in left hemisphere coherence between baseline and retrieval in the high memory group. Although the t-test was not significant, regression analyses (see Table 3) indicated that both left and right hemisphere coherence at retrieval predict performance on this task (left hemisphere coherence at retrieval is a positive predictor of performance, and right hemisphere coherence is a negative predictor of performance). This suggests that although verbal encoding does not seem to explain individual differences in performance on the memory task, the use of linguistic cues at retrieval does.

Encoding vs. Retrieval

The observed difference between encoding and retrieval is somewhat surprising, especially since the use of verbal strategies at encoding seems to be a necessary condition if verbal strategies are to be used at retrieval (Morris & Baker-Ward, 2007). Assuming that this is the case, one possible explanation for the different findings at encoding and retrieval is that all or most children used language to some degree during the encoding process but only some made use of previously encoded linguistic cues during retrieval. All of the children in the study were able to communicate verbally, and many verbally named the images as they were presented. It may be that three-year-olds initially encoded stimuli using a variety of environmental cues, some symbolic or linguistic and some not. It is also possible that the level of sophistication of the child’s language affected the subsequent use of linguistic cues at retrieval. Many of the question cards included images that were visually similar but semantically distinct. For example, one card showed a cow and a goat, another card showed water pouring from a watering can and water coming from a shower, another showed a car and a truck, and another showed a helicopter and an airplane. Perhaps children who made labeling errors during the encoding phase (for example, some children referred to the goat as “cow” or “animal”, the helicopter as “airplane” or “flying”, the watering can as “water”, or the truck as “car”) were not able to rely on the linguistic features of the memory at retrieval and were forced to rely more heavily on nonverbal information (leading to an increase in right hemisphere coherence at retrieval in the low performance group relative to the high performance group). The question of whether children rely on the linguistic cues during retrieval or tend to use more nonverbal cues may therefore be of more salience than the question of what happens at encoding. The question of whether or not linguistic encoding can explain individual differences in memory performance may be more relevant at younger ages when some children can communicate verbally and others cannot.

It is also important to address the question of why these findings differed from previous research in which hemispheric differences during encoding related to subsequent performance on a similar task (Cardell & Bell, 2009). Although some of the stimuli were the same in both studies, an important difference is that the present study included twice as many stimuli as the previous study. The failure to find an effect at encoding may simply be because the children became more distracted during the longer task and spent less time focusing on the pictures, which means that the EEG coherence for these epochs includes not only "encoding" but also "distraction". The retrieval portions of the task were much shorter, and the experimenter's questions to the child prompted at least momentary attention to the task. This means that there is likely to be less "noise" in the retrieval data than in the encoding data.

EEG coherence during retrieval at F7-T3 and F8-T4 was not related to differences in performance on the abstract memory task. This suggests that success on the two different memory tasks involves different types of processing or that multiple factors might be involved. It is possible that since the abstract images were meaningless, children's ability to pay attention to such stimuli was an important factor in their performance on the task. It is also possible that children are using more widely varied processing strategies during the task. For example, a few children made a clear attempt to apply meaning to the symbols by naming them. One child even produced nonsense words as the images were presented.

It is unclear what type of processing leads to success on the abstract task. It may be interesting in the future to create an experimental design in which abstract images or novel objects are presented and then either given a label by a researcher for one group or given no label for the control group. This may be one way to manipulate how children process the stimuli and would be a more experimental approach to addressing the question of how the use of language as a system of symbolic thought relates to memory processes. The use of different age groups may give some insight into developmental trends in the use of language as a tool to enhance memory.

Predicting Memory Performance

Regression analyses revealed that receptive language, gender, and EEG coherence at F7-

T3 and F8-T4 during retrieval were all significant predictors of scores on the picture memory task. As previously mentioned, the fact that EEG coherence at lateral frontal and anterior temporal sites in both hemispheres during retrieval is predictive of memory performance provides more evidence that the use of verbal strategies at retrieval enhances performance on a memory task for which images can easily be labeled. As expected, the beta weight for F7-T3 was positive, indicating that greater left hemisphere coherence (verbal processing) is predictive of better performance; the beta weight for F8-T4 was negative, indicating that higher right hemisphere coherence (nonverbal processing) is predictive of poorer performance. The finding that being female is predictive of higher performance is interesting, especially since girls and boys did not differ in their language performance. However, this finding is not surprising given previous research suggesting that women tend to rely more heavily than men on verbal encoding in a pictorial memorization task (Frings et al., 2006). Together, receptive language, gender, and EEG coherence at F7-T3 and F8-T4 during retrieval accounted for 29 percent of the variance in scores on the picture memory measure. None of the variables examined were significant predictors of performance on the abstract memory test. Explaining the processes underlying performance on the abstract memory task was not a primary goal of this study. However, future studies could include additional measures (of visual attention, for example), which might help to predict performance on the abstract memory task.

Coherence at Other Scalp Locations

All of the EEG analyses were limited to coherence between lateral frontal (F7, F8) and anterior temporal (T3, T4) electrode sites. Other frontal-temporal combinations were not examined because brain areas associated with other sites are specifically linked with other types of processing. For example, activation at F3 and F4 as well as coherence between these and temporal areas are largely related to working memory in early childhood (e.g., Bell & Wolfe, 2007; Wolfe & Bell, 2004). The frontal pole electrode sites are linked with emotional processes (e.g., Adolphe, Damasio, & Tranel, 2002; Maddock, Garrett, & Buonocore, 2003) and moral judgement (Moll, Eslinger, & de Oliveira-Souza, 2001). Therefore, any relation of coherence at these sites to individual differences in task performance would not be relevant to the current research questions, and an attempt to link findings in these areas to evidence for verbal encoding or retrieval would be a stretch.

Conclusions

The behavioral data presented here support the notion that language ability and short-term recognition memory are linked in children. The relation between language and memory was limited to a task for which the use of verbal labels as a memory attribute is straightforward. This suggests that the relation of language to memory is related to a difference in processing and not to general mental ability. The EEG coherence data help to elucidate the processes involved, pointing to retrieval rather than encoding as the phase of processing that depends most on language.

If these findings also hold true for episodic memory for autobiographical events, they may have important implications for our understanding of infantile amnesia. Existing theories point to language as a factor in this phenomenon (e.g., Fivush & Hamond, 1990; Hayne, 2004; Leichtman & Ceci, 1993; Simcock & Hayne, 2002). Additionally, analysis of EEG coherence in children with specific language impairment may yield important insight into the memory deficits that often coincide with SLI. For example, children with expressive versus receptive language deficits may have different coherence patterns. As our understanding of the link between language and memory encoding/retrieval increases, it may even be possible to eventually develop intervention programs that will help to attenuate the negative effects that language deficiencies such as SLI have on other areas of cognitive development.

Limitations

It is important not to generalize the trends observed in this sample to other age groups. It is likely that the predictive value of the use of verbal strategies during retrieval is only valid at ages when the ability to use these strategies is varied. Future studies might benefit from the inclusion of multiple age groups or a longitudinal design. This would shed light on any developmental trends in the degree to which differences in linguistic processing account for individual differences in memory performance.

Future Research

Although these findings fuel questions about the nature of the role of verbal encoding and/or retrieval in infantile amnesia, this research should not be taken as evidence that a lack of language early in life is responsible for infantile amnesia, particularly because this study included only children who already had the capacity to communicate verbally. Further research is needed to replicate and extend these findings to other types of memory (such as autobiographical memory) and other groups of children (such as those with a clinically significant language deficit). Further research is also needed to map out general brain development in infancy and early childhood through the examination of coherence during all types of cognitive tasks.

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Table 1. Descriptive Statistics for Behavioral Measures

	Mean	SD	Range	N
Picture Task[a]	80.80	18.28	40-100	50
Abstract Task[a]	61.10	15.23	30-90	50
PPVT-III[b]	53.28	14.83	27-86	50
EVT[b]	42.76	5.36	35-61	33

[a] Scores on the Picture and Abstract Memory Tasks are percentages of correct responses.

[b] Scores on the PPVT-III and EVT are raw scores.

Table 2. Summary of Multivariate Analysis F Values for EEG 6-9 Hz Coherence during Picture and Abstract Memory Tasks

	Group	Hemisphere	Condition	G X H	G X C	H X C	G X H X C
df	1,48	1,48	1,48	1,48	1,48	1,48	1,48
Baseline/Encoding							
Picture Task			3.98^{+}				
Abstract Task	3.75^{+}						
df	1,42	1,42	1,42	1,42	1,42	1,42	1,42
Baseline/Retrieval							
Picture Task		6.02*	3.46^{+}				4.46*
Abstract Task							

$^{+}$ p < .10, * p < .05.

Table 3. Multiple Regression Analysis: Language, Gender, and EEG Coherence (Retrieval) as Predictors of Performance on Picture Memory Task

	Beta (Standardized)	R^2	F
Model		.29	4.06**
Retrieval EEG (F7-T3)	.32*		
Retrieval EEG (F8-T4)	-.31*		
PPVT-III (raw)	.32*		
Gender[a]	.33*		

*$p < .05$, **$p < .01$, [a]Male was coded as 0 and female as 1, so a positive β indicates that being female is predictive of higher performance

Figure 1. EEG Coherence at F7-T3 and F8-T4 during Baseline and Retrieval (G X H X C)