LANGUAGE DEVELOPMENT AND VERBAL ENCODING: IMPLICATIONS FOR INDIVIDUAL DIFFERENCES IN SHORT-TERM MEMORY IN 3-YEAR-OLDS

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There is evidence that language ability is related to a number of cognitive processes, including memory. This study used EEG to investigate the extent to which verbal encoding strategies account for individual differences in short-term recognition memory performance in 44 3-year-olds. As hypothesized, children with better language ability (as measured by the PPVT-III) performed better on the memory task. Analyses of EEG power at the hypothesized electrode sites were not significant, but the hypothesis that children who perform better on the recognition memory task will use more verbal encoding strategies than children who perform less well was partially supported by EEG coherence analyses. Children in the high memory group had significantly greater frontal-temporal coherence in the left hemisphere (F7-T3) than the low memory group. However, this was true both at baseline and during encoding, implying that children in the high memory group have greater overall connectivity between these brain areas and that they tend to use more verbal strategies than the low memory group, as they interact with their environments in general, not just during a memory task.
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DEDICATION

I would like to dedicate this to the students and faculty of Virginia Tech who lost their lives on April 16, 2007. You will live eternally in our hearts. Thank you for reminding us what it means to be Hokies.

I would also like to dedicate this to my Mom and Dad, who have given me a lifetime of unconditional love and support and who taught me to love learning; and to Fr. Samuel, who also supported me immeasurably during this entire process.
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Language Development and Verbal Encoding: Implications for Individual Differences in Short-Term Memory in 3-Year-Olds

Introduction and Background

The idea that language might be an important cognitive tool is not new. Decades ago, Bruner (1966) proposed that as children develop the ability to use language as a conceptual tool, it transforms their thinking. There is evidence that language ability is indeed related to a number of cognitive processes. In particular, language appears to be strongly associated with memory.

Working memory has been conceptualized by Engle and colleagues as maintaining information in an active state and inhibiting other information from entering the active state (Conway & Engle, 1994; Kane & Engle, 2000; 2002). Working memory can be thought of as the ability to use attention to maintain information or to suppress information. According to this point of view, working memory has more to do with executive attention than it does with memory (Engle, 2002).

The relation between working memory and language is well-established. A number of behavioral studies have demonstrated that working memory capacity and language ability are directly linked in children (Avons, Wregg, Cupples, & Lovegrove, 1998; Gathercole, Service, Hitch, Adams, & Martin, 1999; Swanson, 1996), adolescents (e.g., Wesimer, Plante, Jones, & Tomblin, 2005), and adults (e.g., Kemper & Sumner, 2001; MacDonald, Almor, Henderson, Kempler, & Andersen, 2001; see Baddeley, Gathercole, & Papagno, 1998, for a review of studies across the lifespan). Three- and 4-year-old children who performed well on a phonological working memory task also produced more complex language (Adams & Gathercole, 1995), and high receptive vocabulary was predictive of high working memory performance in 4½-year-olds (Wolfe & Bell, 2004). It is possible that this is because language supports the maintenance of information in an active state. Because working memory capacity also supports short- and long-term memory formation, it is likely that language is related to these as well. However, while there have many studies of language and working memory, there have been fewer studies linking language to other types of memory.

Short-term memory, for example, has been studied less frequently but has been linked to verbal ability in several studies. In one study of memory and language in adults, working memory and short-term memory both contributed unique variance in the prediction of Verbal SAT scores (Cantor, Engle, & Hamilton, 1991). There is also some support for this relationship
in children. In one study, for example, infant recognition memory was predictive of language development during the preschool years (Rose, Feldman, Wallace, & Cohen, 1991). In another study of children with Specific Language Impairment, verbal ability was more predictive of event memory than non-verbal IQ was (Bishop & Donlan, 2005). These studies point to a link between the two constructs, but additional investigation of the relation between short-term memory and language is clearly needed. The purpose of the proposed study is to investigate the nature of the potential link between the development of language and short-term memory.

Integration of Language and Memory Developmentally

It is hard to ignore the fact that children’s memory seems to improve as language ability develops, and the idea that language and memory are related is a commonly held belief. Despite this conventional wisdom, few studies have been done in early childhood that attempt to specifically link language ability with short-term memory (e.g., Rose, Feldman, Wallace, & Cohen, 1991). In particular, few studies have investigated the degree to which language ability might enhance strategies of memory encoding and retrieval (e.g., Bishop & Donlan, 2005). Much of the existing research is specifically related to episodic and autobiographical memories. In particular, a number of studies have investigated the infantile amnesia phenomenon.

Most people have few or no memories before about 3 and 4 (MacDonald, Uesiliana, & Hayne, 2000; Mullen, 1994; 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.

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,
suggesting that only the label for the event was encoded, and the memory was retrieved by reconstructing the image from declarative memory. This experiment clearly 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; Schweickert, 1993) who encode information semantically have better subsequent memory of that information than when it is not encoded semantically.

Harlene 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 reach a certain level. 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, gist memory traces are less volatile than precise memory traces (Brainerd & Reyna, 2002; Harnishfeger & Brainerd, 1994). Leichtman and Ceci (1993) proposed that as children age, they are shifting from use of verbatim memory traces to gist memory traces, which may explain why children have difficulty remembering things that happened before the age of 3 or 4. Language ability is developing during this shift 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 very 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 verbal label 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. 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.

Based on the above discussion, it appears that the use of verbal labels facilitates semantic encoding by giving us rapid access to information in long term memory. If this is the case, we would expect to have better recall of events when we know a word that describes them. Similarly, if a child lacks the verbal ability to distinguish between a cow and a goat (two animals which share many visual features) or uses the same label to describe both, then if we show the child a picture of a goat and later show the same child two simple line drawings—one of a cow and one of a goat—we would expect that child to have more difficulty recalling which of the two images he or she had previously been shown. We would expect the same to be true if the child simply does not have a label for either picture.

However, simply finding that a child with better verbal ability has better recognition memory for images is insufficient to clearly support the claim that language enhances memory for pictures because the child is using verbal encoding strategies. 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 this is taking place.

*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 demonstrated 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 studies of brain-injured patients also suggest that medial temporal lobe is important for declarative memory. Additional evidence from brain-damaged patients suggests that the frontal lobes are also important in memory formation (Squire & Knowlton, 1995). This is consistent with other studies that have shown that patients with frontal
lobe damage have difficulty with ordered memory tasks and those with medial temporal lobe
damage have trouble recognizing 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 have
demonstrated that the left frontal cortex is active during tasks that require an individual to
memorize verbal information (Fletcher et al, 1995; Kapur et al, 1996; McDermott et al, 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 et al, 1994); furthermore, several fMRI studies have shown that left frontal activation is
related to subsequent recognition (Buckner, Wheeler, & Sheridan, 2001; Wagner 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 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 et al, 1996). Based on this evidence, left frontal activation can be
considered evidence of verbal encoding of information.

However, 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 the two can be viewed as two sides of the
same coin. 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 et al., 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). 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.

Context for Current Study

One way to gain valuable information about the way in which different cognitive processes relate (both behaviorally and physiologically) is to study these systems as they are emerging. Many of the existing studies involving brain imaging and memory have used adult subjects. Few studies (see above discussion for examples) have investigated the simultaneous development of language and memory. This study helps fill that gap, and the use of brain imaging techniques provides particularly useful insight into the relation between memory and language at the neurological level. The proposed relation between language and memory is likely bidirectional, and better short- and long-term memory probably helps facilitate language development. It is therefore important to note that while the current study is designed to examine the other side of this relationship (that linguistic encoding may enhance memory formation and retrieval), it is not meant to undermine the possibility that memory is also an important factor in language development. Memory formation and retrieval are the result of multiple processes. However, memory research has been previously confounded by the fact that behavioral tests of memory are entirely dependent on retrieval processes and therefore give little or no insight into other processes that might be involved. The temporal resolution of EEG can help tease apart the importance of the various stages of information processing. This study uses EEG to investigate individual differences in encoding strategies during a recognition memory task.

Research Questions and Hypotheses

Based on the above discussion, three hypotheses were identified: 1) Children with better language ability, as measured by the PPVT-III, will also perform better on a short-term recognition memory task than children with lower language ability. (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.) 2) Children who encode the items verbally will perform better on the
recognition memory task than children who use less verbal encoding strategies; specifically, children who perform better on the recognition memory tasks will have greater left lateral frontal (F7) and left anterior temporal (T3) EEG activation during the encoding phase of the task (i.e., while looking at the picture) than children who perform less well on the task. 3) Children with greater connections between left lateral frontal and anterior temporal regions will use more efficient encoding strategies; therefore, children who perform better on the memory tasks will have better coherence between left lateral frontal (F7) and left anterior temporal (T3) regions than children who perform less well.
Method

Participants

Participants were part of the fourth wave of data collection in a larger longitudinal study of individual differences in cognitive development. The original sample consisted of 106 healthy full-term 5-month-old infants from uneventful pregnancies. For the fourth wave of the study, parents were contacted by telephone just after their child’s 3-year-old birthday to schedule the research visit. Sixty-eight agreed to return for the 3-year-old visit, and 46 of these successfully completed the measures necessary for inclusion in this study (44 had valid language and memory measures and 44 had both valid memory scores and EEG data). Twenty children were excluded because they had missing or invalid data on the Corsi-Milner test of recognition memory (either they did not successfully complete the practice trials or they were uncooperative during the task), 6 were excluded due to invalid PPVT-III scores (either they did not complete the measure or were not cooperative during the administration of the test), and 9 children did not have EEG data because they either refused the cap or pulled the cap off between baseline and task.

All children ranged in age from 36-39 months at the time of their lab visit. Mean birth weight was 6.98 lbs. Of those who reported education level (2 fathers did not report), all parents had completed high school. Of these, 78% of mothers and 75% of fathers had a college degree. Of the parents, 85 were Caucasian, 3 were African American, 2 were Hispanic, and 1 was Asian.

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 while a researcher applied the EEG cap and heart rate electrodes. Heart rate is not a variable in this study and will not be discussed further. Physiological data was recorded at baseline while the child watched a 1-minute segment of Finding Nemo. Physiological recordings were also obtained during a battery of cognitive tasks, including the short-term memory task that is a part of this study. A parent was present in the room at all times during the study.

Physiological Recordings. Physiological data was collected, examined, and analyzed according to the procedure described by Bell (in press). 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 was 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 0.1 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 was examined using EEG Analysis System Software (James Long Company, Canoga Lake, NY). The data was referenced to an average reference using the software and was visually examined and scored for artifact (eye, muscle, and gross motor movements). Any artifact was rejected and excluded from analyses. Remaining data was transformed using a discrete Fourier transform (DFT) using a Hanning window of 1-s width and 50% overlap. Power was computed for the 6- to 9-Hz frequency band, which is the dominant frequency band for preschool children (Marshall, Bar-Haim, & Fox, 2002).

Brain activation can be conceptualized as increased neural firing within a given cortical region. This increase in neural firing results in summated post-synaptic potentials that can be measured with electroencephalography (Davidson, Jackson, & Larson, 2000). This EEG measurement is typically labeled as “power” and will be expressed as mean square microvolts. The power data were subjected to natural log (ln) transformation to normalize the distribution because power data typically exhibit a positive skew (Davidson et al, 2000). Whereas power values yield information about the electrical activation of a given brain area, coherence values between two electrode sites are presumed to be a measure of the strength and number of synaptic connections between the corresponding brain areas (Thatcher, 1994). 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.

**Short-term Recognition Memory Task.** Short-term memory was assessed using a variation of the Corsi-Milner test of recognition memory (Corsi, 1972, cited in Milner, 1972). During this task, the children were shown 20 cards, each depicting a simple monochromatic line drawing of an everyday object, and 5 question cards, each depicting one image that was previously presented and one image that was not previously presented. See Appendix A for a
sample of stimuli and question cards. See Table 1 for descriptive statistics for the Corsi-Milner task. 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 was required to demonstrate that he or she understood the meaning of the words already seen by correctly identifying which card was “already seen” in at least two of three practice trials. 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, and 20, 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.

During the administration of the task, a research assistant sat at a computer in the corner of the 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 event marks were 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 to be separated from the retrieval phase in the EEG file.

**Language measure.** The Peabody Picture Vocabulary Test-III (PPVT-III; Dunn & Dunn, 1997) was administered to assess each child’s receptive vocabulary and verbal comprehension. This test was selected because it is age appropriate and is a widely accepted and nationally standardized instrument. Raw scores were used in all analyses. See Table 1 for descriptive statistics on the PPVT-III.

**Results**

Children were divided into two groups based on their performance on the Corsi-Milner recognition memory task. Groups were determined by median split. Because over half of the children achieved a perfect score on the memory task, the median score was 5. Children in the
high performance group had a score of 5 (a perfect score) on the Corsi-Milner recognition memory task, and children in the low performance group had scores ranging from 0 to 4.

Behavioral Analyses. To test the first hypothesis (that children with higher language ability also have better short-term memory than children with lower language ability), an independent groups t-test was conducted using the mean PPVT-III score for each group. Children who had valid scores on both the PPVT-III and the Corsi-Milner test of recognition memory were included in these analyses. Of the 44 children who had valid scores on both measures, 25 were in the high performance group and 19 were in the low performance group. The results of the t-test supported the first hypothesis, $t(42) = 2.89, p = .006$, indicating that those in the high-memory group ($M = 51.52, SD = 10.54$) had higher scores on the PPVT-III than those in the low-memory group ($M = 41.37, SD = 12.75$). A Pearson product-moment correlation of scores on the Corsi-Milner and scores on the PPVT-III also supported this hypothesis, showing a positive correlation between language and memory, $r(44) = .528, p < .0005$.

EEG Power Analyses. To test the second hypothesis (that children who perform better on the recognition memory tasks will have greater left frontal (F7) and left anterior temporal (T3) EEG activation during the encoding phase of the task than children who perform less well), a repeated measures MANOVA was performed on the ln EEG power values at F7 (left lateral frontal) and F8 (right lateral frontal) and at T3 (left anterior temporal) and T4 (right anterior temporal). The within subjects factors were hemisphere (left, right) and condition (baseline, encoding portion of C-M task); and the between subjects factor was group (high or low performance on the recognition memory task). MANOVA results are shown in Table 2. Children who had both EEG data and valid scores on the Corsi-Milner recognition memory task were used in this and subsequent EEG analyses.

To fully support for the second hypothesis, there should have been a Group X Hemisphere X Condition interaction, with those in the high performance group showing higher power values than the low performing group at both left hemisphere sites (F7 and T3) during the encoding phase of the task. This hypothesis was not supported. There were no main effects or interaction effects at F7 and F8. There were also no main effects or interaction effects at T3 and T4.

Since the specificity of the hypothesized electrode pairs was based on limited studies done with adults and because activation patterns change, becoming more specified between
infancy and 4.5 years (Bell & Wolfe, 2007), additional analyses of all frontal and temporal sites were conducted to check for group differences in power values. The significant findings of these additional repeated measures MANOVAs are also displayed in Table 2.

Additional analyses provided partial support for the second hypothesis. There was a Group X Hemisphere interaction effect at F3 and F4, $\eta^2 = .10$, such that the high memory group had greater left than right hemisphere power, and the low memory group had greater right than left hemisphere power (see Figure 1). However, simple effects testing did not reveal any significant differences: $t(25) = 1.32, p = .20$ and $t(17) = -1.57, p = .14$, respectively. In addition to the interaction effect, there was a main effect of condition at Fp1 and Fp2, $\eta^2 = .15$, such that both groups had higher power values during encoding ($M = 2.92, S.E. = .050$) than at baseline ($M = 2.82, S.E. = .066$). Additional main effects of condition that approached significance at T3, T4 and at T7, T8 ($p’s < .10$) showed trends in the same direction.

EEG Coherence Analyses. To test the third hypothesis (that children who perform better on the memory tasks will have better coherence between left frontal (F7) and left medial temporal (T3) regions than children who perform less well), a repeated measures MANOVA was performed 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, task), and the between subjects factor was group (determined by high or low performance on the recognition memory task).

To fully support the third hypothesis there should have been a Group X Hemisphere X Condition interaction, such that the children in the high memory group had greater coherence between left hemisphere sites (F7 and T3) than the low performing group during the encoding phase of the task. MANOVA results are shown in Table 3. The third hypothesis was partially supported. There was a Group X Hemisphere interaction, $\eta^2 = .10$, such that children in the high memory group had greater left hemisphere coherence ($M = .22, S.E. = .012$) than children in the low memory group ($M = .17, S.E. = .014$), $t(42) = 2.55, p = .01$, but right hemisphere values did not significantly differ between groups, $t(42) = -.964, p = .34$ (see Figure 2). However, this was across conditions and not just during encoding.

Although this hypothesis was partially supported, additional MANOVAs of all frontal-temporal combinations were conducted because recent research has shown that coherence patterns become tied to more specific electrode pairs between infancy and 4.5 years (Bell &
Wolfe, 2007). Significant findings are included in Table 3. There was a Group X Hemisphere X Condition interaction at F7-T7 and F8-T8, $\eta^2 = .10$, such that the high memory group had significantly higher left than right coherence at baseline, $t(25) = 2.46$, $p = .02$, and the low memory group had significantly higher left than right coherence during encoding, $t(17) = 2.89$, $p = .01$ (see Figure 3). There was also a main effect for Condition at F3-T7 and F4-T8, $\eta^2 = .09$, such that there was greater coherence at baseline ($M = .24$, $S.E. = .008$) than during encoding ($M = .23$, $S.E. = .006$).

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, power and coherence were also examined at baseline and during the retrieval portion of the task. Results of these MANOVAs are displayed in Tables 4 and 5, respectively. Similar patterns were expected as for the baseline and encoding hypotheses.

EEG Power Analyses. The power analyses at baseline and retrieval were not significant. A main effect for Condition at F7,F8 approached significance, $\eta^2 = .07$, with greater power during retrieval than at baseline. At T7,T8, a Group X Hemisphere X Condition interaction of moderate size also approached significance, $\eta^2 = .08$, such that children in the high memory group had greater left than right activation during retrieval and children in the low memory group had greater right than left activation during retrieval (see Figure 4), but these trends were not significant, $t(24) = 1.09$, $p = .29$ and $t(17) = -1.516$, $p = .15$, respectively.

EEG Coherence Analyses. There was a main effect for Condition at F3-T3 and F4-T4, at F7-T3 and F8-T4, and at Fp1-T3 and Fp2-T4, such that coherence was greater during retrieval than at baseline for all electrode pairs. There was also a Group X Hemisphere interaction at F7-T3 and F8-T4, $\eta^2 = .09$, such that those in the low memory group had greater right than left coherence, $t(17) = 3.07$, $p = .007$, but those in the high memory group did not have significantly different right than left coherence, $t(25) = 1.16$, $p = .26$ (see Figure 5).

Summary of Findings

The first hypothesis (that language and memory are positively correlated) was fully supported by analyses of the behavioral measures. The second hypothesis (that children who perform better on the recognition memory tasks will have greater left frontal (F7) and left anterior temporal (T3) EEG activation during the encoding phase of the task than children who
perform less well) was not supported, but subsequent analyses of other frontal and temporal electrode pairs partially supported the idea that children in the high memory group may use more verbal encoding strategies than children in the low memory group because there was a trend toward greater left than right activation in the high memory group and a trend toward greater right than left activation in the low memory group at medial frontal sites (F3, F4). The third hypothesis (that children who perform better on the memory tasks will have better coherence between left frontal (F7) and left medial temporal (T3) regions than children who perform less well) was partially supported, indicating that children in the high memory group have greater connections between these regions. However, the effect was in both baseline and encoding conditions rather than only during encoding.

Discussion

The goal of this research was to examine verbal encoding as a source of individual differences in short-term recognition memory. To accomplish this, it was first necessary to establish that there is indeed a positive relation between language and short-term recognition memory. The first hypothesis (that language ability and short-term recognition memory are positively related) was supported. There was a positive correlation between the language and memory measures, and the children in the high memory group performed better on the language measure than children in the low memory group. This finding corresponds with previous research suggesting a link between language and memory in childhood (e.g., Rose, Feldman, Wallace, & Cohen, 1991).

However, simply confirming the association does little to explain the source of individual differences. To find support for the argument that verbal encoding during stimulus presentation is a source of individual differences in short-term recognition memory, brain activation patterns and coherence were examined at baseline and during the encoding phase of a short-term recognition memory task. Based on previous research suggesting that the left lateral frontal (F7) and anterior temporal (T3) regions are associated with linguistic processing, group differences in activation and coherence of these areas are taken as evidence of different encoding processes.

The hypothesis that children in the high memory group would have greater activation of these areas during encoding than children in the low memory group was not supported. That is, there was no Condition X Hemisphere X Group interaction at either of these electrode sites. However, given that the initial hypotheses were generated using adult activation patterns, and
based on previous research suggesting that very young children may have less specific activation patterns than adults (Bell & Wolfe, 2007), all left frontal and temporal electrode sites were examined as potential sources of group differences.

These additional analyses provided limited support for the second hypothesis with a Group X Hemisphere interaction at F3 and F4 that showed trends in the predicted direction. Children in the high memory group tended to have higher left than right medial frontal activation and children in the low memory group tended to have higher right than left medial frontal activation. Although a simple effects test of the trend was not significant, the effect size was moderate, indicating that the problem may lie in the small sample size. The trend should therefore be considered meaningful but should be interpreted cautiously.

While these trends were no different at baseline than during the encoding phase of the memory task, it is important to note that baseline EEG was collected during a short video clip, which included both images and dialogue, so it is not surprising that similar processing patterns emerged in the two conditions. In fact, watching a video could also be considered an encoding task if the dependent measure happened to be based on memory for that event. Therefore, the fact that condition was not a factor in the interaction does not render the finding meaningless. However, it may be more useful in future studies to use a baseline measure that does not involve language processing and does not include images to which verbal labels can be applied. For example, a child might be presented with a series of abstract images or changing patterns.

The hypothesis that children in the high memory group would have greater coherence between left lateral frontal (F7) and left anterior temporal (T3) than children in the low memory group during the encoding phase of the task was partially supported. Children in the high memory group had greater left lateral frontal and left anterior temporal coherence than children in the low memory group. While this was true during both baseline and encoding, this finding provides some support for the idea that children with better memory may be using more verbal encoding strategies. Again, due to the nature of the baseline measure, the fact that condition was not a factor in the interaction was not surprising. It may also be the case that children in the high memory group continuously perceive their environments in more linguistic terms than children in the low memory group, which would explain why there is no difference in coherence between baseline and encoding.
Examination of the other frontal-temporal electrode pair combinations did not contribute much to an understanding of processes involved in successful encoding. The high memory group had greater left than right coherence between lateral frontal (F7, 8) and posterior temporal (T7, 8) locations at baseline, and the low memory group had greater left than right coherence between these electrode sites during encoding. It is important to note that both groups tended to have greater left than right coherence between these electrode sites in both conditions, but only the above mentioned findings reached statistical significance (so there was no real difference in pattern for the two groups). There was also greater overall medial frontal (F3, F4)/posterior temporal (T7, T8) coherence at baseline than during encoding for both groups. These findings, while interesting, neither support nor refute the hypothesis. It appears that for 3-year-olds, coherence between the hypothesized electrode pairs is the best indicator of encoding patterns, indicating that connections between these two brain areas are beginning to mature by age 3. Previous research has demonstrated that clear coherence patterns are apparent by age 4½ for some cognitive activities (Bell & Wolfe, 2007).

After some support was found for the initial hypotheses, EEG power and coherence were also examined at baseline and during retrieval. Although there were no significant EEG power findings, trends indicated greater lateral frontal (F7, F8) activation during retrieval compared with baseline. This was not unexpected since this area of the frontal lobes was hypothesized to be involved in the task. However, the fact that group differences did not emerge suggests that lateral frontal activation patterns during retrieval do not distinguish between high and low performance on a short-term recognition memory measure. The only indicator of group differences in brain activation during retrieval processes was a trend observed at the posterior temporal scalp locations (T7, T8). The trend was in the expected direction, indicating that children in the high memory group had greater left than right activation during retrieval and children in the low memory group had greater right than left activation during retrieval. While this Group X Hemisphere X Condition interaction was not statistically significant, the effect size was moderate, indicating that perhaps the small sample size led to insufficient statistical power. This trend provides at least preliminary evidence that greater left temporal activation is tied to successful retrieval during a recognition memory task.

As was the case with the analysis of EEG data during the encoding phase of the task, coherence at the hypothesized scalp locations was more informative than EEG power during
retrieval. Coherence was greater during retrieval than at baseline between all three frontal electrode pairs and the anterior temporal region (T3, T4). This finding was not unexpected and suggests that processes involved in retrieval may be more effortful than during encoding and may recruit multiple brain areas.

In addition to the differences in coherence between baseline and retrieval for both groups, children in the low memory group had greater right than left coherence between lateral frontal and anterior temporal locations. This may indicate that children in the low memory group are using more nonverbal strategies to recall the previously presented information. Previous research with adults suggests that pictures that cannot be associated with a verbal label tend to lead to right hemisphere activation (Kelley et al, 1998; Wagner et al, 1998a). While these studies relate to frontal lobe activation patterns rather than to coherence, they do suggest an overall hemispheric difference in brain activity for verbal vs. nonverbal stimuli.

The behavioral data presented here strongly support the notion that language ability and short-term recognition memory are linked in children. The physiological data also provide some support for the idea that verbal ability, particularly the use of verbal vs. nonverbal encoding strategies, may account for some of the individual differences in the development of short-term memory in children. The potential to find significant effects in EEG power may have been limited by several factors. First, given the fact that there were several trends of moderate strength that were not statistically significant, it is possible that the small sample size reduced statistical power. Additionally, given that 60% of children had a perfect score on the recognition memory test, there may have been a ceiling effect because the task was easy for these children. Therefore the nature of the task made distinguishing among these children impossible. The task could be improved by including more trials and by adding more stimuli between presentations of the question cards.

Despite these limitations, the hypothesis was supported by the coherence findings. It may be that differences in coherence are more robust and that coherence is a better indicator of encoding (and retrieval) processes than EEG power. The frontal and temporal lobes (along with the rest of the brain) are not separate entities; they are part of a system. Therefore it is not surprising that connectivity and communication between regions is more closely tied to performance than simple activation in isolated brain areas. Coherence findings indicate that maturation of connections (including pruning of unnecessary connections) appears to contribute
to a child’s ability to verbally encode visual events. The fact that findings did not differ between baseline and encoding indicates that the maturation of lateral frontal/anterior temporal connectivity may affect the way children process information in the world around them in general—not just during the presentation of stimuli for a memory task. Maturation of these connections may be a developmental turning point that facilitates the use of verbal encoding processes that are more efficient than those used in infancy.

Further studies like the current one, but involving other types of memory may yield insight into these processes as well. 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), but no other studies have linked language and memory with specific hemispheric differences in brain activity in young children.

Additionally, analysis of EEG power and especially 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 EEG power and/or 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.

This research has provided support for a link between verbal encoding and short-term recognition memory. Further research is needed to eliminate limitations of this study (such as small sample size and an easy memory task) and to replicate and extend these findings to other types of 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 and comparison of EEG power and coherence during all types of cognitive tasks.
References


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Table 2. Summary of Multivariate Analysis F Values for EEG 6-9 Hz Power (Baseline and Encoding)

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* p < .05, ** p < .01, + p < .10
Table 3. Summary of Multivariate Analysis F Values for EEG 6-9 Hz Coherence (Baseline and Encoding)

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+ p < .10, * p < .05, ** p < .01
Table 4. Summary of Multivariate Analysis F Values for EEG 6-9 Hz Power (Baseline and Retrieval)

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*p < .10, *p < .05, **p < .01, ***p < .001
Figure 1. EEG Power at F3, F4 during Baseline and Encoding (G X H)
Figure 2. Coherence at F7-T3 and F8-T4 during Baseline and Encoding (G X H)
Figure 3. EEG Coherence at F7-T7 and F8-T8 during Baseline and Encoding (G X H X C)
Figure 4. EEG Power at T7, T8 during Baseline and Retrieval (G X H X C)
Figure 5. EEG Coherence at F7-T3 and F8-T4 during Baseline and Retrieval (G X H)
Appendix A
Sample of items in the Corsi-Milner task
Stimulus Cards:

![Stimulus Card](image1)

![Stimulus Card](image2)

Question Card (“Which of these pictures have you already seen?”):

![Question Card](image3)

![Question Card](image4)
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derogation of others: A case for self-image enhancement? In D. Chadee and J. Young

Oral Presentations
conditioned? Paper presented at the annual Carolinas Psychology Conference, Raleigh, NC.
Posters Presented at Professional Meetings


Honors and Awards

GSA Travel Funding Program Award 2006, 2007
Galper Graduate Fund Award 2006
NIH Travel Award to attend ISDP in Washington, DC 2005
Outstanding Senior Psychology Student (Stew Worthington Award) 2004
AASU Internal Grant to conduct research for Honors Thesis 2003
Member of Psi Chi 2003-2007

Membership in Professional Organizations

Association for Psychological Science (APS)
International Society for Developmental Psychobiology (ISDP)
International Society on Infant Studies (ISIS)
Southeastern Psychological Association (SEPA)
Society for Research in Child Development (SRCD)

REFERENCES PROVIDED UPON REQUEST