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The Structure and Function of Semantic Memory in Children with Attention-Deficit/Hyperactivity Disorder

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The Structure and Function of Semantic Memory in Children with Attention-Deficit/Hyperactivity Disorder

by

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Dedication

In loving memory of Gilbert Gay Nevius, a true optimist in every sense of the word.

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The Structure and Function of Semantic Memory in Children with Attention-Deficit/Hyperactivity Disorder

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Semantic memory, the organized knowledge network an individual possesses about words, objects, facts and concepts and the relationships among them, emerges from direct experience with the environment. The network is constructed and refined over the course of development as the individual encounters new stimuli in the environment and relates them to representations of previously encountered material. This process is highly dependent on attentional processes and executive functions as the individual must select which aspects of the stimulus to attend to and what to relate it to in the long-term memory stores. Previous research has demonstrated that children with ADHD perform more poorly than their normal peers on measures tapping attention and executive function, thus they may also demonstrate deficits in measures tapping semantic memory abilities.

The present study set out to investigate whether children with ADHD demonstrate differential patterns of development of the semantic memory network compared to age-matched controls. The sample included 19 children with ADHD combined type, 29 children with ADHD inattentive type and 25 normal control children. Structure of the semantic memory system was investigated using a priming task where relationship between target and prime word were varied for degree of abstraction in the relationship (semantic vs. functional) and for strength of association (high vs. low). It was hypothesized that children with ADHD would demonstrate less priming in the semantic low association strength condition as creating such relationships in the semantic network is more cognitively demanding. Function of the semantic memory was investigated using two list learning tasks, one in which subjects were cued to use semantic clustering as an aid in encoding and one in which these cues were absent. It was hypothesized children with ADHD would be less likely to utilize strategies such as semantic clustering if not cued to do so.

Data were subjected to analysis of variance. The results indicated that children with ADHD do demonstrate less priming for words that are more abstractly related to one another. Children with ADHD did not differ from controls, however, in their use of semantic clustering as an encoding strategy or their recall ability.

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CHAPTER 1: INTRODUCTION AND BACKGROUND INFORMATION

Attention Deficit/Hyperactivity Disorder (ADHD) is one of the most prevalent childhood disorders with a prevalence rate currently estimated to be between 3-7% of all children in the United States (Lockwood, Marcotte & Stern, 2001; Willcutt, Pennington, Boada, Ogline, Tunick, Chhabildes & Olson, 2001; Barkley, 1997; APA 1994). ADHD is more commonly diagnosed in boys, with a male to female ratio of 3:1 to 9:1 depending upon whether the sample is a community based sample or a clinic based sample (Pennington and Ozonoff, 1996; APA, 1994). According to current diagnostic criteria, the two core diagnostic features of ADHD are symptoms of inattention and symptoms of hyperactivity/impulsivity. The diagnostic significance of these behavioral features has changed significantly over time, however. As will be outlined in the following section, significant changes in the conceptualization of the causes and diagnostic criteria of what we now term ADHD make it difficult to compare studies of the cognitive performance of individuals with ADHD and may, in fact, create confusion in interpreting the results of such studies.

THE HISTORY OF ADHD DIAGNOSIS

Initially, damage to the central nervous system was conceptualized to cause the symptoms of hyperactivity and impulsivity observed in some children; thus this disorder was labeled “minimal brain damage.” It proved difficult to find a single etiology that explained the condition in childhood as similar symptoms were elicited by stroke, degenerative disease, psychopathology or abnormality of development (Berger and Posner, 2000). Difficulties in documenting a single central nervous system dysfunction underlying this condition gradually led to its abandonment as a diagnostic category (Frick and Lahey, 1991; Lahey, Carlson and Frick, 1997).

By the time the second edition of the Diagnostic and Statistical Manual of Mental Disorders was published in 1968, a new diagnostic category had taken the place of minimal brain dysfunction: hyperkinetic reaction of childhood (APA, 1968). This new diagnostic criteria marked a turning away from an attempt to pin down an etiology in favor of diagnoses based on a stable constellation of symptoms. The focus of this diagnosis was on the symptoms of motor hyperactivity observed in many children with minimal brain damage. Over time, however, it became apparent that specific cognitive symptoms were also important in the identification of this childhood disorder (Lahey et al., 1997; Swanson, Posner, Cantwell, Wigal, Crinella, Filipek, Emerson, Tucker and Nalcioglu, 1998).

Publication of the DSM-III broadened the diagnostic criteria to include 2 cognitive symptom domains, inattention and impulsivity, in addition to the motor hyperactivity already present in the DSM-II (APA, 1980). The disorder was termed Attention Deficit Disorder (ADD), which reflected the importance of inattention in the symptom constellation. Under this new set of diagnostic criteria, it was possible to diagnose two subtypes of ADD; ADD-H (with hyperactivity) and ADD/WO (inattention without hyperactivity) (APA, 1980). This marked a significant shift in the conceptualization of the disorder, with symptoms of inattention replacing motor hyperactivity as the cardinal features of the disorder. In fact, the ADD/WO subtype marked the first time a diagnosis could be made in the absence of symptoms of hyperactivity (Lahey et al., 1997).

In the subsequent DSM-III-R the importance of inattention symptoms was somewhat downgraded by combining the three symptom domains (inattention, impulsivity and hyperactivity) into a single unidimensional set of symptoms, now termed Attention-deficit/hyperactivity disorder. For diagnosis, an individual had to display 8 of 14 possible symptoms covering any or all three of these domains (APA, 1987).

This lack of separation between symptoms in the motor domain from symptoms in the cognitive domain effectively eliminated the diagnosis of Attention Deficit Disorder in the absence of symptoms of hyperactivity. Although a diagnostic category, termed undifferentiated ADD, was included in the DSM-III-R that allowed the diagnosis of an attention deficit disorder in the absence of symptoms of hyperactivity, use of this diagnostic category was problematic in several ways. First, the diagnostic category was not accompanied by specific diagnostic criteria, leading to its being utilized less often than the ADHD category. Secondly, children who did not display symptoms of hyperactivity, but did display symptoms of impulsivity were lumped into the ADHD category along with children who did display hyperactivity. Subsequent factor analyses indicated that symptoms of inattention clustered together reliably more often than did symptoms of hyperactivity and impulsivity, indicating that this represented a separate diagnostic domain (Lahey et al, 1997).

The current diagnostic criteria for ADHD as outlined in the DSM-IV once again separate the cognitive symptom domain from the motor hyperactivity domain. Children are diagnosed on the basis of 9 inattentive symptoms and 9 symptoms of hyperactivity/impulsivity. They must display 6 of 9 symptoms of a given domain (i.e., cognitive or motor) for the domain to be considered present and clinically significant (APA, 1994).

Depending upon how many features of each of these domains are present in a given individual, diagnosis of three types of ADHD is possible. These are ADHD, Predominantly Inattentive Type (6 or more symptoms of inattention alone), ADHD

Predominantly Hyperactive-Impulsive Type (6 or more symptoms of hyperactivity/impulsivity alone), or ADHD Combined Type (6 or more symptoms of both domains) (APA, 1994).

EVIDENCE FOR THE VALIDITY OF ADHD SUBTYPES

There is still some controversy as to whether these subtypes of ADHD represent three expressions of the same disorder, or whether they, in fact, represent distinct disorders. Evidence for the former comes from the examination of the developmental course of hyperactivity symptoms. The onset and diagnosis of ADHD-HI tends to be earlier than any of the other subtypes and diagnosis of this subtype tends to be rather rare compared to the other subtypes, with a peak age of about 3-4 years of age (Pennington et al., 1996).

At the same time, the diagnosis of ADHD-I tends to be later in childhood and some children diagnosed as ADHD-C may more closely resemble ADHD-I as they develop (Barkley, 1997). Based on this evidence, one school of thought proposes that hyperactive symptoms are a subset of symptoms caused by the same deficit as inattentive symptoms. These symptoms are more outwardly observable and cause more problems at an earlier age, and thus were mistakenly taken to be a core feature of the disorder when they are simply an associated feature that is highly sensitive to the effects of development. Instead, this theory proposes, inattention is better conceptualized as the core deficit of ADHD, but this symptom only becomes apparent as children enter school, and cognitive demands tax their attentional abilities (Barkley, 1997).

In contrast, there is also evidence that the subtypes of ADHD-I and ADHD-C/ADHD-H represent two different disorders entirely. For example, the subtypes exhibit different patterns of co-morbid disorders, with ADHD-I being more often associated with internalizing disorders (e.g., depression and anxiety) and ADHD-C being more often associated with externalizing disorders (e.g., aggression and antisocial acts). This may indicate two separate causal pathways with two independent behavioral outcomes (Lockwood et al., 2001). Closer examination of the neuroanatomical and neuropysiological correlates of ADHD may help to clarify the relationship between these subtypes.

CHAPTER 2: THEORETICAL MODELS OF ADHD

ANATOMICAL AND PHYSIOLOGICAL MARKERS OF CORTICAL ABNORMALITY IN ADHD: PROPOSED MECHANISMS

Children and adolescents with ADHD display a variety of abnormalities of cortical structures. Overall, children with ADHD have a smaller than would be expected anterior right frontal cortex, indicating a loss of normal asymmetry in this structure (e.g., right being larger than left). It is unclear whether this indicates underdevelopment of this structure or a failure of synaptic pruning on the left hemisphere over the course of development (Oades, 1998). This is accompanied by decreased glucose metabolism and blood perfusion in the right frontal and striatal cortex relative to normal controls (Lockwood et al., 2001; Pennington et. al., 1996). Additionally, the basal ganglia and portions of the corpus callosum show reduced volume on MRI (Lockwood et. al., 2001).

Evoked response potentials also demonstrate abnormalities of cortical function in children with ADHD. In target detection and processing, a variety of positive and negative neural potentials normally occur. Negative potentials are generally associated with excitation of a region, while positive are associated with inhibition. Normally a positive potential occurs approximately 60 msec following presentation, which is thought to represent the arrival of the stimulus related signal to the cortex. At approximately 100 msec post-presentation, a negative potential (N1) occurs which is thought to be associated with excitation and allocation of specific sensory channels for processing the stimulus. At approximately 180 msec, a positive potential (P2) occurs, associated with inhibition of adjacent areas of sensory cortex that could compete for resources with the allocated processing channel. This occurs in the secondary cortices of the superior temporal gyrus. Finally a negative potential occurs (N2) followed by a positive potential (P3). It has been proposed that these represent categorization of the target stimulus and updating of associations between the target and existing information. This involves the limbic and neocortical areas as well as frontal cortex, and represents the first time the individual has conscious access to the processing of information (Oades, 1998). By adolescence, the N2 amplitude becomes sensitive to attention conditions (divided or not) and P2 shows shorter latencies as cognition becomes more efficient.

This pattern is disturbed in children with ADHD (subtypes unspecified). Here the latency to N1 and P1 is shorter, possibly indicating less complete registration of the stimulus. P2 amplitude is larger, indicating abnormal patterns of cortical inhibition. N2 and P3 display abnormal patterns of amplitude, indicating difficulties with categorization. Additionally, children with ADHD tend to demonstrate a left sided bias for N2 and P3, while these potentials generally occur on the right in unaffected children and adolescents (Oades, 1998). Together these results suggest that information processing proceeds with fewer contextual checks in early processing (Oades, 1998).

The disturbed function of two cortical areas, the frontal lobe and the temporal lobe have been proposed to be central to the behavioral difficulties observed in children with ADHD (Oades, 1998). The structures associated with these circuits are highly associated with allocation of attention as well as executive functions. That is, they are associated with the process of facing a problem, forming a mental representation of the problem, choosing a strategy to solve the problem, and checking to be sure progress is being made toward the goal of solving the problem.

Studies of delayed reinforcement learning in primates as well as PET studies of response planning in humans have shown activation in the dorsolateral frontal cortex. This is thought to represent the invoking of executive functions (EF) in order to plan and execute strategies to solve a problem (Oades, 1998). The orbitofrontal-amygdala axis is responsible for monitoring emotional input and output and making adjustments in EF based on this input. Within this circuit the amygdala moderates arousal, or the phasic shift in physiological activation in response to a stimulus. The basal ganglia moderate activation or the tonic physiological readiness to respond while the hippocampus is responsible for the coordination of these two structures (Oades, 1998). Working together through feedback circuits the frontal lobe and limbic system appear to be responsible for choosing an effective problem solving strategy while inhibiting less effective strategies, monitoring progress toward the goal of solving the problem, and making adjustments in emotional state and physiological arousal necessary for achieving the goal.

Indirect anatomical evidence points to dysfunction of this system as being responsible for the symptoms of ADHD. For example patients who have had temporal lobectomy on the left demonstrate larger P2 evoked potentials, similar to children with ADHD (Oades, 1998). In addition latent inhibition, the ability to "unlearn" that a stimulus has no consequence, and conditioned blocking, the ability to ignore superfluous stimuli added after conditioning to another stimuli has begun have both been shown to be dependent on the hippocampus. The performance of children with ADHD is impaired on both tasks, indirectly implicating inefficient functioning of the hippocampus (Oades, 1998).

DIFFERENCES VS. SIMILARITIES IN COGNITIVE FUNCTION OF ADHD SUBTYPES

In some cases, children with ADHD-I appear to demonstrate a different pattern of neuropsychological dysfunction compared to children diagnosed with ADHD-C. For example, in examining the performance of children with different subtypes of ADHD on various neuropsychological measures, several researchers have found that children with ADHD-I appear to perform more poorly on tasks tapping early processes of information processing. These would include tasks related to filtering background information from target signal and automatic shifting of attention between the target and other stimuli (Lockwood et al., 2001; Schmitz, Cadore, Paczke, Kipper, Chaves, Rohde, Moura, & Knijnik, 2002).

Vigilance, or maintaining adequate cognitive arousal to meet the demands of a cognitive task has also been shown to be reduced in children with ADHD-I. For example, children with ADHD-I made more errors of omission (i.e. failed to respond to trials) on a Stop Signal Reaction Time test compared to controls and compared to children with ADHD-C when Full Scale IQ and reading achievement scores were controlled for (Chhabiladas, Pennington, & Willcutt, 2001). On a Go/No Go task, children with ADHD-I made more errors on early trials, but their errors decreased over subsequent trials until they were not significantly different from controls. This pattern of performance indicates that children with ADHD-I may take longer to increase cognitive arousal to meet the demands of a task at hand (Milich, Ballentine, & Lyman, 2001).

There is also evidence that cognitive processing speed is reduced in children with ADHD-I. They have been shown to take more time to complete a variety of neuropsychological tasks including the Stroop Color-Word condition, the WISC-III Coding subtest and the Trail Making Test (Chhabildas et al., 2001; Schmitz et al., 2002). This slower processing speed, or sluggish cognitive tempo has been hypothesized by several authors to be the core underlying deficit differentiating ADHD-I from the ADHD-C and ADHD-HI subtypes (Barkley, 1997; Chhabildas et al., 2001; Carlson & Mann, 2002). DSM-III criteria for diagnosis of ADHD/WO included several criteria specifically tapping sluggish cognitive tempo (APA, 1980). Subsequent revisions of the diagnostic criteria, as outlined above, changed the diagnostic criteria for ADHD to recognize two, supposedly separate domains, inattention and hyperactivity/impulsivity. Sluggish cognitive tempo criteria were eliminated, in favor of an emphasis on inattention symptoms as cardinal features of ADHD-I. Factor analytic studies have shown, however, that some of the symptoms coded along the dimension of inattention may actually be more accurately considered symptoms of impulsivity in the cognitive domain (e.g., Marks, Himmelstein, Newcorn & Halperin, 1999; Rasmussen, Neuman, Heath, Levy, Hay & Todd, 2004). Several authors have suggested that the current diagnostic criteria for ADHD-I may reflect a more heterogeneous diagnostic category including at least two subtypes, the cognitively impulsive inattentive child and the child with sluggish cognitive tempo. Further research is needed to determine if the sluggish cognitive tempo criteria better differentiate an independent inattentive subtype from ADHD-C, ADHD-HI and controls.

Children with ADHD-C, on the other hand, have been shown to have more difficulty on tasks that require effective choice of response strategy to solve a problem. In other words, they demonstrated significantly more difficulty on tasks which required them to choose an effective strategy while suppressing other, possibly overlearned, strategies, monitor the use of that strategy, and change strategies when it became apparent that their strategy was not the most optimal (Lockwood et al., 2001). These deficits in behavioral inhibition have been observed across a variety of tasks including the Wisconsin Card Sort Test, where children with ADHD-C had more difficulty shifting set in response to changes in the desired sorting category (Schmitz et al., 2002). Children with ADHD-C also make more errors of commission on Stop Signal tasks, Go/No Go tasks, and Continuous Performance tasks (Marks et al., 1999; Milich et al., 2001; Chhabildas et al., 2001). Using the current diagnostic criteria, studies have shown that some of the differences in impulsivity and behavioral inhibition outlined above differentiating ADHD-C from ADHD-I may diminish over time, possibly indicating that the various subtypes of the current criteria may represent different phases of maturation, with ADHD-HI maturing to ADHD-C then ADHD-I (Chhabildas et al., 2001). At the same time, however, children with both ADHD-I and ADHD-C had some common cognitive deficits including deficits in moderation of arousal, motivation and effort as well as maintenance of attention over time (Lockwood et al., 2001). These deficits, then, rather than differing deficits in attention or motor impulse control may be the core, underlying feature of a common ADHD disorder. The differing results on other tasks may simply represent different types of difficulties stemming from this single deficit or the effects of maturation.

THE COGNITIVE ENERGETIC MODEL

Considering the evidence presented in the model above, difficulties with arousal, motivation and effort may be the core deficits underlying all types of ADHD. Normally, an individual must adjust cognitive activation in order to meet varying task demands. In some cases, stimuli may be presented slowly or in isolation, decreasing the cognitive load necessary to process the incoming information. Generally, however, multiple stimuli are presented at one time and the individual must actively filter extraneous stimuli and flexibly choose the most advantageous strategy to accomplish the solution of a problem at hand.

According to a model developed by Sergeant, deficits in state arousal and activation lie at the heart of cognitive processing deficits in ADHD (all subtypes). He proposed three simultaneous steps involved in information processing. The first is the process/computational component. This component is involved in encoding stimuli, cognitive search and decision-making and motor organization in response to a problem (Sergeant, 2000).

The second component of his model is state of arousal or activation. According to this model, there are three energetic pools from which an individual may draw physiological energy in order to accomplish a goal. The first of these pools is effort, which refers to the energy needed to meet an immediate task demand. This pool becomes activated when the organism's current state does not meet the needs of a current cognitive load. The second energetic pool is arousal, which represents phasic changes in physiological responding, time locked to the processing of a stimulus. The final pool is activation, which is a tonic or stable change in physiological activity. The activity of this pool is mediated by the basal ganglia and corpus striatum (Sergeant, 2000).

The final component of Sergeant's model is Management and Evaluation. This corresponds to executive functioning in other models and refers to the ability to maintain an appropriate problem solving set for attainment of future goals. It involves inhibition of irrelevant responses, maintenance of a mental representation of a problem, and strategic planning to accomplish the goal (Sergeant, 2000).

Sergeant proposes that children with ADHD have particular difficulty with the executive function and energetic pools in this model. Furthermore, difficulties in each of these components exacerbate difficulties in the other through feedback mechanisms. For example, on a stop signal task, children are asked to perform an action in response to a stimulus. On some trials, however, a signal is paired with the stimulus, cuing the individual to stop the response. In children with ADHD, N1 evoked potentials occur posteriorly too early to be a response to a stop signal (Oades, 1998). This indicates a failure to inhibit associations to the target signal before the stop signal can be processed. In other words, the brain is not in an energetic state that allows for complete processing of incoming stimuli. This failure of arousal leads to mistakes in responding due to incomplete information reaching the management/evaluation systems (Sergeant, 2000).

More evidence for difficulties in this system comes from tasks in which the rate of stimuli presentation is varied as on Continuous Performance tasks. In conditions where stimuli are presented faster or more slowly, children with ADHD make more errors of commission indicating that they are unable to adjust activation in response to changing demands of a task (Rapport, Cheng, Shore, Denney, & Isaacs, 2000). Children with ADHD, then, demonstrate inadequate activation of inhibitory control mechanisms housed in the executive functioning domain (Sergeant, 2000).

Finally, children with ADHD appear to have more difficulty completing tasks requiring more cognitive effort, indicating that they may have more trouble increasing arousal in order to meet the demands of more difficult tasks. For example, children with ADHD show no difference compared to controls in their ability to recall word lists that do not exceed the capacity of working memory. They do, however, show significantly poorer recall when they are asked to recall longer lists of items (Douglas & Benezra, 1990).

Similarly, children with ADHD had more difficulty recalling paired associates of words they had previously learned when the words were semantically related, but they did not have significantly poorer recall compared to controls when the words were acoustically related to their paired associate (Ackerman, Anhalt, Dykman & Holcomb, 1986). The authors proposed that creating and accessing memory of semantic relationships is more cognitively effortful than creating and accessing memory of acoustic similarity. Taken together, these results suggest that children with ADHD may have more difficulty maintaining stable physiological arousal to meet the demands of longer, more challenging cognitive tasks.

BARKLEY'S MODEL OF EXECUTIVE FUNCTION DEFICIT

Barkley has proposed another model, which emphasized deficits in executive function as the central deficit in ADHD. He emphasizes, however that this model is applicable only to the ADHD-C subtype. In this model, behavioral inhibition (i.e. the inhibition of prepotent responses, the ability to stop an ongoing response and inhibition control) directly control motor control abilities as well as fluency and syntax in problem solving. In other words, behavioral inhibition allows the individual to inhibit irrelevant responses, execute responses toward a goal, whether they are novel or previously learned, as well as remaining sensitive to feedback in the process of problem solving (Barkley, 1997).

The effect of behavioral inhibition also influences the performance of a group of four executive functions that, in turn, also directly impact behavior. These include 1) working memory, 2) self-regulation of affect, motivation, and arousal, 3) internalization of speech (i.e. moral reasoning, description and reflection etc.) and 4) reconstitution (i.e. analysis and synthesis of behavior, verbal fluency, creativity in problem solving). According to this model, poor motor control, as well as motor fluency and coordination of smaller behavioral units into a meaningful response is directly related to deficits in response inhibition, and may be related to idiosyncratic deficits in executive function as well (Barkley et al., 1997). This may explain why various researchers have found differing patterns of deficits on various neuropsychological tasks in children with ADHD.

Taken together, it appears that neurocognitive deficits in children with ADHD may stem from a common deficit in executive functions. However, each child may demonstrate a different pattern of executive deficits leading to idiosyncratic differences in performance on various neurocognitive tasks. For example, in reviewing the results of past studies Barkley found that children with ADHD have more difficulty stopping ongoing responses when signaled to do so as on stop signal tasks, and have difficulty adjusting responses when feedback suggests that their chosen response is ineffective or maladaptive, as on the Wisconsin Card Sorting Task (WCST).

A review of 13 studies investigating the performance of ADHD children on the WCST yielded significant differences compared to controls in only 8 of the studies (Barkley, 1997). It was not clear, however, whether the studies identified children on the basis of DSM-IV subtype or whether the groups were based on earlier diagnostic criteria. If the latter was the case, the groups in some cases would be comprised only of children who would be considered ADHD-C or ADHD-HI while other groups would include ADHD-I children as well.

Barkley clearly stated that deficient behavioral inhibition is related to hyperactivity/impulsivity and would therefore be observed significantly more often in the ADHD-C and ADHD-HI subtypes than the ADHD-I subtype. Children with ADHD-C would be more likely to display inadequate behavioral inhibition, and it may be that the studies that found differences in WCST performance used groups with a higher prevalence of ADHD-C children. It may be, however, that this deficit is not present in all children with ADHD, or may be less important than other deficits in executive function in some children with ADHD, for example those with ADHD-I.

Different patterns of cognitive dysfunction in the areas of modulation of arousal and executive function may explain the behavioral differences observed in the different subtypes of ADHD. ADHD-I may be more often associated with deficits in regulating motivation and arousal as proposed by Sergeant, while children with ADHD-C may more often have difficulties with response inhibition as proposed by Barkley. While these patterns may emerge in large group studies, there may be further individual differences in the patterns of dysfunction in executive function among individuals with ADHD. These more idiosyncratic deficits would be more difficult to detect in large groups, which may be the reason why the results of studies of cognitive function in children with ADHD sometimes yield contradictory findings.

CHAPTER 3: MEMORY AND ADHD

Research has indicated that children with Attention Deficit Hyperactivity Disorder show a variety of deficits in memory function compared to normal control children as well as children with learning disabilities. Indeed, when tested using the Wide Range Assessment of Memory and Learning (WRAML), a test of memory in both the verbal and non-verbal domains, children with ADHD score lower than age-matched controls on the General Memory Index, which taps both immediate and delayed recall (Mealer, Morgan, & Luscomb, 1996; Kaplan, Dewey, Crawford & Fisher, 1998).

According to the DSM-IV, “often forgetful in daily activities” is one of the symptoms of the core deficit of inattention (APA, 1994). This indicates that children with ADHD, at minimum, have difficulty accessing information as it is needed. It is unclear, however, whether this represents difficulty accessing previously stored information, or whether children with ADHD have trouble consolidating information into a long-term memory store at the time of encoding. There is therefore considerable confusion as to whether these memory difficulties represent a global cognitive deficit, a generalized memory deficit, or whether only specific memory functions are affected (Kaplan, et al., 1998).

The findings of various studies are inconsistent, and in some cases contradictory. For example some authors have demonstrated deficits in ADHD children’s long-term recall of narratives or lists suggesting a deficit with longer-term consolidation or retrieval (Felton, Wood, Brown, Campbell & Harter, 1987; Tannock, Purvis & Schachar, 1993). Others have demonstrated that once a memory trace has been consolidated, ADHD children show little difficulty recalling previously encountered information. Rather, these studies suggest a deficit in initial encoding and memory consolidation that is responsible for poorer performance of ADHD children on memory measures (Ackerman et al., 1986; Kaplan et al., 1998).

As was outlined in the previous sections Barkley and Sergeant propose that memory is not an independent cognitive process. Instead, memory function is highly related to allocation of attention and other executive functions related to utilization of efficient rehearsal strategies, as well as activation and motivation. Neuropsychological tests tapping memory abilities may prove an extremely useful tool in probing the cognitive deficits underlying ADHD, thereby clarifying the nature of memory deficits in ADHD. A careful examination of previous research, therefore, provides a method by which hypotheses regarding the use of executive functions in children with ADHD may be developed. Memory deficits occurring only at specific points in the memory creation and consolidation process may point to a specific deficit in memory. On the other hand, more variable memory function at all phases of memory creation, consolidation and recall may point to more general "executive" dysfunction.

THE SENSORY REGISTER

Broadly, memory can be divided into several different interrelated components. The first component in memory function is the sensory register. The sensory register functions as a temporary storage component for stimuli immediately as they occur. These stimuli are held here only for several hundred milliseconds after which they rapidly decay, or are alternatively maintained by processing in short-term/working memory stores. Attention plays an important role at this stage. Stimuli which are not adequately attended to will decay more rapidly, or may never enter the sensory register at all (Mealer et al., 1996).

THE WORKING MEMORY

Once a stimulus has entered the sensory register, the working memory system can access information about the stimulus. This memory system creates a more durable representation of the stimulus, allowing for further processing as long as the stimulus is actively rehearsed or attended to. For example information maintained in working memory can be compared to information already existing in long-term memory stores. This component of the memory system can accommodate approximately 7 individual bits of information at a time. Once a stimulus has entered the working memory store it begins to decay after approximately 30 seconds unless its memory trace is prolonged by utilizing a mnemonic or rehearsal strategy (Roodenrys, Koloski & Granger, 2001). Barkley has proposed that children with ADHD have difficulty with this prolongation process (Barkley, 1997).

The working memory has been hypothesized to be comprised of three primary components (Roodenrys et al., 2001). The first is the central executive, which can be conceptualized as the control system for working memory processes. The central executive monitors stimuli within the working memory system, allocates attentional resources to the processing of stimuli, activates rehearsal strategies, suppresses less effective strategies, and moderates the activity of two separate and independent memory systems which process the information through prolongation or comparison processes. These two "slave systems," the phonological loop and visuospatial sketchpad are connected to long-term memory stores and are involved in the processing of verbal and visual stimuli, respectively and engaging rehearsal strategies (e.g., subvocal rehearsal) (Roodenrys et al., 2001). Working memory, then consists both of the capacity to hold approximately 7 items in memory, as well as the attentional and other resources needed to manipulate, organize and prolong the representation of these 7 items.

Experimental evidence suggests that the capacity of working memory in children with ADHD is intact and that deficits in working memory function are more related to deficits in the attentional/executive function components modulating the function of working memory. For example, when presented with lists that are equal to, or less than the working memory span, and asked to recall the list immediately following presentation, children with ADHD (i.e., ADD/H by DSM-III criteria) perform as well as normal controls (Douglas and Benezra, 1990).

Working Memory Deficits on the WISC-III

Although there is some experimental evidence that the simple capacity of the working memory buffer in children with ADHD seems to be equivalent to that of control children, it appears that children with ADHD do display difficulties with working memory on several cognitive tasks. If the size of the span of the working memory is intact, some other aspect of working memory would appear to be impaired in children with ADHD (e.g., executive functions or attention). Closer examination of the performance of ADHD children's performance on cognitive tasks tapping working memory may help to clarify the function of working memory in ADHD.

A number of studies have indicated that the Freedom from Distractibility Index of the Wechsler Intelligence Scale for Children, third edition (WISC-III), is significantly impaired in children with ADHD (DSM-III-R, DSM-IV criteria) compared to their Verbal Comprehension Index or Perceptual Organization Index scores (Mealer et al., 1996; Rapport et al., 2000). The subtests included in this index are Arithmetic, a timed test tapping mental arithmetic abilities, and Digit Span, a test tapping ability to immediately recall strings of auditorily presented digits. Both of these tasks are highly dependent on attention, concentration and working memory for successful completion.

When compared to a sample of normal, age-matched controls, children with ADHD scored significantly lower on the Freedom from Distractibility Index. In analyzing the performance of children with ADHD (DSM-III-R criteria) compared to controls, the four index scores produced by the WISC-III yielded a function that correctly classified children in each group at a rate of 70%. The Freedom from Distractibility Index was the most powerful discriminating variable in this function (Mealer et al., 1996). In addition, when considered as a group, poor scores on FD were highly correlated with teacher ratings of inattention (Mealer et al., 1996).

Some studies have indicated that the Processing Speed Index of the WISC-III may also indicate cognitive difficulties related to working memory specific to children with ADHD (DSM-III-R criteria) (Mealer et al., 1996). This index was added in the latest revision of the WISC. It is comprised of two subtests, Symbol Search, a timed test of matching visual stimuli to a sample, and Coding, a timed test requiring children to rapidly copy symbols according to a number code. In the previous version of the WISC, Coding was included in the Freedom from Distractibility Index and, as for Arithmetic and Digit Span, working memory plays an important role in efficient completion of this task (Mealer et al., 1996).

The results of studies comparing the performance of children with ADHD to controls were less consistent for this old version of the Freedom from Distractibility Index. Some studies indicated that ADHD children (DSM-III-R criteria) performed significantly more poorly than controls, while others showed no difference (Mealer et al., 1996). Coding, as a subtest, seems to be more weakly related to cognitive deficits associated with ADHD. In fact, Symbol Search, the other subtest included in the new Processing Speed Index, is a significant predictor of ADHD vs. control status, while Coding does not appear to have as much predictive power (Mealer et al., 1996). Deficits in Processing Speed are associated with ADHD, however they are not correlated with deficits in functioning on other memory measures indicating that slower processing speed may be a separate feature of ADHD (Mealer et al., 1996). Barkley has proposed that sluggish cognitive tempo may be a core feature of the primarily inattentive subtype of ADHD (Barkley, 1997). It may be, then, that the inconsistent findings regarding this index may be a result of heterogeneity among the ADHD samples.

Working Memory Deficits on the WRAML

Although ADHD children show deficits on the General Memory Index of the WRAML closer examination of their performance on selected indexes and subtests of the WRAML points more specifically to difficulties with working memory processes. Children with ADHD, using DSM-III-R criteria, have shown deficits compared to normal controls on the Learning Index, the Verbal Memory Index and the Visual Memory Index of the WRAML (Mealer et al., 1996; Kaplan et al., 1998).

The subtests that contributed most to ADHD children's poor performance on these measures were Finger Windows, Verbal Learning, Sentence Memory, and Number Letter Memory (Mealer et al., 1996; Kaplan et al., 1998). Each of these tests requires immediate processing and recall from working memory of novel material. The fact that these tests tap both verbal and non-verbal working memory is of interest because other studies have shown that children with ADHD generally have less difficulty processing and retaining information in the non-verbal domain (Webster, Hall, Brown & Bolen, 1996).

Whether ADHD children's poorer performance on these tasks is due to a frank deficit in working memory or may be due to more global deficits in attention remains unclear. Some researchers have posited that there is an additional factor on the WRAML that is highly associated with attention and concentration. The subtests that cluster with this factor are Number Letter Memory, Sentence Memory and Finger Windows, the same tests also associated with working memory (Kaplan et al., 1998). Attentional resources must be allocated to prolonging stimuli within the working memory store. If attention is drawn away from stimuli in the working memory store, the representation may decay before rehearsal strategies allow for a more lasting memory trace to be created. It seems then, that attentional processes are integral to working memory functioning.

Working Memory Deficits in Memory Updating

As stated above, the working memory is limited in its capacity to hold and process information to approximately seven bits of information. When this capacity has been reached and new information enters working memory, the central executive must selectively shift stimuli to make room for this new information. This can be accomplished by creating a more durable short-term memory trace through consolidation, thereby freeing space in the working memory buffer, or by halting the prolongation process, and eliminating the stimuli altogether. If this memory updating does not take place in an efficient manner, some novel stimuli may be ignored, or some old stimuli may be incompletely processed, and therefore forgotten.

Several neuropsychological tasks tap this ability, and individuals with ADHD perform more poorly than children with reading disabilities or normal controls. The Paced Auditory Serial Addition Task (PASAT) is one such test. This test requires individuals to attend to an auditory presentation of a string of numbers. They are to add each number to the number that came before it, vocalize the sum while holding the last digit in working memory then add the next number they hear (Gronwall, 1977). Both children and adults diagnosed with ADHD according to the Conner's rating scale (subtype unspecified) perform significantly more poorly than controls and children with reading disabilities, making significantly more errors of omission and addition errors (Schweitzer, Faber, Grafton, Tune, Hoffman & Kilts, 2000; Roodenrys et al., 2001).

Roodenrys and colleagues used the Running Memory Task, which taps similar updating abilities to compare performance of children with ADHD to control children. On this test, individuals are asked to attend to a string of auditorally presented words. Subjects do not know how long the string of words will be. At random points, they are asked to recall only the most recent items (e.g., the last 5). Here again, children with ADHD performed significantly more poorly than controls. Interestingly, when fewer items were presented as part of the string, the ADHD group's performance improved. The authors interpreted this finding as indicating that the ADHD children were able to engage in simple rehearsal strategy (i.e., subvocal rehearsal), but were not able to switch tasks within working memory to update the items in the working memory buffer (Roodenrys et al., 2001).

Working Memory Deficits in List Learning

List Learning Tasks involve learning and recalling a list of familiar words. The list may be structured (e.g., clustered by semantic groups), unstructured, of varying lengths, presented a single time or multiple times, and may be recalled immediately or following a delay with or without cueing. Children with ADHD have varying levels of difficulty with this task depending on the presentation and length of the list.

As more demands are placed on the working memory system, children with ADHD (DSM-III-R criteria) begin to demonstrate deficits in working memory, though their performance seems to depend heavily on the manner in which the list is presented. With a single presentation of a 12-item list, children with ADHD's free recall was not significantly different than that of controls. They did, however, make significantly more errors of intrusion in immediate free recall and significantly more acoustic ("sound alike") errors when they were asked to recognize the words they had been presented from several choices (Douglas et al., 1990). This is not to say working memory capacity may not be affected by ADHD. In some cases researchers have found that children with ADHD (DSM-III-R criteria) recall significantly fewer items from word lists compared to normal controls (e.g., Felton et al. 1987).

In a similar paradigm, but with multiple presentations of the list, children with ADHD show further disturbance of working memory. For example, Douglas and colleagues found that while children with ADHD recall the same number of items after the first trial, their learning curve is significantly flatter over the succeeding trials (Children categorized by hyperactivity score of 1.5 or higher on hyperactivity factor Conners Teacher Rating Scale and Conner's Parent Rating Scale) (Douglas et al., 1990).

By grouping words together utilizing an elaborative mnemonic strategy, more individual items can be held in the working memory buffer. Essentially each group of related words is encoded as a single item in the working memory buffer. This may be accomplished by grouping words by acoustic similarity, semantic similarity or by creating an elaborative mnemonic relationship (e.g., combining the words in a sentence). It appears that children with ADHD are less likely to utilize these strategies unless it is made explicit for them at the time of encoding. In one study, Voelker and colleagues elegantly demonstrated this phenomenon in boys diagnosed with ADD-H, DSM-III-R criteria. Children were presented with a series of word lists that exceeded working memory capacity. Two contained words that could be clustered by acoustic similarity and two contained words that could be clustered by semantic similarity. On one list in each condition the words were presented already clustered by acoustic or semantic similarity, and on the other the words were presented in a randomized order. Children with ADD-H demonstrated significantly more difficulty utilizing the semantic clustering strategy. All of these children recalled fewer words in the unclustered semantic condition compared to controls, and the youngest ADD-H children recalled significantly fewer words in the clustered semantic condition as well (Voelker, Carter, Sprague, Golowski, & Lachar, 1989).

Other authors found a similar effect when the words were presented visually, when the words were presented as pairs with cueing of one of the words at recall, and with multiple presentations of the words. In addition, children with ADD-H were more likely to make errors of intrusion when the words were presented as pairs, indicating that they did not utilize the intrinsic organization present in the pairs (Ackerman et al., 1986; Borcherding, Thompson, Druesi, Bartko, Rapoport & Weingartner, 1988; Douglas et al., 1990; Felton et. al., 1987). Again, the children participating in all of these studies were diagnosed as ADD/H leaving open the question of whether children who are not hyperactive would show similar deficits.

Taken together these studies demonstrate that children with ADD-H lag behind developmentally in applying mnemonic strategies independently. They are most adept at serial rehearsal (i.e., repeating the words over and over), however this does not allow them to effectively exceed working memory capacity (Voelker et al., 1989; Douglas et al., 1990).

As the strategies become more complex, ADHD children have more difficulty employing them independently. There is some evidence that they are more likely to use acoustic clustering, however this strategy was not very effective (Ackerman et al., 1986; Douglas et al., 1990). When the words are not related, children with ADHD were extremely unlikely to utilize an elaborative mnemonic strategy (e.g. making a sentence utilizing the words) (Douglas et al., 1990). Children with ADHD, thus appear to have a memory deficit for supraspan lists without any intrinsic organizing structure (Felton et al., 1987). The deficits observed in working memory of ADHD children, therefore, appear to be related more to deficits in executive functions related to working memory, than to simple working memory span.

Narrative Recall and Working Memory Deficits

The literature on narrative recall in children with ADHD is somewhat more contradictory. Some studies find that when children with ADHD are asked to repeat a story they have just heard, they produce less elaborate narratives and recall fewer bits of information compared to age-matched controls while other studies have found no difference in these children's recall (Tannock et al., 1993).

A closer examination of the literature, however, seems to indicate that children with ADHD may not have a frank deficit in narrative recall. It seems that their recall is largely dependent on how the story is presented and how recall is elicited. In a free recall paradigm, children do tend to produce shorter narratives, but an analysis of their utterances reveals that children may not have significant difficulty recalling stories. Children with ADHD (DSM-IV criteria, any subtype) recall proportionally more of the most thematically relevant bits of information, just as normal controls do. Similarly, they recall more bits of information directly related to the chain of causes and effects which drive the narrative than they do bits which are irrelevant to the plot (Lorch, Sanchez, van den Brock, & Milich, 1999). These results all indicate that children with ADHD are sensitive to the factors that create a meaningful narrative and utilize these principles to organize their recall. Their comprehension of the thematically important elements of a narrative, therefore, appears to be intact.

More evidence for their intact narrative comprehension comes from recognition paradigms and from cued recall paradigms. Here the children are asked structured questions regarding key elements of the story plot. In some cases they are given several choices from which to choose the correct answer. Here, children with ADHD perform as well as control children, demonstrating that they do encode the same amount of information as controls and do comprehend how events are relevant to the narrative's plot (Tannock et al., 1993; Lorch et al., 1999).

Where ADHD children seem to have the most trouble is in the actual production of the narrative. In a study in which children were given a set of pictures and asked to construct a narrative describing them, children with ADHD produced significantly shorter narratives, with a simpler plot (i.e., their story events had fewer events with multiple connections to other events) (Tannock et al., 1993). Similarly, in free recall of narratives children with ADHD were less sensitive to events having multiple connections to other events in a story, and made more errors. These errors included relating events out of sequence, substituting semantically inappropriate words, making ambiguous references and misinterpreting events in the story (Tannock et al., 1993; Lorch et al, 1999).

Because the ADHD children's narratives, both recalled and novel, were shorter, less well elaborated and less sensitive to the effect of an event having multiple connections to other events in the story, their difficulties may reflect a deficit in working memory capacity or difficulty with elaborative mnemonic rehearsal and other executive function deficits (Mealer et al., 1996). It is most likely that the latter is the greater difficulty, as the ADHD children did not differ significantly in verbal memory span. In addition, the children made more errors related to semantic intrusions (Tannock et al., 1993).

In other words, children with ADHD seem to have more trouble maintaining multiple story events and their connections in the working memory buffer. This may be related to difficulty inhibiting memory nodes which are related semantically to story events, but which are not contained in the story. These irrelevant bits of information then occupy space in the working memory buffer during recall, reducing its capacity for relevant story information (Lorch et al., 1999).

With working memory capacity reduced by the activation of irrelevant memory nodes, it appears that ADHD children link each event as it is presented temporally, without being able to maintain a representation of the events that occur more distally before or after it. Consequently the structure of their narratives tends to be more simplistic, and they are apt to make more sequencing errors. This theory is supported by the fact that in other studies in which more structure was provided by researchers (i.e., having pictures present during recall as a recall aid, using stories with more predictable sequence), ADHD children's recall is not significantly different from control children (Lorch et al., 1999).

WORKING MEMORY AND ADHD

Reviewing the past literature, a somewhat puzzling picture emerges in considering the function of working memory in children with ADHD. It appears that working memory is affected by ADHD, however the nature of the disturbance remains somewhat murky. The first question to be addressed is whether the capacity of working memory is reduced by ADHD. Some researchers report that children with ADHD are able to recall fewer bits of information immediately after presentation (Felton et al., 1987), while others have found that children with ADHD display a similar capacity for information in the working memory buffer (Douglas et al., 1990).

The difference in some of these studies was how the capacity was tested. For example, in the study by Douglas and colleagues, the list presented to the children was either just at working memory capacity (i.e., 7 items) or below capacity. In this condition, children appear to have no difficulty immediately recalling the words. In contrast, Felton and colleagues presented a word list that exceeded working memory capacity, and gave the children multiple practice trials to learn the list. Faced with the more difficult task of recalling more words than working memory capacity would allow, children with ADHD recalled fewer words (Felton et al., 1987). The fact that this is a more cognitively challenging way to test working memory makes it difficult to conclude that ADHD children's poorer recall is due to reduced working memory capacity alone. Because the task is more challenging, other factors such as reduced attentional resources, reduced task persistence, and poorer ability to manipulate information within the working memory buffer (i.e., poorer executive function) could all contribute to ADHD children's poorer performance on this task.

The question of diagnostic status also makes interpretation of these studies difficult. Most children in the studies cited were diagnosed according to DSM-III-R criteria. As was outlined earlier, the unidimensional diagnostic criteria utilized in this revision of the DSM is problematic because it makes a diagnosis of ADHD in the absence of hyperactivity unlikely (Lahey et al., 1997). At the same time, some individuals with what would now be considered ADHD-I may have been lumped with children who were more hyperactive/impulsive thereby spuriously including group differences that may have been present. For example, reduced processing speed has been demonstrated to be an associated feature of ADHD, however it does not appear to be present in all cases of ADHD (Mealer et al., 1996). It may be that this deficit is more highly associated with ADHD-I as a subtype (Barkley, 1997). Faced with rapidly presented information that exceeds working memory capacity, children with poorer processing speed may simply miss some of the information, and as such it would never reach the working memory buffer. By including these children in a sample with other children with intact processing speed, it may appear that working memory capacity is reduced in the whole sample.

Other cognitive deficits would also give the appearance of reduced working memory capacity. In particular, children with ADHD appear to have difficulty applying executive functions to manipulate information within the working memory buffer. For example, children and adults with ADHD appear to have more difficulty with memory updating, that is selectively removing information from the working memory buffer to make room for new information (Schweitzer et al., 2000; Roodenrys et al., 2001). This would, in effect, limit the working memory capacity by taking up space with information bits that are no longer relevant.

Finally, children with ADHD appear to have deficits in executive functions, which would also impact working memory function. For example, children with ADHD have more difficulty employing memory organizational strategies, such as clustering information based on relatedness, which allow more information to be manipulated within the working memory buffer (Douglas et al., 1990; Felton et al., 1987). Similarly, in recalling or producing a narrative, children with ADHD appear to have more difficulty maintaining multiple story events and their connections effectively within the working memory buffer. The result is that although they are able to comprehend stories and recognize information important to the plot as well as their nondisordered counterparts, their narrative production is reduced and contains more errors of intrusion (Lorch et al., 1999; Tannock et al., 1993). These deficits are somewhat remediated by providing external cues (e.g., pictures to remind the children of story events) to organize their production (Lorch et al., 1999).

Taken together, working memory function appears to be impaired in children with ADHD. It is unclear, however, whether these deficits are simply the result of reduced working memory capacity, or whether they are due to deficits in attentional, processing speed and executive function deficits. Additionally, further research is needed to clarify whether there are deficits common to all children with ADHD or whether there are specific deficits associated with cognitive subtypes of ADHD. It is of particular importance to investigate working memory because it is here that connections are initially created and strengthened between novel bits of information and previously encountered information. These connections are what become durable memory traces and allow later recall of information from memory stores. Any deficits at the working memory stage are likely to lead to difficulties in recalling information at a later time.

LONG TERM MEMORY AND ADHD

After processing in the working memory buffer, information can be consolidated into a durable, long-term memory store through elaboration (i.e., linking to previously memorized material) and multiple rehearsal (Ackerman et al., 1986). In an efficient memory system, novel information in the working memory buffer is matched to previously stored information schema, fit into the schema, and then the schema is adjusted overall to accommodate this new information (Ackerman et al., 1986). This information will persist, then, even when it is not being actively rehearsed. An individual can then go back and pull up the memory representation when it is needed at a later time.

There is some evidence that children with ADHD have difficulty with creating these more durable memory traces. For example on the RAVLT (Lezak, 1983), children are presented with a supraspan word list over 5 trials, they are then presented with a second list which acts as a distracter and prevents further rehearsal of the first list. They are then asked to recall the first list once again. Children with ADHD (DSM-III criteria, all subtypes) recall significantly fewer words following this distracter list compared to control children (Felton et al., 1987). It is not clear, however that this is due to difficulties with long-term memory. It may, instead be due to deficits in retrieval organization, similar to the deficits seen in recall of narratives. The deficit may therefore be more closely related to deficits in working memory and appropriate application of executive processes to organize information and organizing recall.

Further examination of ADHD (DSM-III criteria, all subtypes) children's recall of encoded information, however, does not point to deficits in long-term memory access. Children with ADHD show a flatter learning curve across trials of the RAVLT, and by the 5th learning trial are already recalling fewer words compared to controls (Felton et al., 1987). It may be that children with ADHD simply have trouble holding stimuli in working memory so fewer words are consolidated into long-term memory for later access.

Support for this hypothesis comes from examining retention ratio. This refers to the ratio of items recalled following a delay, divided by the number of items recalled immediately (i.e., while working memory is actively processing the stimuli). This is a measure of how much individuals retain based on how much they were able to originally encode. Children with ADHD's retention scores are not significantly different compared to controls (Kaplan et al., 1998). It appears, therefore, that children with ADHD do not experience significant memory decay following consolidation into long-term memory.

CHAPTER 4: SEMANTIC MEMORY

Semantic memory is defined as the organized knowledge network an individual possesses about words, objects, facts and concepts and the relationships among them (Mareschal & Quinn, 2001; Greene, & Hodges, 1996; Lee & Obrzut, 1994). This network is culturally specific, not temporally specific and begins to develop from early life (Greene et al., 1996). This network is constructed from a series of interconnected information nodes, which may be accessed by spreading neural activation (Damian, 2000). Inefficient functioning of this complex network can lead to difficulties with academic activities such as relating new material to previously encoded information, as well as deficits in reasoning and reading comprehension (Lee et al., 1994). These are deficits that are common to children with ADHD and thus deficits in the functioning of semantic memory may underlie the pattern of academic difficulties displayed by children with ADHD. A closer examination of the structure, function and development of this memory system, therefore, may lead to a better understanding of the cognitive deficits associated with ADHD.

THE STRUCTURE OF SEMANTIC MEMORY

According to Kounios, the structure of semantic memory can be conceptualized as consisting of three levels. These are the microstructure, the macrostructure and the global level (Kounios, 1996). The microstructure consists of individual, primitive units of information that relate to individual characteristics of a concept or object. It is composed of individual neurons or small populations of neurons, which can be individually activated when incoming perceptual input matches previously encountered stimuli (e.g., the shape of a fruit) (Kounios, 1996). As an object is encountered in the environment, each of its perceptual features can be weighed against these granular bits of information and weighted for similarity. In this manner, an additive representation of the novel stimuli can be constructed and compared to previous stimuli.

Electrophysiological evidence for this level of structure comes from speed accuracy decomposition experiments. In this method, subjects are asked to make rapid semantic judgments about a series of stimuli. On half of the trials they are allowed to take as much time as is needed to make a correct judgment. On the other half of the trials, a tone is sounded before a complete decision can be made, and subjects are asked to take their “best guess.” These experiments indicate that there is a linear relationship between the amount of time individuals are allowed to make a simple semantic judgment and the accuracy of their performance. In other words, they are able to gradually construct partial representations of a semantic concept by activating individual units of the microstructure (Kounios, 1996).

The next level of semantic structure is the macrostructure. This is a unitary representation of a semantic concept constructed of a modular collection of microstructure units. It is unclear whether these modular bits of information are organized cytoarchitechtonically or neurophysiologically, with widely distributed neurons firing in synchrony; however there is some evidence that both types of organization may play a role. For example, evoked response potentials are additively greater for concrete, imagable words than for abstract words. It has been hypothesized that this is because two sets of neurons process the concrete words, those which are related to visual representations and those which are responsible for processing linguistic information, leading to a greater level of activity than for the abstract words, which are processed by the linguistic neurons alone (Kounios, 1996).

The modular structure of the macrolevel allows hierarchical organization of semantic concepts. By adding features to a semantic concept, a more specific representation is constructed which may lead to the creation of a new concept at the basic semantic level or the refinement of an existing concept into a subordinate level. By subtracting features, a more generalized concept is formed which may correspond to a superordinate level (Kounios, 1996). In this manner an efficient search tree is created whereby an individual can rapidly access pertinent information stored in memory by activating the relevant semantic node through similarity to a superordinate concept and then searching the associations of this superordinate category to find the relevant basic or subordinate conceptual representation.

The final level of semantic organization is the global level, which refers to the hierarchical structure of the semantic network as well as the integrated functioning of verbal, nonverbal and amodal processes overarching the semantic network (Kounios, 1996). To illustrate how the various levels of the structure of the semantic memory network according to this model, one may imagine encountering an object in the environment. An individual first notes that the object has legs, which corresponds to a primitive unit of information which might be stored in the microstructure by a set of neurons which fire in response to incoming stimuli with legs. He or she may then search the object for other features, such as noting the object is made of wood. This would stimulate additional microunits and eventually, a set of distributed microstructure units would begin to fire in synchrony, signaling the individual that this set of features matches the semantic concept of a table. This coordination of collection of microunits corresponding to the concept of table would occur at the macrostructure level. Finally this concept of table would be housed in a hierarchical storage system, the global level, which relates similar concepts under the heading of furniture. If the individual wants to locate another concept related to the present one, they could search under this major heading, rather than searching all objects with legs. This avoids searching through living things, for example, making the search more efficient. It is perhaps easier to understand the role of this level of semantic structure by examining how it functions.

MODALITY SPECIFIC STRUCTURE OF SEMANTIC MEMORY

Semantic memory is dependent on the organized operation of a complex neural network, which is widely distributed over the cortex (Greene et al., 1996). It is necessary for a wide variety of brain structures to be involved in the processing and storage of semantic information given the wide variety of types of stimuli that may be encountered in the environment. For example, an object that may be processed visually presents very different demands than an abstract word, such as “justice.” At the same time, even concrete objects may have associated abstract concepts that can be used to categorize them. For examples, animals may be categorized by shape, but they may be further categorized by more abstract concepts such as how they digest food (e.g., cows vs. dogs). This raises the question of how semantic knowledge networks are organized. Are there separate dedicated systems storing verbal/concrete based information and visual/abstract information or is semantic knowledge based on a single amodal system?

It appears that a combination of both systems are involved in semantic memory function. Neuroimaging studies using positron emission tomography investigated whether there were different patterns of activation when participants were asked to make semantic judgments about pictures compared to when they were asked to make semantic judgments about words. If participants were asked only to study the words or pictures, separate systems were activated to encode the information. For pictures, the right middle occipital gyrus was activated while words activated the left inferior parietal lobe (Harmony, Fernandez, Fernandez-Bouzas, Pereyra, Bosch, Diaz-Comas, & Galan, 2001).

Adding the demand of making a semantic judgment activated additional areas, however there were separate, independent patterns of activation for verbal versus visual information. Pictures activated the left posterior inferior temporal sulcus while words activated the left superior temporal sulcus, the left anterior middle temporal gyrus and left inferior frontal sulcus (Harmony et al., 2001). The authors postulated that these areas are responsible for processing modality specific semantic information. According to Harmony and colleagues, visual characteristics of pictures are stored in an "iconongen" system, a granularly organized system, while information about the visual and phonological characteristics of words are stored in a "logogen" system (Harmony et al., 2001).

There were common areas activated by both paradigms. These included wide areas of the left hemisphere stretching from the superior occipital gyrus through the middle and inferior temporal cortex and forward to the inferior frontal gyrus (Harmony et al., 2001). This common activation indicates that the information in the iconogen and logogen systems are eventually integrated. It is believed that it is here that abstract, modality independent concepts are stored (Harmony et al., 2001).

Additional evidence for this hypothesis comes from studies utilizing evoked response potentials. In making semantic judgments about words or pictures, an early positive wave occurs in the interval from 150-300 msec following presentation of the stimulus. This is associated with modality specific processing of the stimulus and is concentrated in the left hemisphere for verbal information, and the right hemisphere for image based information (Kounios, 1996). This is followed by a negative evoked potential at approximately 400 msec following presentation. The onset for this N400 signal is slightly earlier for visually presented information indicating that the neural generators of the signal are not the same (Harmony et al., 2001; Kounios, 1996).

N400 is thought to be associated with integration of information from the modality specific semantic processing networks and semantic decisions based on abstract meaning. It is present regardless of whether semantic stimuli are presented in a single modality or in mixed modalities, indicating that it is modality independent. Further, its amplitude is greater when pairs of stimuli are semantically incongruent, indicating that it may be associated with the process of evaluating semantic congruity (Harmony et al., 2001; Kounios, 1996). The evidence thus indicates that there are two interrelated networks involved in semantic memory activation. The first is a downstream, modality specific network which is responsible for processing and recognizing individual features of a stimulus, the second is a more widely distributed amodal network which takes information from these downstream networks to make semantic judgments (Greene et al., 1996; Harmony et al., 2001; Kounios, 1996).

PARTIAL AND HOLISTIC PROCESSING OF SEMANTIC INFORMATION

Given the above evidence, it seems that individual granular features of a given stimulus are stored as individual bits of information in the modality specific semantic networks. It is less clear, however, how abstract semantic concepts are constructed and stored in memory. It may be that concepts are stored holistically, and are accessed and activated via stimulating any of the underlying verbal or perceptual features of a stimulus. On the other hand, it may be only the granular features that are stored in long-term memory and abstract concepts are constructed on-line as the weights of association strength of individual features are added in the amodal system (Kounios, 1996).

As was outlined in the section on the structure of semantic memory, there is some evidence from work with speed accuracy decomposition experiments that demonstrates that semantic memory has a “bottom-up” component. That is, individual perceptual features of a stimulus (e.g. seeing the legs, and touching the wooden construction of the table) are activated in the modality specific network. Adding the weights of these features, the semantic memory system can gradually build a partial representation, which can be used to make semantic judgments about stimuli (Kounios, 1996).

In examining reaction time data, however, this does not appear to be the only mechanism for storage of semantic information. The reaction times predicted by the partial trials of the speed accuracy decomposition paradigm, as outlined in the previous section, are considerably slower than those actually observed in typical semantic judgment reaction time tasks. There appears to be a second knowledge representation mechanism which operates independently of the granular system, but which yields a more rapid all- or-none response (i.e. noting both the legs and wood simultaneously and activating the semantic node for furniture or tables) (Kounios, 1996).

Semantic memory can therefore be accessed via a slower computational route that constructs semantic representations on-line, or an independent, fast search mechanism that directly accesses discrete and more complex representations of semantic concepts. These two routes race against one another until one or the other yields enough information for a semantic judgment to be made (Kounios, 1996).

This dual process model would be advantageous for several reasons. The fast search mechanism with its more complete representations provides an efficient mechanism for rapid access of relevant familiar information. The slower computational mechanism could be useful when an individual encounters novel information. In this way, new conceptual representations can be created or novel features can be linked to existing concepts.

ACTIVATION OF NODES

The semantic memory system, thus, can be conceptualized as a series of information nodes with each storing a discrete semantic concept. These nodes are organized hierarchically with a more abstract superordinate concept situated above and linked to basic-level and subordinate exemplars of that concept. Each of these nodes is, in turn, linked to other conceptual nodes and the links in this complex network represent the relationships between concepts, with stronger links representing closer relationships (Kounios, 1996).

Much of the operation of the semantic network is unconscious and automatic (Naccache and Dehaene, 2001). As an individual encounters an object or word in the environment, its features enter the semantic processing network within the first 150 msec and, by 400 msec following stimulus onset, complex semantic decisions can be made. This is accomplished via spreading activation and spreading inhibition. The features of a particular stimulus are matched to a semantic node based on similarity. Once a relatively close match has been established, that node and its connections are activated, with stronger connections being activated most rapidly. The activated nodes are searched until the relevant exemplar or concept is located, at which time it can be retrieved and consciously manipulated. Irrelevant or confounding nodes may be selectively inhibited at the same time, thereby facilitating location of relevant semantic concepts (Naccache et al., 2001; Damian, 2000).

Much of this activation process takes place automatically and below the level of consciousness. Semantic priming experiments provide evidence for this unconscious processing. For example in one study, Naccache and colleagues asked adult subjects to evaluate whether a number presented on a computer screen was greater or less than 5. Prior to display of this target number, a different number was rapidly displayed on the screen, and then masked before it could be consciously detected. When this priming number was incongruent with the target (i.e., was the opposite direction from five), reaction time was significantly slower. Additionally, the closer the priming number was to the target number, and presumably the stronger the semantic connection between the numbers, the greater the effect on reaction time (Naccache et al., 2001). Unconsciously detected stimuli, therefore, can have significant interference or enhancing effects on conscious behavior.

Further evidence of semantic processing below the level of consciousness is provided by functional imaging and electrophysiological studies of activation during exposure to consciously and unconsciously detected stimuli. Both consciously and unconsciously detected word stimuli evoked N400 evoked potentials in a semantic judgment task. Similarly, unconscious presentation of numerical stimuli provoked fMRI activation of parietal areas known to be associated with quantity evaluation (Naccache et al., 2001). Semantic memory appears to be largely a subconscious process activated as stimuli are encountered in the environment. This is not to say, however, that it cannot be consciously accessed. Strategies such as visualization and mnemonic strategies can be consciously employed as aids in encoding and retrieval of novel material. Learning to consciously apply these strategies is a developmental process which can be learned, and which improves with age (Mareschal et al., 2001; Vicari, Pasqualetti, Marotta, & Carlesimo, 1999; Nida & Lange, 1995).

SEMANTIC MEMORY DEVELOPMENT

As previously stated, semantic memory is culturally dependent, indicating that the semantic memory network is constructed through experience (Greene et al., 1996). It follows logically, then, that construction of the semantic memory network is a developmental process. The construction of an efficient semantic network as well as the knowledge of how best to utilize the relations between semantic nodes is crucial to many cognitive activities. Failures in the development of the structure and function of this system are likely to underlie many deficits in academic functioning, such as low reading comprehension, and difficulty with reasoning (Lee et al., 1994). An understanding of normal semantic memory development may indicate areas for remediation in children with deficient semantic memory function.

According to the dual process model, the mature semantic memory system is comprised of two independent pathways, the slower computational pathway, gradually adding features of the stimulus, and the fast search pathway which directly accesses previously stored holistic conceptual representations in an all or nothing fashion (Kounios, 1996). In considering development of the semantic network, it is important to consider whether these two pathways develop simultaneously, whether one develops from the other, or whether the two pathways are actually different modes of access to the same pathway.

Evidence for primacy of the computational pathway

The ability to group concepts into meaningful categories underlies the ability to construct a semantic memory network. Categorization of objects can be observed as early as infancy. Several methods have been developed to examine infants' ability to categorize. Habituation is one such method. Infants from 0-12 months are shown a novel category exemplar or series of category exemplars until the amount of time they spend looking at the stimuli decreases, indicating they have habituated to the category. They are then presented with a pair of stimuli, one from a novel category and one from the habituated category. Infants tend to preferentially gaze at the novel category stimulus exemplar, indicating they recognize the difference between category features. This has been accomplished using simple geometric features and schematic faces, as well as more complex color photographs (Mareschal et al., 2001). Additional methods such as conditioning infants to kick their legs in response to familiar categories, and preferential manipulation of objects yield similar results (Mareschal et al., 2001).

In each of these experimental paradigms, the only information available upon which to make category judgments is featural information; yielding indirect evidence that infant categorization is more dependent on the slower computational pathway for categorization. Additional evidence for this hypothesis comes form the work of Rakison and Butterworth. These authors used a sequential touching methodology to investigate whether infants of 13, 18, and 22 months used featural parts (e.g., legs) to categorize furniture, animals and insects. They found that the two youngest groups failed to distinguish different categories, while 22 month olds were able to distinguish furniture from insects and animals. These oldest infants, however, failed to distinguish animals from insects (Rakison & Butterworth, 1998).

The results of this experiment indicate that children organize categories "partonomically." That is, they based their category judgments on featural parts of the objects. The youngest infants based their judgments on a single feature, legs, while the older infants used more than one feature to distinguish the living objects from the non-living objects (Rakison et. al., 1998). In a second study the authors created confounded categories by putting wheels on animal figures and legs on vehicles. Infants were able to categorize vehicles and animals when the parts were congruent with the object, but in the confounded condition, they failed to form categories (Rakison et al., 1998).

These results indicate a preference for utilizing the featural computational pathway to categorize objects. The categories are elaborated by the addition of new features as more are encountered in the environment. The easiest categories to learn, then, would be those for which parts are characteristic of membership. This would explain why insects and animals would be confounded categorically as they share many features (Rakison et al., 1998).

Further evidence for the primacy of this computational process comes from infant gaze bias. Infants are instinctively drawn to examine particular features of a stimulus. For example they have been shown to gaze preferentially at faces from birth. In examining faces they tend to focus on the outer contour of the head and the internal features of the face (Mareshcal et al., 2001). Similarly, infants use acceleration and deceleration of an object to discern the boundaries of an object and to detect it as a unitary entity separate from its background (Mak & Vera, 1999; Spelke, Phillips & Woodward, 1995). Infants are, in effect, hard-wired to attend to important featural information and utilize these features in a computational manner in making semantic category inclusion judgments.

It may be that the fast search categorical system is constructed over time by constructing abstractions from the features of the slow computational pathway. As more and more exemplars are encountered, the features that co-occur frequently are gradually linked via neural connection or simultaneous neural firing. This could then create an abstracted prototypical conceptual representation, which could be directly accessed as a new exemplar is encountered (Mareshal et al., 2001).

Evidence for simultaneous development of the computational and fast search pathways

Though the computational pathway clearly plays a role in early infant categorization, it does not account completely for infants' and young children's ability to form semantic categories. Infants as young as 3 months were able to form categories of domestic cats which included novel cats, but excluded other animals including dogs and tigers, which share similar perceptual features. Similarly they formed a superordinate category for mammals that excluded nonliving things as well as birds and fish. Infant categorization, then, is flexible and infants are responsive to a variety of characteristics in a stimulus simultaneously (Mareshcal et al., 2001).

Infants also display interesting asymmetries in categorization, which cannot be explained by utilization of the computational pathway alone. Infants familiarized with pictures of both cats and dogs formed a category representation for cats that excluded dogs, but the category for dogs did not exclude cats (Mareschal et al., 2001). This indicates that the infants were able to construct an abstracted category for cats, but were relying more on featural information to categorize dogs. This would make sense, because dogs as a category have greater variability in their features relative to cats, making it more difficult create an abstracted category for dogs. Thus, infants are able to construct abstract conceptual representations in some cases, but rely more on weighing of feature similarity in other cases.

Mandler (1992) proposed a developmental model similar to the dual process model by which infants and young children could simultaneously construct abstracted conceptual categories available to the fast search processing network while gradually constructing featurally based computational categories. She proposed that children could use non-obvious features of objects to draw inferences and create categories.

For example, infants are able to differentiate living things from non-living things from the age of 4-5 months (Mandler, 1992). This is despite the fact that infants of this age have limited visual acuity. Mandler proposed that infants use motion cues to construct abstracted categories in a process she termed “perceptual analysis.” In this process, an infant attends closely to a perceptual array. In attending to this array, one object may be compared to another in order to determine sameness or difference, or a new previously unattended feature of a familiar object may be analyzed. From this analysis, a concept is formed, in that the information is recoded in a new format that represents an abstraction of the object. This abstraction is not dependent on perceptual information directly, but is rather a simplified, modality independent redescription of the object, which contains meaning about that object (Mandler, 1992). For example, an abstraction of an apple may include only the contour of a typical apple and the color red rather than all of the possible sizes, shapes and colors of an apple.

This redescription of the object does not take place independently from perception, as the two may occur simultaneously, and the formation of the concept is not dependent on accessing previously constructed perceptual representations of the object. Rather, this is an independent process that can later be accessed independent of perception (Mandler, 1992). In other words, an abstraction of the concept “apple” can then be accessed and manipulated, even in the absence of an apple.

Animacy is an early-developing category, which is determined from perceptual analysis of motion of various objects. Animate objects are capable of moving without the intervention of another object while inanimate objects lack this agency. Once in motion, inanimate objects travel in a straight path, unless acted upon by another object, while animate objects travel along an unpredictable trajectory (Mandler, 1992). Thus, without attending to any of the obvious perceptual features of an object, then, infants can create abstract representations of types of movement. They can then use these abstracted representations to make predictions about the behavior of objects and to categorize objects on the basis of their movement (Mak et al., 1999).

Mandler’s theory represents a developmental restating of the dual process theory. She proposed that categorization takes place along two dimensions. The first is perceptual schemas, categories based on appearance alone that can be gradually elaborated by additional perceptual features over time. This would be the equivalent of the computational pathway in the adult model, with the similarities of individual features of a given stimulus being compared and weighed against previously stored information. The second dimension is the image schema, which is a conceptual primitive containing some meaning about an object (Mareschal et al., 2001; Mandler, 1992). These conceptual primitives can be elaborated upon over time as new aspects of stimuli are attended to in the process of perceptual analysis. Image schemas, then, are the seeds for abstract adult concepts utilized in the rapid pathway of the adult model.

Image schemas may act as the scaffolding upon which adult categories are formed. The conceptual primitive of animacy appears to be an important factor in later elaboration of categorization of animals and inanimate objects. For example, in one study 4 year-children used motion cues as the basis to make inferences about class inclusion for both animals and geometric shapes while 7 year-olds were more likely to use motion as a cue for category inclusion in animals alone (Mak et al., 1999). This indicates a refinement of the animacy concept over the course of development.

Additionally, as children develop, they shift from a preference for perceptual features to causal features (i.e., features which cause other features like DNA) as a basis for categorization of animals. By the age of 7, this preference is clearly established (Ahn, Gelman, Amsterlaw, Hoenstein & Kalish, 2000). This shift indicates a developmental change in the understanding of animacy. Children are taught about biological principals as they grow older, and they learn that these unseen features are important in determining animal categories (Ahn et. al., 2000). This biological knowledge is likely appended onto image schemas, thereby creating a more complex and useful conceptual category.

This is not to say that image schemas are the most efficient strategy for categorization, or that these image schemas may be abandoned later for more complex categories. For example, several authors have postulated that children show an early preference for creating categories based on thematic similarity. In other words, concepts and objects may be grouped on the basis of their occurring together within an event (e.g., floor and broom go together because one uses a broom to clean a floor) rather than in a taxonomic manner (broom and rag go together because they are cleaning implements) (Nation & Snowling, 1999; Waxman & Namy, 1997). Waxman and Namy demonstrated that this preference is somewhat flexible, and if children are cued to taxonomic relationships ("show me another one") they are able to form taxonomic categories (Waxman et al., 1997). These taxonomic categories represent a more efficient organizational strategy, as objects are categorized onto a single category rather than multiple categories.

Development of memory strategies

As was previously stated, semantic memory can operate as either an implicit or explicit memory structure. Learning to utilize strategies to access the semantic network acts both to refine the network and to relate novel material to existing categories. This, in turn, increases learning and memory efficiency (Vicari et al., 1999). Learning to utilize memorization strategies is also a developmental process.

Conscious recollection of previous experiences increases with age, peaking in adolescence (Vicari et al., 1999). The development of this ability depends on the use of mnemonic strategies, an elaborated knowledge base (including more elaborated semantic networks) and on knowledge about memory (Cycowicz, 2000). These abilities are closely tied to development of the frontal lobes and the consequent development of executive functions. For example when faced with memorizing new material, children must identify salient semantic categories from their internal representations, and must choose an effective memorization strategy from a repertoire of memorization behaviors (e.g., simple repetition versus clustering).

One way in which this developmental lag of frontal functions can be observed is in investigating how children utilize clustering strategies in supraspan list learning tasks. In these tasks, the number of items exceeds the capacity of working memory. By clustering items in semantically related categories, the load on memory capacity is reduced and more items can be encoded. In addition, category information can be utilized as a cue for later recall of this information (Vicari et al., 1999).

Studies demonstrate that the spontaneous use of clustering as a strategy increases linearly over the course of development (Vicari et al., 1999). This is associated with a significant decrease in forgetting in long-term recall. Preschoolers are extremely unlikely to utilize this strategy in verbal learning tasks. Similarly they utilize clustering with nonverbal stimuli only when the clusters are made particularly salient (e.g., including numbers or letters as a category) (Nida & Lange, 1995). By the age of 7 or 8, children begin to effectively and spontaneously utilize this strategy (Vicari et al., 1999). Increases in clustering are associated with smaller size of forgetting at delayed recall (Vicari et al., 1999).

ABNORMAL DEVELOPMENT OF SEMANTIC MEMORY AND THE RELATION TO ADHD

As was previously stated, children with ADHD have been shown to display certain behavioral and cognitive deficits associated with executive functions. These include difficulty with behavioral inhibition, as well as deficits in working memory, self-regulation of affect/arousal, internalization of speech, and analysis and synthesis of behavior (Barkley, 1997; Sergeant, 2000). Barkley has proposed that deficient behavioral inhibition plays a central role in producing the symptoms of ADHD-C. While the evidence does support the idea that group differences between ADHD-C children and controls are strongly related to differences in behavioral inhibition, the possibility remains open that deficits in the other areas of executive function outlined above may also play an important role in ADHD symptoms.

For example, if faulty behavioral inhibition is largely responsible for the profile of symptoms seen in ADHD-C, what is responsible for the development of ADHD-I? Some authors have postulated that ADHD-I may be related to more sluggish cognitive tempo (Barkley, 1997). If this were shown to be true, it would support Sargeant's assertion that moderation of affect and arousal may be the primary deficit producing symptoms of inattention.

At the same time, it appears unlikely that a single type of executive function deficit could be responsible for the full profile of symptoms seen in ADHD. Individual, idiosyncratic patterns of dysfunction in the other executive functions may also play a role in ADHD. Various studies have shown deficits in working memory (e.g., Douglas et al., 1990; Mealer et al., 1996), internalization of speech and reconstitution (see Barkley, 1997 for review). In other words, beyond the large group differences accounted for by behavioral inhibition and physiological arousal, individuals with ADHD may have unique patterns of deficits in executive function that may be lost in large group analyses. This may explain the discrepant findings in the literature regarding memory function in ADHD. For example, Felton and colleagues' discrepant finding that children with ADHD have a reduced working memory capacity (Felton et al., 1987) may be due to inadvertently including a larger number of ADHD children with specific working memory deficits in their sample.

Examination of semantic memory function in children with ADHD may provide a better method for assessing whether there are unifying cognitive deficits that may impact cognition as well as academic achievement regardless of ADHD subtype. As was previously discussed, the semantic memory network emerges in a developmental process and is entirely dependent on experience (Greene et al., 1996). As such, it is highly likely to be sensitive to the effects of multiple elements of executive function. These would include passive processes like neural excitation and inhibition, and modulation of attention and arousal, the mechanisms proposed by Sargeant to be the causal deficit in ADHD.

On the most basic level, semantic memory function is dependent on patterns of neural activation and inhibition. The creation of a semantic category occurs when a system of related neurons are simultaneously excited or when those neurons fire in a particular pattern, and repeated excitation of those neurons strengthens the connections between features or between concepts (Kounios, 1996). Additionally, spreading activation through a semantic node is the method by which semantic categories are searched for retrieval while spreading inhibition may be responsible for temporarily limiting access to irrelevant nodes during recall (Naccache et al., 2001; Damian, 2000).

Children with ADHD have been shown to have deficient neural inhibitory mechanisms, as it is postulated that Ritalin and other stimulant medications act primarily to increase inhibitory mechanisms (Pennington & Ozonoff, 1996). Children with ADHD may have more difficulty in constructing neural connections which are weighted for association strength within the semantic memory system as all features of a stimulus are as likely to be activated in response to encountering the stimulus (e.g., having four legs would be given the same weight as living vs. non-living status).

Similarly, perturbations in modulation of arousal and allocation of attentional resources as proposed by Sargeant would also be expected to disrupt semantic memory development. For example, low arousal may lead to less complete processing of a stimulus, allowing only a limited number of features to enter working memory. It would simply depend on chance whether these features would be important or unimportant in categorizing the stimulus (e.g., having fur is less important in distinguishing cats from dogs than is the shape of the animal's body).

A core feature of ADHD is reduced attentional capacity. Additionally, children with ADHD have difficulty allocating this reduced attentional capacity to tasks. In Mandler's developmental dual processing model, attention plays a vital role. In order to construct image schemas, attention must be allocated to core features of a stimulus. These features are then abstracted, the image schema is constructed and attentional resources are then freed to attend to other aspects of the stimulus (Mandler, 1992). Reduced attentional capacity may mean that children with ADHD do not have attentional resources to attend to these core features, and image schemas may not be formed. Alternatively, children may attend to irrelevant features of stimuli, leading to spurious semantic connections between stimuli. Taking all of these passive mechanisms of semantic network creation into account, one would expect that the semantic memory networks would be more poorly organized in children with ADHD, with a lack of weighting of similarity and more idiosyncratic connections between apparently unrelated items.

Deficits in more active executive functions may lead to difficulties consciously accessing and organizing the semantic network. For example, strategies such as taxonomic clustering have been shown to be more cognitively effortful in applying to a list-learning task, though repeated application of this strategy gradually automates clustering over time. Children with ADHD are less likely to choose a more effortful strategy (i.e., they are more likely to use repetition), and are more likely to perseverate on a single strategy they have begun to employ even when it becomes apparent that a different strategy may be more efficient (Borcherding et al., 1988). In this way children are less likely to be able to access the semantic network to relate novel stimuli to pre-existing memory traces, and are therefore more likely to have recall difficulties. These deficits in strategy selection, evaluation of strategy effectiveness and creativity in application of goal-directed strategy would map onto the working memory, internalization of speech and reconstitution factors of Barkley's executive function model of ADHD (1997).

This is not to say that children with ADHD would not be able to utilize semantic organizational strategies. Studies with children with reading disabilities (RD) indicate that if the salience of the semantic relations between stimuli is increased, they are able to utilize clustering strategies (Lee et al., 1994). Similarly, one would expect that if the semantic relations between stimuli were made explicit for children with ADHD, they would be more likely to recognize these relationships from the beginning of encoding, and would therefore be more likely to employ a clustering strategy as an aid in encoding and retrieval.

To summarize, it appears that deficits in executive function, such as working memory deficits, difficulty regulating motivation for more effortful tasks, and difficulties choosing, maintaining, and shifting cognitive strategies, lead to difficulties constructing and utilizing semantic memory networks. Disordered function of semantic memory structures, in turn, would likely make it more difficult to efficiently store new information in short-term memory stores. As was stated above, children with ADHD are more likely to construct idiosyncratic semantic relationships within their memory stores, which may explain the relatively discrepant findings on various memory tasks as each child is likely to display a unique pattern of strengths and weaknesses within the semantic network. Overall, however, it would be expected that children with ADHD would demonstrate more difficulty in creating and utilizing semantic networks compared to nondisordered controls, regardless of diagnostic subtype or individual differences in executive function (EF).

Support for this idea comes from examining the performance of children with reading learning disabilities. This population is of interest as children with ADHD are frequently diagnosed with co-morbid reading disabilities and demonstrate difficulty automatizing the reading process (Ackerman et al., 1986). Reading is proposed to be one mechanism responsible for much of the growth and refinement of the semantic memory network. In reading, children are exposed to novel words and concepts embedded in a context, which may make it easier to create semantic representations that can later be accessed (Nation et al., 1999; Lee et al., 1994).

Children with RD do, in fact, show deficits in semantic memory function. They are less likely to use taxonomic clustering in list learning tasks (Lee et al., 1994). In addition, their reaction times to words are not significantly reduced when they are preceded by a semantically related prime with low association strength while children with normal reading ability do show significant priming in the same condition (Nation et al., 1999). These studies are of interest because they did not control for ADHD status. Reading disability is a frequent comorbidity with ADHD (Tirosh & Cohen, 1998). In particular, these children tend to have intact phonological decoding skills but poor reading comprehension and reduced lexical/syntactic abilities, the pattern of disability selected in the Nation and Snowling study (Nation et al., 1999). This pattern of reading disability has been shown to be related to deficits in sequencing and short-term memory rather than IQ or attentional factors (Tirosh et al., 1998). There appears to be a pattern of cognitive deficits present in ADHD, including poorer reading, which are highly related to specific deficits in memory function.

Thus, difficulties with executive functions related to encoding appear to lead to deficits in both explicit and implicit semantic memory function. Factors other than EF may be responsible for deficits in semantic memory. For example, slower cognitive processing speed could cause deficiencies in semantic memory by limiting the number of stimuli an individual is able to process when the stimuli are rapidly presented. Lower IQ could limit an individual's abstract reasoning abilities, thereby limiting the ability to recognize connections between more complex abstract concepts. Further research is needed to clarify whether deficits specific to EF play a more important role in semantic memory function, or whether other factors like those mentioned above may be more important.

Very few studies have explicitly investigated semantic memory function in children with ADHD. The current study will attempt to demonstrate that ADHD is associated with disordered function of the semantic memory system, specifically that children with ADHD show decreased priming for semantically related words as compared to age-matched normal controls. Further, the present study will investigate whether the ability to utilize semantic clustering strategies can be accounted for by efficient, intact executive function alone, or whether other factors such as working memory capacity or IQ account more for differences in explicit dysfunction of semantic memory in ADHD children.

CHAPTER 5: RATIONALE AND HYPOTHESES FOR THE CURRENT STUDY

The present study sought to gain a better understanding of semantic memory function in children with ADHD. Construction of a semantic memory network is hypothesized to be a developmental process dependent on attention to stimuli in the environment, and efficient utilization of executive function. As these are both hypothesized to be causes of the symptoms profile observed in ADHD, it was expected that semantic memory development would be disrupted in children with ADHD, leading to more poorly organized semantic networks, with functional relationships (e.g., things one encounters at the same time, like broom and floor) having stronger neural connections than semantic relationships (i.e., more abstract, hierarchical relationships). This organizational structure was predicted, as the processing of functional relationships is believed to be cognitively less demanding than abstract semantic relationships and less prone to idiosyncratic associations. Differences in semantic network structure between children with ADHD and normal controls were assessed using the semantic priming task. In particular differences in association strength for functionally vs. semantically related words was assessed.

Semantic Priming Task

1. It was predicted that children in the ADHD groups would show less priming in the low association strength, semantically related condition compared to controls. This was expected to occur because children with ADHD were expected to have a more poorly organized semantic memory network. As such, it was expected that they would demonstrated priming only for those word pairs with overlearned, strong connections.

Once a semantic network has been constructed, its structure can be utilized as an aid in encoding and consolidating information about novel stimuli. The semantic memory network can be conceptualized as a filing cabinet with similar concepts being filed together. Searching for a concept (e.g., dog) would, in effect, open the proper file drawer (animals) and grant access to a particular file of concepts strongly related to the desired concept (e.g., furry pets). As new concepts are encountered, the structure of the semantic network can be used as an aid to encode and consolidate information (i.e., by comparing to previously encountered stimuli), thereby freeing space in the working memory buffer. If the semantic memory network of an individual is more poorly organized, it is likely that he or she will use less efficient memorization strategies and will be able to encode less information. This hypothesis was tested with the list learning tasks.

List learning tasks

2. It was predicted that the two ADHD groups would spontaneously utilize semantic clustering strategies significantly less than control children when they are not cued to the presence of semantic relationships, as on the MALT, with the youngest children having the fewest semantic clusters. When provided with external organizing structure (i.e. semantic cues on the experimental list learning task) children with ADHD were expected to utilize semantic clustering as effectively as control children.

3. It was predicted that the two ADHD groups would freely recall significantly fewer words in the MALT (uncued at encoding) condition compared to controls. No difference was expected in the experimental list learning condition. Children with ADHD were expected to recall fewer words because they were expected to utilize less efficient encoding strategies (e.g. clustering) when they were not cued to apply these

strategies. This, in turn, was expected to limit their ability to process and encode new information.

4. It was expected that the two ADHD groups would make more errors of intrusion during free recall on both of the list learning tasks versus controls. As the ADHD children were expected to have more poorly organized semantic memory systems, it was expected that presentation of the words on the list was likely to activate a wide variety of memory nodes which had been spuriously related to the stimuli words in past experience. Additionally, because children with ADHD have poorer behavioral inhibition, it was predicted that they would have more difficulty in limiting recall to words presented on the list because they would be less able to inhibit activation of irrelevant memory nodes.

5. It was predicted that children in the ADHD groups would make significantly more repetition errors on the MALT versus control children. This was expected because children with ADHD were expected to utilize fewer organization strategies in encoding and retrieval when not cued to use semantic clustering, and as such, would have more difficulty tracking which words they had previously recalled compared to normal controls.

6. It was predicted that children in the ADHD groups would recall significantly fewer words on the reorganization trial of the experimental list learning tasks compared to controls. As children with ADHD were expected to have more poorly organized semantic networks, it was expected that they would have less flexibility in their access of rehearsed information, being able only to recall information in the context in which it was encoded.

CHAPTER 6: METHODS

PARTICIPANTS

Participants included 19 children with ADHD-C, 29 ADHD-I, and 25 normal control children. More detailed information regarding diagnostic criteria is included below in the section on the SNAP-IV. The age range of participants was restricted to children between the ages of 7 and 13 years of age with *M* = 115.56 months; *SD* = 21.66 months. The participants were primarily Caucasian (84.9%) and male (72.6%). Detailed information regarding the age, ethnic, and gender composition of each group is provided in the results section and in Tables 1 and 2.

The children in the two ADHD groups were recruited from referrals to Austin Neurological Clinic and children who had previously participated in research through the University of Texas ADHD Laboratory. Control children were recruited utilizing a "snowball" methodology by asking ADHD participants to refer normal control peers by means of a letter given to each of the participants at the end of testing. Control participants were also given the same recruiting letter. The control group, then, consisted of normal control siblings and friends of the ADHD participants as well as normal control children who were acquainted with the study staff. Participants who agreed to complete a three hour research protocol consisting of several related studies received $40 for their participation. Children were excluded if their parents reported a history of serious head injury, seizures or other serious medical disorder. Inclusion criteria are outlined in more detail below.

MATERIALS

Measures A variety of measures were used to classify the children into groups and to obtain other demographic and descriptive information.

Demographic Variables

SNAP-IV

The SNAP-IV is a questionnaire consisting of the diagnostic criteria for ADHD-I, ADHD-C and ADHD/H as well as the diagnostic criteria for oppositional defiant disorder as outlined in the DSM-IV. The ADHD symptoms are rated on two subscales, symptoms of inattention (IA), and symptoms of hyperactivity/impulsivity (HI). Parents and teachers were asked to rate the presence or absence of each symptom on a 0-3 scale with 0 indicating the child does not display the symptom and a 3 indicating that the child displays the symptom “very much.” A symptom was considered present if the parent or teacher rated the symptom as a 2 or 3.

To be included in the ADHD-I group, children were required to have been rated as displaying 6 of 9 symptoms of inattention. In order to maximize subtype differentiation, children classified as IA were required to have 4 or fewer HI symptoms. To be included in the ADHD-C group children met 6 of 9 symptoms of both inattention and hyperactivity/impulsivity. Thirty-seven children with ADHD (11 C and 26 I) met DSM-IV criteria based on both parent and teacher ratings. An additional 11 ADHD children (8 C and 3 IA) who met criteria by one rater and missed criteria by the other rater by 1 symptom were also included. Thus, all ADHD children would have met criteria by the less stringent algorithm used in the Multimodal Treatment Study of Children with ADHD (MTA: MTA Group, 1999), in which a symptom was counted as “present” if it were endorsed by either the parent or teacher.

To be included in the non-diagnosed control group, children were required to have been rated by both parent and teacher as having fewer than 4 symptoms of either IA or HI; 25 children who met these criteria comprised the control group. Additionally, children were excluded if they met DSM-IV diagnostic criteria for Oppositional Defiant Disorder (four or more of eight possible symptoms).

Weschler Intelligence Scale for Children-III (WISC-III; 1991)

All subjects were administered the Vocabulary and Block Design subtests of the WISC III. For most of the children in the ADHD groups, WISC-III scores were obtained from previous neuropsychological testing completed as part of a referred clinical work-up for ADHD. In cases where testing was more than one year old, these subtests were repeated. This abbreviated form of the WISC-III has been shown to adequately correlate with Full Scale IQ. Prorated Full Scale IQ estimates for the group ranged from 83 to 146 (*M* = 112.49; *SD* = 15.02). Please refer to the results section and Table 1 for more detailed information regarding IQ for each of the groups.

Wide Range Achievement Test-III (Wilkinson, 1993)

The WRAT-III (Wilkinson, 1993) is a test of achievement consisting of 3 subtests, two of which were administered in the present study. Scores on this measure are based on grade-level corrected subtest standard scores with a mean of 100 and a SD of 15, allowing direct comparison to prorated FSIQ scores. The Reading subtest is a word recognition test in which participants pronounce single words aloud. The Arithmetic subtest consists of timed arithmetic problems. Once again, most children in the ADHD groups had completed this test as part of a previous neuropsychological battery. In such cases these scores were used, provided they were less than one year old.

Previous research has indicated that ADHD is frequently associated with poorer academic achievement (Rapport, Scanlan, & Denney, 1999). These subtests tapping academic achievement were included to evaluate whether poorer performance on measures of achievement are associated with poorer performance on the experimental measures. For the group, scores ranged from 83 to 136 on the Reading subtest (*M* = 106.71; *SD* = 12.85) and from 84 to 141 on the Arithmetic subtest (*M* = 105.79; *SD* = 14.09). More detailed information regarding the performance of the various diagnostic groups on this measure is included in Table 2 and the Results section. For the purposes of the present study, children were classified as having a learning disability in the area of reading if they obtained a WRAT Reading score of less than 80, and there was a discrepancy of 15 or more points in their WRAT Reading score and their prorated Full Scale IQ. None of the children in this sample met these criteria for diagnosis of a reading learning disability.

Dependant Variables

The Missouri Auditory Learning Test (MALT)

The MALT is a list-learning test consisting of 16 words, presented in a semi-randomized order, which can be grouped into 4 categories (animals, body parts, foods, and articles of clothing). The words on this list are matched for length, imageability, category strength and frequency. The list is presented to the child 5 times with each presentation followed by free recall. Words are presented in semi-random fashion such that no items from the same semantic category are presented contiguously. Children are instructed that they may recall the list in any order, and need not recall them in the order presented. Following the fifth trial children are presented a distractor list consisting of 16 items followed by a single free recall. This is done to prevent active rehearsal of the first list. The child is then asked to freely recall the items from the first list once again immediately following recall of the distractor list. The child is then cued to the fact that the items may be grouped by category and the categories are supplied if the child cannot generate them. The child is then asked to recall the items in category groups (e.g. "Now tell me all of the animals"). Children are asked to freely recall the list one last time following a 30-minute delay. Each trial is scored for number of words correctly recalled, number of words repeated on each trial, number of intrusion errors, and number of words clustered according to group. A cluster consists of two words from the same category recalled sequentially. To correct for chance clustering, total cluster score will be corrected for each trial using the following formula:

$$ER = \frac{n^2_1 + n^2_2 + n^2_3 \ldots\ldots n^2_k}{N} - 1$$

Where ER is the number of expected clusters, n_1, n_2, n_3, *and* n_k are the number of items which are recalled from the various categories and N is the total number of items recalled (Vicari et al., 1999). For purposes of direct comparison to the experimental list learning task, total correct responses, total errors of perseveration, total errors of intrusion and total corrected clusters score for the MALT are based on the first three learning trials.

Experimental List Learning Task

In this task, similar to the MALT, children are asked to memorize a 16-word list, which can be grouped into four categories based on where they can be seen (grocery store, hospital, farm, and school). However, on this task children are cued to the presence of categories by telling the children where each item can be seen as it is presented. Children are given three learning trials, with each trial being followed by free recall. Once again, children are instructed that they may recall the items in any order. After the final free recall trial, the children are cued to recall the words in the categories supplied during encoding. They are then asked to recall the words according to uncued categories, which are provided to them (things with wheels, white things, jobs people have, and tools people use to do their work). The children are then asked to immediately recall the words in the originally cued categories a second time. For each trial children are scored for number of words correctly recalled, errors of repetition, errors of intrusion, and number of words grouped by category.

Semantic Priming Task

This computer-based task was adapted from the paradigm used by Nation and Snowling (1999). On this task children are asked to make a lexical decision, as rapidly as possible, whether words presented in an auditory modality are real words, or non-words. Children press a button to respond to each item, and reaction time is recorded. The task is designed to measure priming, with some words facilitating a more rapid response to subsequent related words.

The stimuli of interest in this task are comprised of 40 related word pairs, consisting of one priming stimulus and one target stimulus, which were selected from the stimuli used by Nation and Snowling (1999). Half are related through category membership (abstract semantic relationship e.g. cat and dog) and half are functionally related (related by function e.g. one uses a <u>broom</u> on a <u>floor</u>). Each group is further divided by strength of association with 1/2 being strongly related and 1/2 being unrelated, or weakly related according to normative lists of word association(Nation and Snowling, 1999). The target words of interest are related to their primes in one of four ways: semantic relationship high association strength, semantic relationship low association strength, functional relationship high association strength, or functional relationship low association strength. Each of the target words was paired in one trial with a related prime, and in one trial with a prime to which it was not related. Thus, there are eight cells with 10 target words in each. A weighted average of correct response reaction times for each cell was calculated, and this average reaction time is the variable of interest for this measure.

The stimuli were organized into two lists of 179 words. Each target item appears once in each list, with it being paired with its related priming stimulus (e.g. Brother and Sister) on one list and appearing with an unrelated prime on the other list (e.g. Brother and Head). An additional 40 non-words, matched for length and number of phonemes were added to the lists. Each word appeared two times to make an equal number of “no” lexical responses. To interrupt the pattern of prime and target words appearing together, an additional 21 real words were added to the lists. Both the additional words and non-words were the same across the two lists. Related pairs, unrelated pairs, filler words and non-words were semi-randomly distributed across the two lists with the order determined by random drawing. Care was taken to ensure that patterns of responding were randomized across the lists (e.g. avoiding patterns such as two “yes” responses always being followed by a single “no” response).

The words were digitally recorded using SoundEdit software and were presented in the experiment in the auditory modality using SuperLab software on a PowerMacintosh 6100 computer. Children are asked to make a lexical decision to each word by pressing either the space bar for a real word or the #1 key for a non-word. The dominant hand is used to make the real word response. Children have 2000 msec to make a response following presentation of a trial with a 250 msec delay following response or expiration of the response period. Each word list begins with presentation of 7 practice trials. Following presentation of the first list children are given a break and leave the room to complete other tasks before completing the second list. The order of presentation of the two lists was counterbalanced across children in each group.

Variables for Exploratory Analysis

The Conner's Continuous Performance Task (CPT)

The CPT (Conners and Multi-Health Systems Staff, 1995) is a computer-based test of sustained attention. In this task, a series of letters are presented singly and at varying interstimulus intervals on a computer screen. Children are asked to respond to each of these letters by pressing the space bar on the computer keyboard unless the letter is an "x" in which case they are asked to withhold responding. The task yields scores evaluating children's attention over the course of the test, reaction time, and errors of omission and commission. Variables of interest, which were included in post-hoc exploratory analyses, were errors of omission (a measure of cognitive effort), errors of commission (a measure of behavioral (dys)inhibition), variability of reaction time in response to changes in interstimulus interval (a measure of cognitive arousal), and variability of response time over the course of the task (an indicator of sustained attention).

Weschler Intelligence Scale for Children-III Digit Span (WISC-III;1991)

The Digit Span subtest is comprised of two parts. In the first, digits forward, children are asked to repeat a series of numbers ranging in length from three to nine digits in length with two trials at each span. The test is discontinued when both trials of a span length are failed and children earn a point for each trial repeated correctly. This portion of the subtest represents simple immediate memory capacity. In the second portion of the subtest, digits backward, the children are read a series of numbers, ranging from two to eight digits in length and asked to repeat them aloud in reverse order. Again, children are given two trials at each span, and testing is discontinued after failure of two trials of the same length. Children are awarded one point for each trial successfully repeated. This portion of the subtest, requiring manipulation of stimuli in the working memory buffer, is a measure of complex working memory capacity. Variables of interest, which were included in post hoc analysis of models related to semantic clustering were the length of longest span each child successfully in the digits forward and digits backward conditions.

PROCEDURE

Children in the ADHD groups and their parents were initially informed of the study by a neuropsychologist at Austin Neurological Clinic after completing an assessment for ADHD at the clinic. For those ADHD children identified through participation in previous research studies, a letter was sent to their parents via contact information provided in the previous research. If they expressed an interest in participating in the study, they were mailed a letter providing additional information, and were subsequently contacted by telephone by study personnel and formally invited to participate in the study. Twenty-nine (59%) of the children in the ADHD groups were taking prescription stimulant medication. They were asked to discontinue their stimulant medication the day before participation in the study, providing an 18 to 48 hour minimum washout period. One child in the ADHD-I group was taking an SSRI antidepressant medication. One child in the ADHD-C group was taking a trycyclic antidepressant medication. Both children continued to take these medications on the day of testing.

Children in the control groups were recruited via a letter given to the ADHD children or by direct contact with study personnel. They were also contacted by study personnel via telephone to schedule testing sessions.

Study personnel consisted of the author, 4 additional graduate students who also had instruments included in the experimental battery, and 2 college-level research assistants. All personnel were trained on administration of the experimental measures by the author or the other graduate students.

Test batteries were completed at the Austin Neurological Clinic on weekends in order to avoid distraction by employees of the clinic during the workweek. Children and their parents were greeted by study personnel who provided a study specific consent form for the parents. After the consent form was signed, one of the study personnel read an assent form aloud to the child and the child expressed his or her willingness to participate by signing the form. After obtaining parental consent and child assent, each child participated individually in a testing session lasting approximately 3 hours. The current study is part of a larger research project conducted under a grant provided by the Hogg Foundation and the total time for completion of the tasks of interest in this document was approximately 1 1/2 hours in total. While children participated in the study, their parents completed the SNAP-IV and other paper and pencil measures related to other studies.

If the MALT was not completed in prior neuropsychological testing, it was completed first, followed by presentation of the two trials of the semantic priming task and the experimental list-learning task. Each of these tasks was interspersed with tasks related to other studies, such as motor tasks, playing a memory-type card game, and completing a computer based experimental attentional measure. The experimental tasks (MALT, priming task and list learning task) were completed in the first 1 1/2 hours of testing. The Conner's CPT, WISC-III, and WRAT-III were completed at the end of the testing day as needed. The order of presentation for the tasks related to this experiment and the other unrelated project tasks was the same for all children in order to control for fatigue. Additionally, motor tasks and non-verbal tasks were administered between the priming tasks and the immediate and delayed recall of the MALT to minimize interference effects. Children received a small toy for participating halfway through the testing day. At the completion of testing, children and their parents were each paid $20, for a total of $40 for their participation.

Paper and pencil measures were scored by the staff member who administered the measure. The scoring was later checked by at least one other staff member during data entry. All procedures and measures in the present study were approved by the University of Texas at Austin IRB.

CHAPTER 7: DATA ANALYSES AND RESULTS

DEMOGRAPHICS

Demographic comparisons were made between the three groups, including the normal controls (*n* = 25), the ADHD-C group (*n* = 19), and the ADHD-I group (*n* = 29). The demographic characteristics of the sample are presented in Table 1 and Table 2. Potential group differences for demographic variables involving frequency were calculated with Chi Square tests using the Pearson value. For the remaining demographic variables, multivariate analysis of variance (MANOVA) tests were conducted using the Pillia's *F* statistic. In cases in which cells were missing data, the participant was dropped from the analysis. Post hoc analyses of between group differences were conducted using one-way analysis of variance with Bonferroni correction for multiple comparisons.

Age

The age range of study participants was restricted to 7 to 13 years. Not surprisingly, groups did not differ significantly for age in months (*F* (2,67) = .586; *p* =.559). Average age in months for children in the ADHD-C group was 116.222 (*SD* = 23.663), for the ADHD-I group was 118.444 (*SD* = 23.349), and for the control group was 111.960 (*SD* = 18.384).

Gender

Consistent with prevalence statistics on ADHD, the majority of participants in the study were male (72.6% for the entire sample). Groups did not differ significantly for gender composition (X^2= 1.746; *p* = .418). Percentage of males in the ADHD-C group was 84.2%, in the ADHD-I group was 69.0%, and in the Control group was 68.0%.

Ethnicity

The sample was primarily Caucasian (84.9%). Groups did not differ significantly for ethnic composition (X^2 = 6.391; *p* = .249). The ADHD-C group was 89.5% Caucasian, 10.5% Hispanic, and 0% Asian ethnicity. The ADHD-I group was 89.7% Caucasian, 6.9% Hispanic, and 3.4% Asian ethnicity. The control group was 76.0% Caucasian, 8.0% Hispanic, and 16.0% Asian ethnicity.

IQ

All groups were compared using prorated Full Scale IQ scores derived from their performance on the Vocabulary and Block Design subtests of the WISC-III. The groups differed significantly on FSIQ (*F*(2, 67) = 3.346; *p* = .041). Post-hoc analyses revealed a significant difference between ADHD-I subjects (*M* = 108.185; *SD* = 14.234) and control subjects (*M* = 118.36; *SD* = 12.96) (*p* = .042). The difference between ADHD-C (*M* = 110.779; *SD* = 16.910) was not significant for either the ADHD-I group (*p* = 1.00) or for controls (*p* = ..289).

WRAT Reading

Because previous research has demonstrated an association between reading ability and semantic memory function (Nation et al., 1999), it was important to evaluate whether the ADHD groups differed from controls in reading ability. The groups did differ significantly on WRAT reading scores (*F*(2,67) = 7.986, *p* = .001). Post hoc analyses indicated that control children had significantly higher reading scores (*M* = 114.16; *SD* = 11.564) than either ADHD-C (*M* = 101.44; *SD* = 13.879) or ADHD-I (*M* = 103.33; *SD* = 10.232) (*p* = .002 and .004, respectively).

WRAT Arithmetic

The multivariate analysis of demographic variables also indicated a significant difference between groups on this test of arithmetic achievement (*F*(2, 67) = 4.404; *p* = .016). Post hoc analyses indicated a significant difference (*p* = .022) between the standard scores of the Control group (*M* = 112.16; *SD* = 12.618) and the ADHD-I group (*M* = 101.85; *SD* = 12.532). The ADHD-C group's scores did not differ significantly from either the ADHD-I or Control groups (*M* = 102.83; *SD* = 15.704).

POTENTIAL COVARIATES

All demographic variables were examined for their relationship with the experimental variables on the priming task and the list learning tasks. Each was examined using Pearson product-moment correlation coefficients. Participants with missing data were dropped from the correlations.

Age

Performance on list learning tasks has been shown to improve with development (Vicari et al., 1999). Similarly, construction of semantic memory networks and utilization of semantic memory strategies has been demonstrated to be dependent on development (Mandler, 1992; Vicari et al., 1999). It was important, therefore, to investigate whether age was significantly related to performance on the experimental tasks.

Pearson product-moment correlation coefficients were computed between age and each of the average reaction time scores for the 8 cells of the priming task (2 (semantic vs. functional) x 2 (high vs. low association strength) x 2 (primed vs. unprimed)). Three subjects (one from each of the diagnostic groups) did not complete the priming task due to computer problems and were consequently not included in the analysis. Significant correlations were detected between age and the semantic/high/primed condition (*r* = -.403; *p* = .001), the functional/high/primed condition (*r* = -.340; *p* = .004), the semantic/high/unprimed condition (*r* = -.354; *p* = .003), the semantic/low/unprimed condition (*r* = -.453; *p* = .000), the functional/high/unprimed condition (*r* = -.379; *p* = .001) and the functional/low/unprimed condition (*r* = -.350; *p* = .003). Because age covaried so strongly with the majority of the variables included in the analysis of performance on the priming task, age was included as a covariate in subsequent analyses.

Pearson product-moment correlations were also calculated for each of the variables analyzed from the list-learning tasks using the entire sample. On the MALT, age correlated significantly with total correct responses (*r* = .244; *p* = .038) and correct responses in the cued recall condition (*r* = .293; *p* = .012). On the experimental list-learning task, age correlated significantly with total correct responses (*r* = .441; *p* = .000), correct responses on the third learning trial (*r* = .412; *p* = .000), correct responses in the cued recall condition (*r* = .375; *p* = .001) and correct responses in the reorganized recall condition (*r* = .547; *p* = .000). Age was entered as a covariate in analyses examining variables with which it was significantly correlated. Significant correlates of age in months are presented in Table 3.

IQ

Inclusion of IQ as a covariate in studies examining ADHD has provoked some controversy in the literature. Children with ADHD typically score slightly lower on measures of intelligence, and Barkley has argued that controlling for IQ may eliminate group differences that are, in fact, related to the disorder itself (1997). In the present study, the Full Scale IQ (FSIQ) score was prorated from two subtests, Vocabulary and Block Design, which may be less impacted by attentional processes than other subtests in the full WISC-III battery. While this procedure may have potentially mitigated poorer

FSIQ scores, the ADHD-I group did have significantly lower prorated FSIQ scores compared to the other groups in the study. This raises the possibility that the results of analyses may be misinterpreted as being due to diagnostic differences when they may instead be directly related to lower IQ. In the present study, therefore, analyses were run both with and without controlling for FSIQ as was recommended by Barkley (1997b). For those analyses in which inclusion of IQ as a covariate significantly changed the pattern of overall findings, both analyses with and without IQ are included in the results section. For those analyses in which controlling for IQ made no significant difference, results for the uncorrected analyses are presented in the text while the corrected analyses are included in Appendix C.

IQ did not correlate significantly with reaction time in any of the cells in the priming task analyses. On the list learning tasks, FSIQ correlated significantly only with total correct responses (r = .299; p = .011), correct responses on the third learning trial (r = .269; p = .023), and correct responses in the reorganization recall condition of the experimental list learning task (r = .287; p = .015).

WRAT Reading

In addition to lower IQ scores, children with ADHD typically demonstrate deficits in academic achievement compared to nondisordered peers (Lee et al., 1994). Of particular interest to the present study is the potential for deficits in reading ability to impair development of the semantic memory network by limiting exposure to new concepts and new relationships between concepts, as was demonstrated in Nation and Snowling’s study (1999) of semantic memory structure in poor reading comprehenders. The present study was interested in investigating whether deficits in attention observed in ADHD may inhibit semantic memory development beyond what would be expected from decreased reading ability alone.

Unexpectedly, WRAT reading scores did not correlate significantly with any of the reaction time scores on the priming task. It was therefore eliminated as a covariate in all analyses of this measure. On the experimental list learning task, WRAT reading scores did correlate significantly with corrected total clusters (*r* = .248; *p* = .045), total correct responses (*r* = .328; *p* = .006), total correct on the third learning trial (*r* = .287; *p* =.018), total correct in the cued recall condition (*r* = .308, *p* = .011) and total correct in the reorganized recall condition (*r* = .279; *p* = .021). For variables on the MALT, WRAT reading score was significantly correlated with total correct responses, (*r* = .258; *p* = .031). WRAT reading score was included as a covariate for all analyses including a variable with which it was significantly correlated. Significant correlates of WRAT Reading subtest scores can be found in Table 4.

EXPERIMENTAL TASKS

Priming Task

Performance on the Priming Task was examined using a 2 (functional vs. semantic) x 2 (high vs. low association strength) x 2 (primed vs. unprimed repeated measures analysis of covariance (ANCOVA) with group diagnosis as the between subjects variable and age in months entered as a covariant. It was hypothesized that children in the ADHD groups would demonstrate significantly less priming in the semantic relationship, low association strength condition compared to controls.

There was a significant main effect for association strength [*F* = 8.831 (1, 66); *p* = .004) Unexpectedly, children responded more rapidly to target words with low association strength (adjusted *M* = 650.434; *SE* = 16.427) than to words with high association strength (adjusted *M* = 697.949; *SE* = 18.332). To investigate whether children were responding unexpectedly slowly to the high association strength words due to unfamiliarity or some other unforeseen factor a separate ANCOVA was run looking at the words only in the unprimed condition (group x relationship type x association strength) with age as a covariate. In this baseline condition where the targets and primes were unrelated, there was no significant main effect for association strength [*F* (1, 66) = 1.280; *p* = .262). It would seem, then, that the association strengths calculated for the previous study did not apply to the current sample of American children.

There was also a significant main effect for priming condition [*F* (1, 66) = 11.153; *p* = .001] with all children responding to target words faster when they were paired with related primes (adjusted *M* = 649.712; *SE* = 17.034) than when they were paired with unrelated primes (adjusted *M* = 698.671; *SE* =17.683).

Partially supporting the *a priori* hypothesis, there was a significant relationship x priming condition x diagnostic group interaction [*F* (2, 66) = 3.937; *p* = .024]. Post hoc analyses with Bonferroni correction for multiple comparisons indicated that for semantically related words, children in the control group had significantly faster reaction times for primed words (adjusted *M* = 609.999; *SE* = 29.190) than either children in the ADHD-C group (adjusted *M* = 677.355; *SE* = 677.355) or the ADHD-I group (adjusted *M* = 688.855; *SE* = 26.977). The groups did not differ significantly for reaction time to functionally related words or when words were not paired with a related prime (See Tables 5 and 6). The covariate, age in months, interacted significantly with priming condition [*F* (1, 66) = 4.837; *p* = .031) with younger children gaining less benefit from priming than older children. Two children (one ADHD-I and one ADHD-C) produced average reaction time scores more than two standard deviations from the mean. A separate ANCOVA was run eliminating these two outliers to ensure that their scores did not significantly impact the model. The pattern of results was the same with these children excluded.

A separate ANOVA was calculated to examine group differences in errors of commission and omission produced on this task. Children in the ADHD-C made significantly more errors of commission on this task (*M* = 55.000; *SD* = 26.0427) compared to both ADHD-I subjects (*M* = 32.379; *SD* = 20.837) and controls (*M* = 25.040; *SD* = 13.299). ADHD-I and control subjects did not differ significantly from one another. None of the groups differed significantly for errors of omission [*F* (2,69) = .797; *p* = .455).

List Learning Tasks

Clusters

Use of semantic clustering was examined using a mixed model repeated measures ANCOVA with condition (semantic cues provided at encoding vs. not provided) as the within subjects variable and diagnostic group as the between subjects variable. Number of semantic clusters produced for each subject were corrected for chance. WRAT Reading score was included as a covariate. It was hypothesized that children in the two ADHD groups would spontaneously use semantic clustering (i.e. on the MALT) significantly less than the children in the control group, but that all groups would utilize semantic clustering equivalently when cued to do so (i.e. on the experimental list learning task).

Contrary to the hypothesis, there was no significant interaction between encoding condition and diagnostic group [*F* (2, 59) = .843; *p* = .435). Similarly, there was no main effect for encoding condition [*F* (1, 59) = 2.010; *p* = .162] (See Table 7). The covariate, WRAT reading scores interacted significantly with encoding condition [*F* (1, 59) = .4.626; *p* = .036].

To ensure that the correction for chance clustering did not artificially restrict the range of scores for clustering in each condition, a separate 3 x 2 repeated measures ANCOVA was run for total cluster scores (i.e., uncorrected) with encoding condition as the within subjects factor. Group diagnosis was entered as the between subjects factor and age and WRAT reading scores were included as covariates. This model produced a significant main effect for encoding condition [*F* (1, 62) = 4.323; *p*= .042] with all children clustering significantly more in the condition where they were cued to the presence of clusters at encoding (adjusted *M* = 9.220; *SE* = .662) vs. when they were not provided cues at encoding (adjusted *M*= 4.019; *p*= .299). In this second model, WRAT reading scores also interacted significantly with encoding condition [*F* (1, 62) = 4.901; *p* = .031) with higher scorers on the WRAT reading subtest producing more clusters in the condition where semantic encoding cues were provided.

Total Correct Responses

Differences in total number of correct responses were examined using a mixed model repeated measures ANCOVA with condition (semantic cues provided at encoding vs. not provided) as the within subjects variable and diagnostic group as the between subjects variable. Age in months and WRAT reading score were included as covariates. It was hypothesized that having semantic cues provided at the time of encoding would aid children in remembering more list items and that they would therefore recall more words in total on the experimental list learning task.

The results of the analysis did not support the hypothesis, as there was no significant difference for encoding condition [*F* (1, 63) = 3.062; *p* = .085]. There was also no significant interaction of diagnostic group and encoding condition [*F* (2, 63) = .376; *p* = .688] (See Table 7).

A separate mixed model, repeated measures ANCOVA was calculated as above, but including IQ as an additional covariate. This model produced a significant main effect for encoding condition [*F*(1,62) = 4.230; *p* = .044] with children recalling significantly more words when they were provided with semantic cues at the time of encoding (adjusted *M*= 26.366; *SE* = .690) than when they were not provided cues at the time of encoding (adjusted *M*= 24.568; *SE*= .567).

Errors of Intrusion

Group differences for total errors of intrusion were examined using a repeated measures ANOVA with condition (semantic cues present at time of encoding vs. no cues) as within subjects factor and diagnostic group entered as the between groups factor. It was hypothesized that children in the ADHD diagnostic groups would make significantly more errors of intrusion on the list learning tasks compared to children in the control group. Contrary to the hypothesis, the groups did not differ significantly for total errors of intrusion, regardless of encoding condition (*F* (1, 68) = 1.117; *p* = .294) (See Table 7).

A separate repeated measures ANOVA was conducted to determine whether the groups' production of intrusion errors differed by learning trial. Encoding condition and learning trial (1-3) were entered as within subjects variables. Diagnostic group was entered as the between subjects variable. The analysis indicated a significant trial by condition interaction for the second trial [*F* (1, 68) = 4.680; *p* = .034) with children making more errors of intrusion on the second trial of the experimental list learning task (*M* = .541; *SE* = .091) than on the MALT (*M* = .309; *SE* = .309) (See Table 8). Supporting the *a priori* hypothesis, the analysis also indicated a significant group by trial interaction (*F* (6, 134) = 2.937; *p* = .010) with children in the ADHD-C group making significantly more errors of intrusion on the first learning trial (*M* = .806; *SE* = .146) than control participants (adjusted *M* = .292; *SE* = .292). ADHD-I participants did not differ significantly in their production of intrusion errors (adjusted *M* = .586; *SE* = .115) compared to the other diagnostic groups and none of the groups differed significantly on the other two learning trials.

Errors of Perseveration

Group differences in number of errors of perseveration produced on each of the list learning tasks were investigated with a repeated measures ANCOVA with encoding condition (semantic cues present vs. absent) as the within subjects variable and diagnostic group as the between subjects variable. It was hypothesized that children in the ADHD groups would make more total errors of perseveration when semantic cues were not present at the time of encoding because without the cues they would have difficulty tracking the answers they had already provided. There were no significant main effects for encoding condition [*F* (1, 68) = .396; *p* = .533), and no interaction between diagnostic group and encoding condition (*F* (2, 68)= 1.462; *p* = .239]. Children produced a similar number of errors of perseveration regardless of encoding condition or diagnostic status.

Reorganized List Recall

In each of the list learning tasks, children were first asked to freely recall the list items without explicit cues to utilize semantic clusters as a recall strategy. They were then asked to recall the list items with the explicit instruction to group the list items in semantic clusters. To determine whether being explicitly cued to use semantic clustering changed their recall of list items, two separate ANCOVAS were calculated. The list tasks were compared separately as the children were given 5 learning trials with free recall before explicit cueing on the MALT, and only 3 learning trials on the experimental list-learning task. It was hypothesized that children in the ADHD groups would recall significantly fewer words when asked to recall them in novel, uncued categories. In other words, they would recall fewer words in the reorganized category condition of the experimental list-learning task than on the free recall and cued recall condition. On the MALT they would recall fewer words in the cued recall condition than on the free recall condition as they were not likely to encode by semantic cues.

The ANCOVA for the experimental list-learning task included reorganization condition (free recall on the final learning trial vs. recall with explicit semantic cues vs. recall with different semantic categories than those provided at encoding) as within subjects variables and group diagnosis as between subjects variable. Age in months and WRAT reading scores were included as covariates. The analysis indicated a significant main effect for reorganization condition [*F* (2, 62) = 5.249; *p* = .008]. Post hoc pairwise comparisons indicated that children recalled significantly more list items when provided with explicit semantic clustering cues (*M* = 12.036; *SE* = .279) than when they were asked to freely recall the items without cues (adjusted *M* = 10.485; *SE* =.317) or when they were asked to recall the items in new categories (adjusted *M* = 9.185; *SE* = .283) (See Table 9). Children also recalled significantly more items in the free recall trial than when asked to recall the items in the reorganized semantic categories.

Contrary to the *a priori* hypothesis, there was no main effect for group [*F* (2, 63) = 2.356; *p* = .103] and no significant reorganization condition by group interaction [*F* (4, 126) = .575; *p* = .681]. The covariate age in months interacted significantly with reorganization condition [*F* (2, 62) =4.933; *p* = .010].

On the MALT list-learning task, children were not asked to reorganize the list items into new semantic categories at recall. The ANCOVA examining their recall included only two within subjects conditions (free recall at trial 5 vs. recall when explicitly cued to use semantic categories) and diagnostic group was entered as the between subjects variable. Age in months was entered as a covariate. The analysis yielded no significant main effects for group [*F* (2, 69) = 1.563; *p* = .217] or condition [*F* (1, 69) = 1.989; *p* = .163] and the interaction between group and condition was also not significant [*F* (2, 69) =.770; *p* = .467] (See Table 10).

Exploratory Analyses

Clusters on the Experimental List Learning Task

Two competing explanatory models of attention have been proposed to explain the deficits in attention observed in ADHD. The first, set forth by Sergeant (2000), proposed that cognitive processing occurs in three phases: processing/computation, arousal/activation, and management/evaluation (i.e. executive function). He proposed that the cognitive deficits observed in children with ADHD can be traced to difficulty modulating arousal/activation to meet shifting attentional demands of cognitive processing, and also deficits in management/evaluation or choosing effective strategies, set shifting and inhibition of irrelevant responses. In contrast, Barkley et al. (1997) proposed that deficits in behavioral inhibition, that is, inhibiting irrelevant prepotent motor responses, are the core deficit observed in ADHD-C.

One aim of the present study was to examine whether variables associated with either of these two models better predicted use of semantic clusters on the two list learning tasks, or whether non-specific variables or organization of the semantic memory network provided better explanatory models of clustering performance. Variables included in the regression model, along with their proposed associations to the models are presented in Table 11.

Use of semantic clusters was examined separately for each of the list learning tasks. The first regression examined clustering performance on the experimental list-learning task. Diagnostic statistics indicated the distribution of residuals for corrected cluster score was not normally distributed. Total cluster scores were therefore converted to loglinear scores. A linear regression was then calculated with the variables listed in Table 11 entered in a stepwise fashion. The final model included two variables WRAT reading score, and digit span backward as significant predictors of corrected number of semantic clusters produced on this task [F (2, 58) = 8.129; p = .001]. The R^2 statistic for the regression equation was .468, indicating that WRAT reading score and digit span backward accounts for approximately 47% of the variance in total semantic clusters produced on the experimental list learning task. All variables entered in the regression with their t and p values listed in Table 12. The second regression examined clustering performance on the MALT. A linear regression with the variables listed in Table 11 entered in a stepwise fashion failed to yield any model that adequately predicted corrected cluster score on the MALT. Correlations of the variables with total cluster score are listed in Table 13.

Gender

To examine the role of gender on performance on the list learning tasks and the priming task, the ANOVAS and ANCOVAS outlined above in the results section were run again once with gender entered as a solitary between subjects variable and a second time with both group diagnosis and gender entered as between subjects variables. As these were exploratory analyses, with no *a priori* hypotheses associated with them, only the analyses that produced significant results for gender will be presented here for general consideration.

Gender and Errors of Perseveration on the List Learning Tasks

To evaluate the role of gender in production of errors of perseveration, a repeated measures ANCOVA was calculated with encoding condition (semantic cues present at encoding vs. absent) included as a within subjects variable and group diagnosis and gender included as between subjects variables. The analysis indicated a significant interaction between encoding condition and gender [F (1, 65) = 5.783; p = .019]. Post hoc analysis indicated that girls made significantly more errors of perseveration on the MALT (M = 2.769; SE = .503) than they did on the experimental list-learning task (M = 1.384; SE = .546). Having semantic cues present at the time of encoding reduced the production of perseveration errors for girls, while increasing it for boys. In the absence of semantic encoding cues, girls produced more errors of perseveration, while boys produced fewer.

Gender and Performance on Reorganized Recall Conditions of the List Learning Tasks

To evaluate the influence of gender on total words recalled in the various reorganization conditions of the experimental list learning task, a repeated measures ANCOVA was calculated with recall condition (free recall vs. recall with the aid of cued categories vs. cued recall to novel categories) as the within subjects variable, and gender and group diagnosis entered as between subjects variables. Age in months and WRAT reading score were entered as covariates. The analysis indicated a significant main effect for condition [F (2, 59) = 6.223; p = .004], with children recalling significantly more words when cued to use the semantic categories provided at encoding (M = 12.300; SE = .322) than when they were asked to freely recall the words (M = 10.293; SE = .385) or when they were asked to recall the words using novel semantic categories (M = 9.230; SE = .343). Children also recalled significantly fewer words in the novel cued condition than in the free recall condition.

The analysis also produced a significant interaction for gender [*F* (2, 59) = 4.577; *p* = .014]. Girls recalled significantly more words (adjusted *M*= 12.995; *SE*= .583) than boys (adjusted *M* = 11.604; *SE* = .318) when they were cued to recall the words using the categories provided at the time of encoding. Girls' and boys' recall did not differ significantly for the free recall trial (adjusted *M* = 10.047; *SE* = .697 and adjusted *M* = 10.539; *SE*= .380, respectively) or for the novel category recall condition (adjusted *M*= 9.409; *SE*= .622 and adjusted *M*= 9.052; *SE*= .339, respectively)

To evaluate the influence of gender on recall on the free and cued recall conditions of the MALT a repeated measures ANCOVA was calculated with recall condition (free recall vs. cued recall) as within subjects variable and gender as a between subjects variable. Age in months was included as a covariate. The analysis yielded a significant main effect for gender [*F* (1, 70) = 5.749; *p*= .046]. Girls recalled significantly more words across the reorganization trials (adjusted *M*= 11.346; *SE* = .469) compared to boys (adjusted *M*= 10.228; *SE*= .287).

CHAPTER 8: DISCUSSION

OVERVIEW OF RESULTS

The present study was undertaken to examine the differences in structure and function of semantic memory in children with ADHD and nondisordered controls. Comparisons of demographic variables indicated that the three groups (ADHD-C, ADHD-I, and controls) were comparable for age, gender and ethnicity. The groups did differ on measures of intelligence and academic achievement with children in the control group on average obtaining higher IQ scores than the children in the ADHD-I group and controls obtaining higher reading achievement scores than either of the ADHD groups. This is a common finding in the ADHD literature, and some authors have postulated that lower IQ scores may actually be reflective of essential underlying features of the disorder (Barkley, 1997).

The two primary hypotheses guiding the current study were that children with ADHD were likely to demonstrate lags in development of the semantic memory network, and that these lags were likely to lead to/be exacerbated by deficits in utilizing executive functions such as semantic clustering as an aid in encoding new material. These hypotheses were partially supported. The results indicate that children with ADHD do demonstrate differences in the structure or accessibility of the semantic memory network compared to control children, though the nature of the differences were slightly different than were originally proposed in this study. The study did not, however, support the hypothesis that children with ADHD differ in their use of semantic memory strategies compared to normal controls. Detailed discussion of the more detailed *a priori* hypotheses and their relationship to the experimental tasks is included below.

STRUCTURE OF THE SEMANTIC MEMORY NETWORK: EVIDENCE FROM PRIMING

In the present study, it was hypothesized that the semantic memory network of children with ADHD would be less efficient than the semantic memory network of nondisordered controls. Semantic memory is comprised of information about the environment and relationships between objects and concepts in the environment. It is entirely dependent on the distinct experience of the individual. The organization of this information is dependent on development, attentional processes and executive functions in order to efficiently relate new information to previously encountered information. This efficient relation of new and old material allows a hierarchical structure to emerge, which, in turn, allows for more efficient retrieval of the information at a later time. Because children with ADHD have been shown to have fewer attentional resources and to demonstrate deficits in executive functions, it was hypothesized that children with ADHD would have a more poorly, less hierarchically organized semantic network. Specifically, it was hypothesized that they would not benefit from priming with word pairs that were more abstractly related to one another and which had a lower association strength.

The present study sought to delineate the structure of the semantic memory network by means of a priming task in which children were asked to make a decision as to whether a word was a real word or a nonsense word. Priming is thought to speed reaction times of such decisions about stimuli by activating chosen memory nodes of related concepts, thereby making memory retrieval more efficient. In this study a prime word (e.g., brother) activated the semantic node related to the target (e.g., family members), in effect turning a spotlight on all closely related concepts (e.g., mother, father, sister, grandfather). When the individual then rapidly encounters one of these related concepts he or she does not have to search the entirety of material encoded in the brain as the relevant material is already highlighted. Children should have faster reaction times for target words that have previously been linked to their prime in the semantic memory network.

The results of the analysis of the children's performance on the semantic priming task partially supported the hypothesis that the structure of the semantic memory network is less efficiently organized than in control children. Children in both of the ADHD groups showed significantly less benefit from priming when target words were semantically, or more abstractly, related to their priming word compared to control children. This finding suggests that the semantic memory network in children with ADHD may include fewer abstract relationships, and may therefore be less efficient than the semantic memory network in children without ADHD.

Associations between concepts which are functionally related, as defined in the present study, are formed simply as the concepts co-occur in the environment. In other words, they are part of the same script that is encountered repeatedly in daily living. Thus, concepts like "toothbrush," "bedtime story" and "pillow" may come to be associated in the semantic memory network because children encounter these concepts together as part of their nightly ritual of getting ready for bed. There is little cognitive effort needed to associate these concepts because they are repeatedly brought into conscious thought in close temporal proximity, often without any initiation by the child. As daily scripts are repeated, the relationship between these concepts is passively strengthened.

The difficulty of relying solely on a semantic memory network based on functional relationships between concepts is that it is less efficiently organized. The strength of the neural connections between concepts are based more on how often the child simultaneously encounters the concepts by chance in the environment. Concepts may become spuriously connected to one another by simply occurring together at various times. This may therefore lead to difficulty accessing a desired concept on demand. An analogy might be a secretary for a large company filing papers based on the day he first encountered them. When his boss later requests a particular paper related to a specific client, the secretary would need to remember on which day he first encountered the paper. He may incorrectly guess the paper was first encountered on Thursday then be forced to search the Thursday and Wednesday files before finding it in the Friday file where it had been filed. Grouping the files by the name of the client is likely to make such future searches more efficient and accurate.

Semantic/abstract relationships between concepts may be considered this more efficient filing strategy. Here, concepts are related to one another through abstracted similarities in some property or set of properties held by the concepts. The strength of neural connections between concepts is increased both by repeated pairing of the concepts over time, and by the degree of similarity between concepts. Over time the semantic memory network becomes hierarchically organized with weighted connections between concepts. For example, “living things” can be subdivided into “plants” and “animals.” “Animals” can be subdivided into “mammals” and “reptiles” and so on thereby allowing efficient, refined searches of memory stores for specialized concepts.

Children with ADHD are more likely to have difficulty constructing such a hierarchically organized memory network due to observed deficits in allocation of attentional resources and less efficient executive function. In order to form abstract concepts of relationships between stimuli, the individual must first focus attention on the stimulus, noting its features while filtering out other stimuli in the environment. He or she must then search the memory store for previously encountered stimuli that share features of the new stimulus while filtering unrelated concepts from the memory store.

Finally, a decision must be made as to how related or unrelated the stimuli are and a new memory trace must be formed in the memory store connecting the concepts. The results of the present study indicate that children with ADHD are less likely to store concepts in semantic memory according to this more cognitively demanding semantic relationship hierarchy. They responded to target words with approximately the same speed whether these words were paired with semantically related primes or unrelated prime words.

The analysis of response errors on the priming task may also lend indirect evidence to less efficient structure of the semantic network in children with ADHD-C. The children in this group on average made more errors of commission (i.e. responding by pushing the incorrect key in response to real target words) than did children in either the ADHD-I group or the control group. This finding is consistent with Barkley's model of ADHD-C, which proposes that the core deficit in ADHD-C is a deficit in inhibition of irrelevant prepotent motor responses. Children in this group showed a clear tendency to respond to stimuli before they had the chance to accurately process the incoming information. This tendency to respond to stimuli before they are fully processed has implications for the development of the semantic memory network as it provides evidence that children with ADHD-C are more likely to act on a stimulus before they have an opportunity to process the salient features of the stimulus and compare it to previously encountered stimuli in long term memory stores. This is likely to present a significant barrier to developing an abstracted, well-elaborated, hierarchical structure in the semantic memory network.

In contrast to the hypothesis, as well as to the results of previous studies utilizing the same stimuli as the present priming task (Nation and Snowling, 1999), all of the children responded more quickly to target words with a weak association strength to their primes, than to targets that were more strongly related to their primes. Analysis of the children's performance on the unprimed trials of this measure, when the targets and primes were unrelated to one another, indicated that there was no main effect for strength. This would argue that at least the prime words contained in the high association strength did not differ in some unexpected way from the primes in the low association strength group.

It is unclear what accounts for this unexpected finding; however there are several possibilities. The original study, upon which this study was based, was conducted in England. It is possible that the association strengths calculated for British English differ from their strengths for speakers of American English. Another possibility is that the words differed along the dimension of their imagability. The ease with which one can form a mental image of a word or concept influences how quickly one can respond to it. Target words in the high association strength condition included words such as meat, tea, and rain, which may be more difficult to visualize than words like lion, train, and penguin which were included in the low association strength condition. The original study did not control for imagability, so it is difficult to say how much this dimension influenced the current findings.

FUNCTION OF THE SEMANTIC MEMORY NETWORK: EVIDENCE FROM LIST LEARNING TASKS

In addition to investigating the structure of semantic memory in children with ADHD compared to controls, the present study also attempted to examine how children with ADHD utilize the semantic memory network as an aid in encoding new information. Previous research has demonstrated that children with ADHD demonstrate a variety of deficits in executive function. These include choosing less efficient problem-solving strategies, having greater difficulty with set shifting if a particular strategy does not work, and having greater difficulty updating information in the working memory buffer as the capacity of the buffer is exceeded (e.g. Douglas et al., 1990; Barkley, 1997; Roodenrys et al., 2001) Of particular interest to the present study, children with ADHD tend to spontaneously utilize less cognitively effortful, but less efficient mnemonic strategies to aid encoding of novel information on supraspan list learning tasks (Ackerman et al., 1986; Borcherding et al., 1988; Voelker et al., 1989; Douglas et al., 1990) . These less efficient strategies, such as serial rehearsal, may be less taxing cognitively in the short-term but significantly limit the individual's ability to move novel information from working memory to longer-term memory stores. This, in turn, is likely to interfere with later memory search and retrieval, as the stimuli on the list are linked only by the temporal proximity of their presentation rather than by meaningful associations between the stimuli and meaningful associations to previously encountered material. Thus, using serial rehearsal or similar strategies is the equivalent of using the day of the week filing strategy outlined above.

The present study examined the performance of children with and without ADHD on two list learning tasks in which the stimuli on the list could be clustered into groups by semantic relationship. On one list, each stimulus was presented with its semantic category at the time of encoding as a cue for the children to use semantic clustering as a mnemonic aid (experimental list learning task). On the other list (the MALT), semantic category cues were not presented until after the children had been given several practice trials to learn the list items. It was hypothesized that children with ADHD were less likely to spontaneously utilize semantic clustering as a mnemonic aid when the cues were not presented, but were equally likely to utilize semantic clustering when cued to do so.

The results of the study did not support this hypothesis. There was no significant difference among the diagnostic groups in their use of semantic clustering whether or not semantic cues were presented at the time of encoding. Unexpectedly, the control group did not spontaneously utilize semantic clustering as an encoding strategy more often than the ADHD group when semantic cues were not presented at encoding. The age of the current sample may have contributed to the lack of significant differences between the diagnostic groups in the use of semantic clustering. The choice of utilizing semantic clustering in encoding is an intentional choice, with the individual selecting the strategy which best meets the demands of the task at hand. The ability to choose the most effective strategy for a given task, an executive function, is mediated by maturation of the frontal lobes which do not fully mature until early adulthood. The use of such a cognitively demanding strategy as semantic clustering may not be expected to emerge as a well-developed strategy until later in development. The young children in this sample, whether in the ADHD or control groups may simply not have yet developed this skill enough to use it spontaneously. This may have created a floor effect, with none of the younger children being likely to spontaneously implement this skill.

The manner in which the semantic cues were provided may also at least partially explain why the children in the ADHD groups did not demonstrate a relative increase in clustering compared to controls. Rather than being explicitly instructed to group the list items by semantic category, the children were simply provided the semantic category at the same time as the list item. For example, children were told “The first item on the list is a bus, you can see a bus at school,” with bus as the list item and school as the semantic category. In order to utilize the semantic clustering, the children would have had to recognize school as a category they could use to relate future items. Without this recognition, the semantic cue simply represented additional extraneous information which might be ignored, or might alternatively occupy additional space in the working memory buffer, interfering with their ability to process additional list items as they were presented. The increased working memory load required to process all of this information may have limited the degree to which they were able to utilize the strategy. More explicit instruction in how to utilize these cues may have increased all of the participants' ability to utilize the cues.

In contrast to previous studies, the children in the ADHD groups were equally as likely to utilize semantic mnemonic strategies as children in the control group. This finding indicates that, at least for the present sample, children with ADHD are as likely as their peers to utilize semantic clustering as a mnemonic aid when provided with some cues to use the strategy. Further study is needed to determine whether their use of semantic clustering is equivalent to non-ADHD peers when instruction to use semantic cues is made more explicit.

It was also hypothesized that children in the ADHD groups would recall fewer words in total on the MALT, because it was believed that their failure to spontaneously utilize semantic categorization would limit their capacity to encode new information. With the semantic cues provided on the experimental list-learning task, it was hypothesized that children in the ADHD groups would increase encoding efficiency allowing them to recall as many words as their peers in the control group.

Once again, the data did not support the hypothesis. Children in the ADHD groups did not differ from children in the control group for recall on either of the list-learning tasks. The groups all showed equivalent total recall scores for both list-learning tasks when age and WRAT reading scores were covaried. When IQ was controlled along with age and WRAT reading scores, all children recalled significantly more words when they were provided semantic cues at the time of encoding. The lack of group differences on these tasks indicates that children with ADHD have a similar memory capacity as their peers without ADHD.

Of note is the fact that the children's recall was not significantly poorer on the experimental list-learning task. This would seem to indicate that the addition of semantic category information did not interfere with encoding by occupying additional capacity in the working memory buffer.

It was hypothesized that children with ADHD would recall fewer items from the lists when cued to recall them utilizing a different strategy than how they were encoded. In other words, they would have less flexibility in their recall strategies. It was believed that children with ADHD would depend more heavily on inefficient encoding strategies, like serial repetition. List items would be encoded in long-term stores based solely on their temporal relationship to one another. This strategy could interfere with later recall as list items could only be accessed through their temporal relationship. Thus, if a child forgot the third item on the list it would be much more difficult to access the fourth, fifth and sixth item. By utilizing a semantic encoding strategy, children could simultaneously search the memory store based on temporal relationship and semantic relationship thereby increasing recall efficiency. For example, recall of the item "bus" may prompt the child to search his memory stores for other school items as well as prompt him to recall "cart" an item that came after it on the list. This in turn would prompt the child to recall other items related to the grocery store. Use of semantic strategies would thereby grant access to recall along multiple memory trace pathways.

The results of the analyses did not support decreased flexibility in access to previously learned material for children in the ADHD groups compared to normal control peers. For the experimental list learning task, children in the ADHD groups demonstrated equivalent recall compared to control groups for a free recall trial, for a trial on which they were cued to recall the items in the provided categories, and for a trial on which they were asked to recall the list items according to novel cues.

Though there was no effect for group, there was an effect for the recall condition. All children recalled significantly more words when cued to recall them according to the cued categories than when asked to freely recall them. In contrast, on the MALT, the children's recall did not improve significantly when prompted to recall the list according to semantic categories compared to free recall. It would appear, then, that children were able to utilize the semantic cues provided to covertly encode even more items than they were able to spontaneously retrieve. Explicit prompts to use semantic cues at recall improved access even more to list items in memory stores on the experimental list-learning task. Because the children did not covertly or overtly use semantic clustering above levels expected by chance in memorization of the MALT, provision of these cues did not provide a second pathway by which the children could access this information and consequently they did not recall more words in the cued recall condition.

When the children were prompted to recall the list items on the experimental list-learning task using novel, unrehearsed categories, their recall declined significantly. Because these prompts had not been present at the time of encoding, children were not able to utilize these clusters as an effective pathway through which to access the list items. Instead, their recall declined as they were forced to translate between the structure they had used to encode the list (i.e., presentation order and semantic clusters) and the novel structure of the novel categories. This translation process is more demanding of cognitive resources of working memory, and significantly interfered with the children's ability to access previously encoded information.

The present study also examined the children's production of errors of perseveration (i.e., repeating a previously recalled word) and errors of intrusion (i.e., producing a word on recall which had not been present on the original list). It was hypothesized that children with ADHD would produce more of each of these types of errors on the MALT, because lacking the structure provided by the semantic categories, the children would have more difficulty inhibiting previously produced or irrelevant responses.

It was hypothesized that children would make more perseverative/repetition errors as they recalled items from the list because they lacked a semantic structure with which to guide their recall. Rather than recalling list items in manageable semantic chunks, these children were forced to attempt to juggle all of the list items simultaneously in the working memory buffer. This would consume greater attentional resources and leave fewer resources to attend to which items they had previously recalled. This hypothesis was not supported by the data. There was no significant interaction between diagnostic status and encoding condition. Children in the ADHD groups made a similar number of perseverative errors across both list-learning tasks as did children in the control group. The children in the ADHD groups also did not make more perseverative errors on the MALT compared to the experimental list-learning task. This finding may be explained by the fact that children in the ADHD groups did not differ from control in their use of semantic clustering as an encoding aid. As all groups were equally likely to utilize semantic clustering at encoding, they were also likely to equally utilize this strategy in the process of recall. Children with ADHD and children in the control groups, then, had similar cognitive loads placed on working memory resources in recall, and produced a similar number of repetitious responses.

The present study was also based on the hypothesis that children with ADHD have more diffusely organized, less hierarchically structured semantic memory networks. In a better elaborated semantic memory network, relationships between concepts are weighted by degree of semantic relationship. As new information is encoded, the weights of associations are compared to previously learned categories and the system is adjusted to consider the similarity of the new information to previously encoded information and the weights of the relationships between the new information are strengthened related to their relevance to the task at hand. When the semantic network is not well elaborated, strengthening of the associations in the network occurs purely by chance co-occurrence. Information is less likely to be weighted for relevance to the task at hand; thus, activation and recall of a list item is as likely to spuriously activate some previously encountered information as it is to activate recall of additional list items.

This hypothesis was partially supported by the data in the present study. In looking at total errors of intrusion produced across all learning trials, there was no difference for encoding condition, no difference for diagnostic group, and no interaction between diagnostic group and encoding condition. Children in the ADHD groups produced a similar total number of intrusion errors as their peers in the control group whether or not semantic clustering cues were present at encoding. When performance was examined on individual trials, however, a group difference did emerge. Children in the ADHD-C group produced more errors of intrusion on the first learning trial of both list-learning conditions than did children in the control group. The groups produced a similar number of intrusion errors through the other learning trials.

This finding, at minimum, suggests that children with ADHD-C have more difficulty inhibiting irrelevant responses, as suggested by Barkley's model of ADHD-C. This finding may also suggest, however, that more diffuse organization of the semantic memory network may at least partially explain this finding. As the children with ADHD-C first encountered the items on the list-learning task, they moved it into longer-term memory stores without cognitive effort to weight the associations between these new items or to compare these new items to previously encountered items. Items on the list, therefore, were as likely to be related to one another by temporal co-occurrence as they were to be spuriously related to previously encountered information. As the list items are rehearsed over multiple trials, however, the weights of their relationship to one another are strengthened by multiple coincident occurrences. The list itself, then, becomes a semantic category of sorts and activation of items outside of this category is decreased. Errors of intrusion are thereby reduced.

CLINICAL IMPLICATIONS

The results of the present study suggest that the structure of relationships between concepts in the semantic memory network may differ in children with ADHD compared to controls. Evidence from the priming task suggests that children in the ADHD groups do not create a hierarchical memory structure based on abstracted similarities between concepts. In other words, they are less likely to organize information in the semantic memory network based on abstract conceptual similarities, rather relying on less efficient organizational strategies such as passively relating concepts which co-occur in the environment. Children in the control group, on the other hand, appeared to utilize both strategies. One benefit of creating and strengthening relationships between concepts along multiple dimensions is that it provides multiple pathways by which to access information at a later time.

In this study, children in the control group were able to respond more rapidly and accurately when asked to evaluate whether or not a word was a real word. An analogous situation could be attempting to recall information on a spelling test at school. Children in the control group may be able to recall information to spell a given item correctly by accessing abstracted knowledge about spelling (e.g. “I before E”), or by one word from a spelling list triggering recall of the next word on the list as they practiced it at home (e.g. the child always spelled “give” followed by “receive.” When “give” is presented in class, the spelling of “receive” is automatically triggered in the child’s mind). Children in the

ADHD groups may be more likely to depend on the serial order of the list as they rehearsed it as a recall tool. If the teacher presents the words in a different order than they were rehearsed, the child may have more difficulty accessing the correct spelling of a given word.

More diffuse organization of the semantic memory network may also lead to difficulty inhibiting irrelevant information as was observed in the increased errors of intrusion on the list learning task for children with ADHD-C. To return to the analogy above, all spelling words in long-term memory stores are associated with approximately the same strength. A child with ADHD may suddenly find himself recalling the correct spelling of a word from last week's list, but have difficulty then accessing the correct spelling of the desired word from this week's list.

The results of the present study also suggest, however, that children with ADHD are as capable as their normal control peers of utilizing semantic organization strategies in encoding new information. When semantic cues were presented at the same time as novel information on the experimental list learning task, both the children in the ADHD groups and the children in the control group effectively utilized this semantic strategy in free recall significantly more often than when cues were not provided and all groups utilized the strategy at chance levels. When explicitly cued to use these semantic categories, recall was additionally improved for all groups indicating that all of the children in the sample were able to use the strategy to encode more information than they were able to spontaneously recall.

By providing explicit instruction in the use of semantic organization and by providing cues to encode and recall based on semantic similarity, teachers, parents and clinicians may be able to provide children with ADHD multiple pathways by which to recall information, thereby improving their academic performance. As the structure of the semantic memory network is constantly altered as new information is encoded, it may be possible for children with ADHD utilizing such cues to develop a more hierarchically organized structure within the semantic memory network over time.

The results indicate, therefore, that children with ADHD do not differ from normal controls in their memory capacity. The strength of the children's memory was adequate for the list-learning tasks in the present study, regardless of diagnostic condition. There is indication from the results of the priming task, however, that the organizational capacity of the semantic memory network does differ significantly in children with ADHD compared to normal controls.

The priming task, in comparison to the list learning tasks, represents a more passive contribution on the part of the subject. The children simply had to rapidly respond to the stimuli with little thought as to the best strategy for accomplishing this task. In support of conceptualizing performance on the priming task as a passive process, previous research has indicated that evaluation of stimulus for category similarity takes only about 400 msec. This is faster than an individual is consciously aware of the stimulus being processed.

The list learning tasks, on the other hand, required the children to actively choose and evaluate whether the strategy they had chosen represented the most effective for encoding and recalling the list items. It also required that they evaluate the efficacy of their chosen strategy during the completion of the task, and choose a new strategy if they found that their chosen strategy was not meeting the demands of the task at hand. This process of strategy choice, strategy evaluation, and set shifting, all executive functions, is mediated by development of the frontal lobes. It is possible that with the young age of the current sample, differences in executive functions related to semantic memory strategies had not yet emerged. Idiosyncratic differences in encoding strategies may be expected to emerge between the ADHD groups and the control group later in development.

EXPLORATORY ANALYSES

Gender and Semantic Memory Function

A series of exploratory analyses examining how gender influenced utilization of semantic strategies on the list learning tasks pointed to some significant differences for boys and girls. Whether they were asked to freely recall the words or to recall the words based on cued or novel categories, girls recalled more words in total than boys on the reorganization trials of the MALT. A second analysis indicated that girls made significantly more errors of perseveration on the MALT than the boys did. On the experimental list-learning task, the pattern was reversed and boys made more perseverative errors than girls. This set of results suggests that girls may have altered their recall strategy in response to the varying structure and demands of the list-learning tasks.

On the MALT, where little encoding structure was provided, the girls seemed to adopt a more conservative recall approach, possibly reviewing the encoded material multiple times to ensure as many items as possible were recalled. This led them to repeat some of the items, however their recall was superior to that of the boys. Two other explanations may explain the girls' increased perseverations and increased recall. First, by recalling more words, the girls have more opportunities to repeat words, so the increase in perseverations may be due just to chance. Alternatively, the increased repetitions of the words may have provided increased chances to rehearse and memorize the words, thereby increasing recall. On the experimental list-learning task, where encoding cues were provided, it appears they relied less heavily on this strategy of reviewing the encoded material and therefore produced fewer errors of perseveration. In contrast, the boys produced more perseverative errors on the experimental list-learning task though this did not significantly improve their recall across the various conditions. It may have been that the increased working memory demands produced by the simultaneous presentation of words and semantic encoding cues may have interfered with the boys' ability to track which items they had previously recalled.

To investigate this hypothesis, the analyses for the list-learning tasks as outlined in the results section were run again including only the boys. The pattern of only one analysis was changed with the elimination of girls. Total words recalled across the two list-learning conditions no longer differed significantly from one another. It would appear, therefore, that boys did not gain a significant benefit in the form of greater recall by having semantic cues provided at the time of encoding. It would be of interest to investigate whether explicit instruction in the use of semantic cues and clustering might increase the boys' performance on the experimental list-learning task.

MEDIATION OF SEMANTIC CLUSTERING

Two regression analyses were conducted to examine clusters of variables as possible mediators of use of semantic clustering as an encoding aid. Of interest in the analysis were whether variables associated with the organization of the semantic memory network, associated with Barkley's model of ADHD (i.e. reduced behavioral inhibition and reduced executive function related to working memory), associated with Sergeant's cognitive energetic theory of ADHD (i.e. deficits in cognitive arousal and effort) or other nonspecific variables (IQ, reading ability, processing speed, working memory capacity) better predicted use of semantic clustering on the list learning tasks.

On the experimental list learning task WRAT reading score, a measure of reading recognition, and digit span backward, a measure of executive function related to working memory significantly predicted use of semantic clustering. The contribution of reading ability to the use of semantic clustering is consistent with the results of Nation and Snowling (1999) who demonstrated that poor reading comprehenders showed significantly less priming for target words related to their primes by a weak semantic significantly less priming for target words related to their primes by a weak semantic relationship. They hypothesized that the semantic memory network, particularly the more abstract relationships between concepts, develops faster as children are exposed to more concepts through reading. In terms of the present study, children with poorer reading ability may not have been exposed to as many abstract semantic relationships between concepts leaving them less able to recognize these relationships as they encode new information.

The relationship between working memory executive function, as represented by backward digit span, and semantic clustering on the experimental list-learning task makes sense when the cognitive demands created by this task are considered. In order to cluster on this task, the child had to attend to two pieces of information simultaneously, the word and the category to which it belonged. He or she would then have to prolong the memory trace of both of these pieces of information as new words were presented. At the same time he or she would need to note that there were fewer categories than words, and that each category corresponded to a number of words on the list. He or she would then have to update their working memory store to reorganize the words in to their respective categories in order to maximize their performance on the task. Backward digit span represents a measure of how easily an individual can utilize executive functions to manipulate bits of information in the working memory buffer. An individual with less ability to manipulate this information would likely have great difficulty carrying out all of the steps outlined above. None of the variables entered into the regression were significant predictors of clustering on the MALT.

Taken together, these results suggest that the measures used in this study to represent components of the Sergeant model do not effectively predict use of semantic clustering in encoding. The Barkley model was partially supported in that executive function related to working memory did contribute to the use of semantic clustering. This was true of all groups in the sample, however, not only the ADHD-C group.

An additional finding is that the structure of the semantic memory network did not seem to predict how the categories embedded in the network were utilized as aids to encode new information. It appears that pre-existing semantic categories in the semantic memory network may not drive use of categorization in the future. This arrangement would allow for more cognitively flexibility. As new stimuli are encountered in the environment they are not forced into some pre-existing semantic category. Rather their attributes are weighed and new categories may be flexibly created in response to previously unencountered category.

LIMITATIONS OF THE CURRENT STUDY

Several aspects of the current study may limit the generalizability and interpretation of the results. One of the most important is the composition of the current sample. In the current study, most of the ADHD subjects were recruited from a clinic-referred sample. This is problematic for two reasons. One, because the families in the sample were able to seek evaluation and treatment at a private practice neuropsychology clinic, they likely were of higher socioeconomic status than the ADHD population at large. They were likely to have had greater access to behavioral and medication interventions to remediate the effects of ADHD which may have altered how the disorder impacted their overall function. Alternatively, it may be that the children in the clinic-referred sample may have exhibited more severe symptomotology than the ADHD population as a whole leading their families to seek out treatment.

In addition, the largest group of ADHD children was the ADHD-I group. In prevalence studies, ADHD-C is typically more common the ADHD-I further indicating that the present sample may have not been an accurate representation of ADHD in the general population.

Finally, the age of the current sample may have contributed to the lack of significant differences between the diagnostic groups on most measures of the list learning tasks. Active use of effective encoding strategies is mediated by executive functions, which is further mediated by maturation of the frontal lobes. Frontal lobe function does not begin to develop fully until adolescence and early adulthood, thus the current sample may have been too young for meaningful differences in utilization of encoding strategies to emerge.

The methodology of the current study also has several features that may limit interpretations of the results. The stimuli used on the priming task were normed for semantic relationship and association strength on British children. Though the list was changed to reflect American dialect (e.g. , changing “jumper” to “sweater”), differences in American and British cultural norms may have altered the association strengths for some stimuli (e.g., Kettle and Tea). In addition, the words on the task were not compared for imagability. This may have led to the unexpected finding that children actually responded more rapidly to words with low association strength and more slowly to words with high association strength.

On the list learning tasks, the experimental list-learning task was abbreviated to allow adequate time for other instruments in the grant funded study battery to be administered. As a result, the experimental list-learning task had fewer learning trials and no delayed recall condition. Previous studies have indicated that children with ADHD perform more like normal control peers in early trials of list learning tasks, but demonstrate a flatter learning curve over later trials (Douglas et al., 1990). By abbreviating the learning trials on the experimental list-learning task, differences in recall on later learning trials may have been obscured. Similarly, the lack of a delayed recall condition prevented analysis of how children with ADHD may differ from control children in delayed recall when they are provided semantic cues at encoding.

DIRECTIONS FOR FUTURE RESEARCH

As stated above, the limited learning trials and lack of a delayed recall condition on the experimental list learning task limited how closely it could be compared to the MALT. It would be interesting to replicate the current study, but with equivalent learning trials and delayed recall conditions across both list-learning tasks. This would allow investigation of whether the flatter learning curve exhibited in children with ADHD could be ameliorated by the provision of semantic cues at encoding. It would also allow investigation of whether the provision of semantic cues at encoding allows improved recall after a more lengthy delay. Inclusion of an interference trial on the experimental list learning task would also be of interest in that it would provide a measure of whether utilizing semantic encoding strategies might also guard against interference effects (i.e. prevent list items from being spuriously associated with non-list items. Given that children did not demonstrate differences in their overt use of semantic clustering strategy across the two list learning tasks, it would be of interest to alter the instructions to more explicitly encourage the use of semantic clustering at encoding. This would provide a more direct measure of whether children with ADHD are as capable of utilizing such a strategy, and whether they benefit with improved recall when the do overtly utilize such a strategy.

As previously stated, the young age of the current sample may have precluded between group differences in use of semantic clustering strategies from being detected. This strategy, like all executive functions, is highly dependent on maturation of the frontal lobes. The younger children in the current sample may not have developed enough cognitively to utilize this strategy spontaneously. It would be of interest, therefore, to repeat the current study with a sample of adolescent children to examine whether more idiosyncratic associations and differential use of semantic encoding strategies emerge later in development.

The results of the priming suggest that the structure of the semantic memory network differs in children with ADHD compared to normal controls. The mechanism producing this difference remains unclear. One more definitive method for determining whether the structure of the semantic memory network differs in children with ADHD would be the use of functional neuroimaging during the semantic priming task. This would allow for greater understanding of the structures involved in creating and maintaining cognitive representations of associations between concepts. Differences in structural activation or inhibition could better elucidate whether children utilize different strategies to construct relationships between concepts in the semantic network.

Finally, the exploratory analyses of gender indicated that boys and girls may utilize different strategies in encoding and retrieving novel information, however additional research is needed to elucidate the nature of these differences and their functional significance. Asking boys and girls to verbalize their retrieval strategy under varying encoding conditions may be of use in determining whether boys and girls actively choose differential memory search strategies. Time spent on recall may be more indirect evidence for differential memory search strategies, as those using a more cautious strategy may take longer in retrieval. Finally, the use of functional neuroimaging could highlight differential patterns of inhibition and activation under varying encoding conditions.

Tables

Table 1: Demographic Characteristics by Group

Variable		ADHD-C (n=19) Frequency (%)	ADHD-I (n=30) Frequency (%)	Control (n=25) Frequency (%)	X^2	*df*	*p*
Gender							
	-Boy	16 (84.2%)	20 (69.0%)	17 (68.0%)	1.664	2	.435
	-Girl	3 (15.8%)	9 (31.0%)	8 (32.0%)			
Ethnicity							
	-Caucasian	17 (89.5%)	26 (89.7%)	19 (76.0%)	4.036	4	.401
	-Hispanic	2 (10.5%)	2 (6.9%)	2 (8.0%)			
	-Asian	0 (0%)	1 (3.4%)	4 (16.0%)			

Table 2: Age, Intellectual and Achievement Characteristics by Group

	ADHD-C (*n* = 18)		ADHD-I (*n* = 27)		Control (*n* = 25)	
Variables	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*
Age	116.22	(23.66)	118.44	(23.35)	111.96	(18.38)
FSIQ[@]	110.78	(16.91)	108.19	(14.23)$_{a}$	118.36	(12.96)$_{a}$
WRAT Reading	101.44	(13.88)$_{a}$	103.33	(10.23)$_{b}$	114.16	(11.56)$_{a,b}$
WRAT Math	102.83	(15.70)	101.85	(12.53)$_{a}$	112.16	(12.62)$_{a}$

Note. Values with subscripts are significantly different from one another ($p < .05$), 2 ADHD-I and 1 ADHD-C subjects missing WRAT data and dropped from analyses

Overall $F(8,130) = 2.190$; $p = .032$

@ Based on Prorated IQ scores calculated from Vocabulary and Block Design subtests of the WISC-III

Table 3: Significant Correlates of Age in Months ($p < .05$)

Variable	*N*	*r*	*p*
Priming Task			
-Semantic High Prime	70	-.403	.001
-Functional High Prime	70	-.340	.004
-Semantic High Unprime	70	-.354	.003
-Semantic Low Unprime	70	-.453	.000
-Functional High Unprime	70	-.379	.001
-Functional Low Unprime	70	-.350	.003
Experimental List Learning Task			
- Total Correct	71	.441	.000
- Correct Trial 3	71	.412	.000
- Cued Recall Correct	71	.375	.001
- Reorganized Recall Correct	71	.547	.000
MALT			
- Total Correct	73	.244	.038
- Cued Recall Correct	73	.293	.012

Table 4: Significant Correlates of WRAT Reading Score

Variable	*N*	*r*	*p*
Experimental List Learning Task			
- Total Corrected Clusters	66	.248	.045
- Total Correct	68	.328	.006
- Total Correct Trial 3	68	.287	.018
- Cued Recall Correct	68	.308	.011
- Reorganized Recall Correct	68	.279	.021
MALT			
- Total Correct	70	.258	.031

Table 5: Descriptive Statistics for Diagnostic Group Mean Reaction Time on the Priming Task

	ADHD-C (*n* = 18)		ADHD-I (*n* = 28)		Control (*n* = 24)	
Condition	*M*	*(SD)*	*M*	*(SD)*	*M*	*SD*
Semantic High Prime	684.530	(205.0344)	696.850	(163.2358)	652.610	(154.3332)
Semantic High Unprime	725.049	(247.5319)	709.504	(151.8634)	762.617	(164.2356)
Semantic Low Prime	667.817	(186.7622)	664.863	(160.1855)	68.822	(109.4499)
Semantic Low Unprime	672.179	(186.2414)	662.787	(181.2896)	683.443	(153.4778)
Functional High Prime	641.904	(194.0422)	668.104	(173.3561)	640.351	(135.9502)
Functional High Unprime	769.776	(267.5337)	708.784	(189.2134)	720.475	(140.4876)
Functional Low Prime	670.115	(212.4639)	621.820	(164.2892)	603.665	(132.3421)
Functional Low Unprime	664.209	(199.8231)	658.727	(153.1454)	651.703	(124.9004)

Age entered as covariate

N = 70, one case from each diagnostic group missing data

Table 6: Adjusted Mean Reaction Times by Diagnostic Group for Semantic Relationship and Priming Condition

	ADHD-C (*n* = 18)		ADHD-I (*n* = 28)		Control (*n* = 24)	
Relationship	Adjusted *M*	*(SE)*	Adjusted *M*	*(SE)*	Adjusted *M*	*(SE)*
Semantic						
- Primed	677.355_{a}	(33.499)	688.855_{b}	(26.977)	$609.999_{a,b}$	(29.190)
- Unprimed	700.142	(35.666)	696.494	(28.723)	709.811	(31.079)
Functional						
- Primed	657.049	(34.764)	652.005	(27.996)	613.011	(30.292)
- Unprimed	718.425	(35.824)	693.460	(28.850)	673.693	(31.216)

N = 70, one subject from each diagnostic group dropped due to missing data
Means adjusted for age in months
Values with subscripts differ significantly from one another ($p < .05$)

Table 7: Descriptive Statistics for Performance on List Learning Tasks Measures

	ADHD-C			ADHD-I			Control		
Variable	*n*	*M*	*(SD)*	*n*	*M*	*(SD)*	*n*	*M*	*(SD)*
MALT									
- Corrected Clusters$^{@}$	16	-.2179	(2.2039)	26	-.2165	(2.1102)	21	-.5545	(1.8651)
- Total Clusters$^{@\%}$	17	4.000	(2.4749)	27	3.963	(2.3119)	23	4.087	(2.3724)
- Correct Responses$^{@\%}$	17	24.176	(5.5704)	27	24.000	(5.2769)	24	25.458	(3.7991)
- Intrusions	18	1.222	(1.5925)	29	1.448	(2.7201)	24	.833	(1.4939)
- Perseverations$^{\%}$	18	1.500	(2.4314)	29	2.000	(2.2361)	24	1.583	(1.5581)
Experimental List									
- Corrected Clusters$^{@}$	16	4.8169	(4.9175)	26	3.0891	(4.1247)	21	4.4238	(4.5948)
- Total Clusters$^{@\%}$	17	10.353	(6.6609)	27	7.556	(5.0713)	23	9.609	(5.6708)
- Correct Responses$^{@\%}$	17	26.647	(8.1773)	27	25.074	(6.3665)	24	27.208	(5.7934)
- Intrusions	18	1.778	(1.4371)	29	1.517	(1.9015)	24	1.208	(1.4738)
- Perseverations$^{\%}$	18	2.667	(2.6789)	29	1.655	(1.9138)	24	1.458	(2.0637)

@ WRAT Reading score entered as covariate

% Age in months entered as covariate

Table 8: Errors of Intrusion by Trial of the List Learning Tasks

	ADHD-C (*n* = 19)		ADHD-I (*n* = 29)		Control (*n* = 25)	
Learning Trial	*Adjusted M*	*SE*	*Adjusted M*	*SE*	*Adjusted M*	*SE*
Trial 1	$.806_{a, b}$	.146	.586	.115	$.292_{a}$	.126
Trial 2	.528	.127	.414	.100	.333	.110
Trial 3	$.167_{b}$	.139	.483	.110	.396	.121

Values with subscripts differ significantly from one another ($p < .05$)

Table 9: Descriptive Statistics for Experimental List Learning Task Reorganized Recall Conditions

	ADHD-C (*n* = 17)		ADHD-I (*n* = 27)		Control (*n* = 24)	
Recall Condition	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*
Free Recall	10.471	(3.4300)	9.667	(3.1132)	11.250	(2.3078)
Cued Category Recall	12.235	(2.7507)	11.259	(2.6975)	12.542	(2.1665)
Novel Category Recall	9.647	(3.5521)	8.407	(3.0541)	9.417	(2.4122)

Age in months and WRAT reading score entered as covariates.
2 ADHD-C, 2 ADHD-I and 1 Control subject dropped due to missing data.

Table 10: Descriptive Statistics for MALT Reorganized Recall Conditions

	ADHD-C (*n* = 19)		ADHD-I (*n* = 29)		Control (*n* = 25)	
Recall Condition	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*
Free Recall	10.474	(2.8938)	10.862	(2.6689)	11.760	(2.4028)
Cued Category Recall	9.526	(2.4578)	10.138	(2.1667)	10.200	(2.2730)

Table 11: Variables Included in Exploratory Regression Model

Variable	Description	Model Variable Associated With
Errors of Commission Conner's CPT	A measure of behavioral dysinhibition	Barkley's model of behavioral dysinhibition
WAIS-III Digits Backward span	A measure of executive function associated with working memory	Barkley's model of behavioral dysinhibition
Hit reaction time interstimulus interval change Conner's CPT	A measure of cognitive arousal	Sergeant's model of cognitive energetic pools
Errors of omission Conner's CPT	A measure of cognitive effort	Sergeants model of cognitive energetic pools
WRAT reading score	A measure of reading ability	Non-specific group difference variable
Hit reaction time Conner's CPT	A measure of cognitive processing speed	Non-specific group difference variable
WISC-III Digits Forwards span	A measure of apprehension span	Non-specific group difference variable
Average reaction time for semantic relationship high and low association strength cells of the priming task	A measure of semantic network organization	Semantic memory network strength/organization

Table 12: Significance of Variables’ Contribution to Mediation Model of Corrected Semantic Cluster on the Experimental List Learning Task

Variable	*t*	*p*
WRAT reading score	2.337	.023*
Prorated IQ	-.361	.720
Forward Digit Span	.507	.614
Backward Digit Span	2.058	.044*
Errors of Commission CPT	-.771	.444
Errors of Omission CPT	.142	.887
Reaction Time Interstimulus Interval CPT	-1.312	.195
Average Reaction Time Priming Task Semantic Relationship High Association Strength Condition	-1.886	.064
Average Reaction Time Priming Task Semantic Relationship Low Association Strength Condition	-.396	.694

* Significant predictor in regression model

Table 13: Correlations of MALT Corrected Semantic Cluster Score

Variable	*N*	*r*	*p*
Prorated IQ	60	-.192	.071
WRAT reading score	60	.020	.438
Forward Digit Span	60	-.015	.453
Backward Digit Span	60	.015	.455
Errors of Commission CPT	60	-.080	.273
Errors of Omission CPT	60	.006	.483
Hit Reaction Time Interstimulus Interval Change CPT	60	-.105	.212
Hit Reaction Time CPT	60	-.065	.310
Priming Task Semantic Relationship High Association Strength Condition	60	.001	.496
Priming Task Semantic Relationship Low Association Strength Condition	60	.101	.222

Appendices

APPENDIX A: ABBREVIATIONS FROM TEXT

ADD	Attention Deficit Disorder (DSM-III criteria)
ADD-H	Attention Deficit Disorder, Hyperactive subtype
ADD/WO	Attention Deficit Disorder, Without hyperactivity
ADHD	Attention-Deficit/Hyperactivity Disorder (DSM-IV criteria)
ADHD-C	Attention-Deficit/Hyperactivity Disorder, Combined Subtype
ADHD-HI	Attention-Deficit/Hyperactivity Disorder, Hyperactive Impulsive Subtype
ADHD-I	Attention-Deficit/Hyperactivity Disorder, Inattentive Subtype
CPT	Continuous Performance Test
DSM	Diagnostic and Statistical Manual
EF	Executive Function
FD	Freedom from Distractibility Index (WISC-III)
fMRI	Functional Magnetic Resonance Imaging
FSIQ	Full Scale Intelligence Quotient
HI	Hyperactive Impulsive Symptoms
IA	Inattentive Symptoms
MALT	Missouri Auditory Learning Test
MRI	Magnetic Resonance Imaging
PET	Positron Emission Tomography
PASAT	Paced Auditory Serial Addition Test
RAVLT	Rey Auditory Verbal Learning Test
RD	Reading Disability
WCST	Wisconsin Card Sort Test
WISC III	Wechsler Intelligence Scale for Children, 3rd edition
WRAML	Wide Ranging Assessment of Memory and Learning
WRAT	Wide Range Achievement Test

APPENDIX B: PRIMING TASK STIMULI

	High Association Strength	**Low Association Strength**
Semantic Relationship	Brother-Sister Dog-Cat King-Queen Moon-Stars Salt-Pepper Coat-Hat Comb-Brush Cup-Saucer Table-Chair Pencil-Pen	Cow-Goat Green-Pink Lake-Mountain Nose-Head Pig-Horse Airplane-Train Kite-Balloon Bed-Desk Sweater-Skirt Violin-Guitar
Functional Relationship	Beach-Sand Butcher-Meat Farm-Animal Kitchen-Sink Christmas-Tree Belt-Pants Bow-Arrow Hammer-Nail Kettle-Tea Umbrella-Rain	Hospital-Doctor Market-Vegetables Circus-Lion War-Army Zoo-Penguin Party-Music Broom-Floor Oven-Potato Knife-Bread Fridge-Cheese

APPENDIX C: WORDS AND CATEGORIES OF THE MALT

Word	Category
Cow Dog Pig Bear	Animal
Apple Corn Milk Cake	Foods
Hand Leg Ear Mouth	Body Parts
Coat Dress Shoe Shirt	Clothes

Note: Words are presented in semi-randomized order, not organized by category

APPENDIX D: WORDS AND CATEGORIES OF THE EXPERIMENTAL LIST-LEARNING TASK

Word	Cued Category	Novel Category
Cashier	Things at the Grocery Store	Jobs People Have
Bus	Things at School	Things with Wheels
Thermometer	Things at a Hospital	Tools/Objects People Use at Work
Nurse	Things at a Hospital	Jobs People Have
Cart	Things at the Grocery Store	Things with Wheels
Sheep	Things on a Farm	White Things
Register	Things at a Grocery Store	Tools/Objects People Use at Work
Tractor	Things on a Farm	Things with Wheels
Ambulance	Things at a Hospital	Things with Wheels
Salt	Things at a Grocery Store	White Things
Ruler	Things at School	Tools/Objects People Use at Work
Rancher	Things on a Farm	Jobs People Have
Chalk	Things at School	White Things
Bandage	Things at a Hospital	White Things
Teacher	Things at School	Jobs People Have
Pitchfork	Things on a Farm	Tools/Objects People Use at Work

APPENDIX E: EFFECTS OF COVARYING FOR IQ

Prorated FSIQ correlated significantly with free recall on the final learning trial of the experimental list learning task (*r* = .269; *p* = .023) and recall on the reorganized semantic clusters recall trial of the experimental list-learning task (*r* = .287; *p* = .015). These variables also correlated significantly with WRAT reading score and age in months (see Tables 3 and 4). To ensure that FSIQ did not significantly impact the results of the analysis of children's performance on the experimental list learning task across the various reorganized recall conditions, the ANOVA examining total words recalled in free recall, recall with encoding categories explicitly cued and total recall with novel cued categories was recomputed including FSIQ along with age in months and WRAT reading score included as covariates. Diagnostic group was included as a between group variable.

The results of the ANOVA indicated that FSIQ did not significantly affect performance across these conditions. The analysis yielded a significant main effect for recall condition [*F* (2, 61) = 6.383], though the significance increased slightly with inclusion of FSIQ as a covariate, from *p* = .008 without FSIQ to *p* = .003 with FSIQ. All children still recalled significantly more words correctly when provided explicit prompts to use the cued encoding categories (adjusted *M* = 12.035; *SE* = .281) than they had on free recall (adjusted *M* = 10.479; *SE* = .316) or recall with novel categories (adjusted *M* = 9.179; *SE* = .281).

FSIQ also correlated significantly with corrected cluster score on the MALT (*r*= -.272; *p* = .025). To examine the effect of controlling for FSIQ on corrected cluster scores, the ANCOVA was recalculated with corrected cluster scores in the two encoding conditions included as the within subjects variable and diagnostic group included as the between subjects variable. WRAT reading scores and FSIQ were included as covariates. Once again, inclusion of FSIQ did not significantly impact the pattern of results. There was no main effect for encoding condition [*F* = (1, 58)] though the significance of this main effect increased slightly with the inclusion of FSIQ (*p* = .098 vs. .162). Similarly, there was no main effect for diagnostic group [*F* (2, 58) = 1.073; *p*= .349] and no significant interaction for diagnostic group and encoding condition [*F* (2, 58) = .727; *p* = .488]. Both of these effects became slightly less significant with the inclusion of FSIQ (previous *p* = .381 and .435, respectively) indicating that inclusion of FSIQ as a covariant may indeed wash out some variance associated with the symptoms of ADHD.

Inclusion of FSIQ as a covariant in this model did cause one change in this model. Controlling for IQ eliminated the significant interaction between WRAT reading score and encoding condition [*F* (1, 58) = .898; *p* = .347] observed in the original model (previous *p* = .036), perhaps indicating that FSIQ and WRAT reading score share a significant proportion of variance and arguing that controlling for one or the other may be sufficient.

References

Ackerman, P.T., Anhalt, J.M., Dykman, R.A., & Holcomb, P.J. (1986). Effortful processing deficits in children with reading and/or attention disorders. Brain and Cognition, 5, 22-40.

Ahn, W., Gelman, S., Amsterlaw, J.A., Hohenstein, J. & Kalish, C.W. (2000). Causal status effect in children’s categorization. Cognition, 76, B35-B43.

American Psychiatric Association. (1968). Diagnostic and Statistical Manual of Mental Disorders (2nd Edition). Washington, DC: Author.

American Psychiatric Association (1980). Diagnostic and Statistical Manual of Mental Disorders (3rd Edition). Washington, DC: Author.

American Psychiatric Association (1987). Diagnostic and Statistical Manual of Mental Disorders (3rd Edition Revised). Washington, DC: Author.

American Psychiatric Association (1994). Diagnostic and Statistical Manual of Mental Disorders (4th Edition). Washington, DC: Author.

Barkley, R.A. (1997). Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. Psychological Bulletin, 121(1), 65-94.

Barkley, R.A. (1997b). ADHD and the Nature of Self-Control. New York: Guilford Press.

Berger, A. & Posner, M.I. (2000). Pathologies of brain attentional networks. Neuroscience and Biobehavioral Reviews, 24, 3-5.

Borcherding, B., Thompson, K., Kruesi, Bartko, J., Rapoport, J.L. & Weingartner, H. (1988). Automatic and effortful processing in attention deficit/hyperactivity disorder. Journal of Abnormal Child Psychology, 16 (3), 333-345.

Carlson, C. & Mann, M. Sluggish cognitive tempo predicts a different pattern of impairment in the attention deficit hyperactivity disorder, predominantly inattentive type. Journal of Clinical Child and Adolescent Psychology 31(1), 123-129.

Chhabildas, N., Pennington, B.F. & Wilcutt, E.G. (2001). A comparison of the neuropsychological profiles of the DSM-IV subtypes of ADHD. Journal of Abnormal Child Psychology, 29(6), 529-540.

Conners, C.K., & Multi-Health Systems Staff. (1995). Conners' Continuous Performance Test. Toronto: MHS.

Cycowicz, Y.M. (2000). Memory development and event-related brain potentials in children. Biological Psychology, 54, 145-174.

Damian, M.F. (2000). Semantic negative priming in picture categorization and naming. Cognition,76, B45-B55.

Douglas, V.I., & Benezra, E. (1990). Supraspan verbal memory in attention deficit disorder with hyperactivity, normal, and reading-disabled boys. Journal of Abnormal Child Psychology, 18 (6), 617-638.

Felton, R.H. Wood, F.B., Brown, I.S., Campbell, S.K., & Harter, M.R. (1987). Separate verbal memory and naming deficits in attention deficit disorder and reading disability. Brain and Language, 31, 171-184.

Frick P.J., Lahey B.B. (1991). Nature and characteristics of attention deficit hyperactivity disorder. School Psychology Review, 20, 163-173.

Greene, J.D.W, Hodges, J.R. (1996). Semantic processing. In: Morris, R.D. (Ed.) The Cognitive Neuropsychology of Alzheimer-type Dementia. New York: Oxford University Press. pp. 128-148.

Gronwall, D.M.A. (1977). Paced auditory serial-addition task: A measure of recovery from concussion. Perceptual and Motor Skills, 44, 367-373.

Harmony, T., Fernandez, T., Fernandez-Bouzas, A., Silva-Pereyra, J., Bosch, J. Diaz-Comas, L., & Galan, L. (2001). EEG changes during word and figure categorization. Clinical Neuropsychology, 112, 1486-1498.

Kaplan, B.J., Dewey, D., Crawford, S.G. & Fisher, G.C. (1998). Deficits in Long-term memory are not characteristic of ADHD. Journal of Clinical and Experimental Neuropsychology, 20(4), 518-528.

Kounios, J. (1996). On the continuity of thought and the representation of knowledge: electrophysiological and behavioral time-course measures reveal levels of structure in semantic memory. Psychonomic Bulletin and Review, 3 (3), 265-286.

Lahey, B.B., Carlson, C.L., & Frick, P.J. (1997). Attention-deficit disorder without hyperactivity. In: Widiger, T.A., Frances, A.J., Pincus, H.A., Ross, R., First, M.B. & Davis, W. (Eds.) DSM-IV Sourcebook (vol.3) Washington, D.C.: American Psychiatric Association. pp. 163-188.

Lee, C.P. & Obrzut, J.E. (1994). Taxonomic clustering and frequency associations as features of semantic memory development in children with learning disabilities. Journal of Learning Disabilities, 27 (7), 454-462.

Lezak, M.D. (1983). Neuropsychological Assessment (2nd ed.) New York: Oxford University Press.

Lockwood, K.A., Marcotte, A.C., & Stern, C. (2001). Differentiation of attention-deficit/hyperactivity disorder subtypes: application of a neuropsychological model of attention. Journal of Clinical and Experimental Neuropsychology, 23(3), 317-330.

Lorch, E.P., Zanchez, R.P., van den Broek, P., Milich, R., Murphy, E.L., Lorch, R.F., & Welsh, R. (1999). The relation of story structure properties to recall of television stories in young children with attention-deficit hyperactivity disorder and nonreferred peers. Journal of Abnormal Child Psychology, 27 (4), 293-310.

Mak, B.S.K., & Vera, A.H. (1999). The role of motion in children's categorization of objects. Cognition, 71, B11-B21.

Mandler, J.M. (1992). How to build a baby: II. conceptual primitives. Psychological Review, 99 (4),587-604.

Mareschal, D. & Quinn, P.C. (2001). Categorization in infancy. Trends in Cognitive Sciences, 5 (10), 443-450.

Marks, D.J., Himmelstein, J., Newcorn, J.H. & Halpern, J.M. (1999). Identification of AD/HD subtypes using laboratory-based measures: a cluster analysis. Journal of Abnormal Child Psychology 27(2), 167-175.

Mealer, C., Morgan, S. & Luscomb, R. (1996). Cognitive functioning of ADHD and non-ADHD boys on the WISC-III. Journal of Attention Disorders, 1 (13), 133-145.

Milich, R., Ballentine, A. & Lyman, D.R. (2001). ADHD combined type and ADHD predominantly inattentive type are distinct and unrelated disorders. Clinical Psychology Science and Practice 8, 463-488.

Naccache, L., & Stanislas, D. (2001). Unconscious semantic priming extends to novel unseen stimuli. Cognition, 80, 223-237.

Nation, K. & Snowling M.J. (1999). Developmental differences in sensitivity to semantic relations among good and poor comprehenders: evidence from semantic priming. Cognition, 70, B1-B13.

Nida, R.E. & Lange, G. (1995). The effects of category distinctiveness and stimulus relations on young children's use of retrieval clustering strategies. The Journal of General Psychology, 122 (4), 345-349.

Oades, R.D. (1998). Frontal, temporal and lateralized brain function in children with attention-deficit hyperactivity disorder; a psychophysiological and neuropsychological viewpoint on development. Behavioural Brain Research, 94, 83-95.

Pennington, B.F. & Ozonoff, S. (1996). Executive functions and developmental psychopathology. Journal of Child Psychology and Psychiatry, 37(1), 51-87.

Rakison, D.H., & Butterworth, G.E. (1998). Infants' use of object parts in early categorization. Developmental Psychology, 34 (1), 49-62.

Rapport, M.D., Chung, K.M., Shore, G., Denney, C.B., & Isaacs, P. (2000). Upgrading the science and technology of assessment and diagnosis: laboratory and clinic-based assessment of children with ADHD. Journal of Clinical Child Psychology, 29 (4),555-568.

Rapport, M.D., Scanlan, S.W. & Denney, C.B. (1999). Attention-deficit/hyperactivity disorder and scholastic achievement: a model of dual developmental pathways Journal of Child Psychology and Psychiatry, 40(8), 1169-1183.

Rasmussen, E.R., Neuman, R.J., Heath, A.C., Levy, F., Hay, D.A. & Todd, R.D. (2004). Familial clustering of latent class and DSM-IV defined attention-deficit/hyperactivity disorder (ADHD) subtypes. Journal of Child Psychology and Psychiatry 45(3), 589-598.

Roodenrys, S., Koloski, N. & Grainger, J. (2001). Working memory function in attention deficit hyperactivity disordered and reading disabled children. British Journal of Developmental Psychology, 19, 325-337.

Schwartz, M., Cadore, L., Paczko, M., Kipper, L., Chaves, M., Rohde, L., Moura, C. & Knijnik, M. (2002). Neuropsychological performance in DSM-IV ADHD subtypes: an exploratory study with untreated adolescents. Canadian Journal of Psychiatry, 47(9), 863-869.

Schweitzer, J.B., Faber, T.L., Grafton, S.T., Tune, L.E., Hoffman, J.M. & Kilts, C.D. (2000). Alterations in the functional anatomy of working memory in adult attention deficit hyperactivity disorder. American Journal of Psychiatry, 157 (2), 278-280.

Sergeant, J. (2000). The cognitive-energetic model: an empirical approach to attention-deficit hyperactivity disorder. Neuroscience and Biobehvioral Reviews, 24, 7-12.

Spelke, E.S., Phillips, A. & Woodward, A.L. (1995). Infants' knowledge of object motion and human action. In: Sperber, D., Premack,D and Premack, A.J. (Eds.) Causal Cognition; A Multidisciplinary Approach. Oxford: Clarendon Press. pp. 44-78.

Swanson, J., Posner, M., Cantwell, D., Wigal, S., Crinella, F., Filipek, P., Emerson, J., Tucker, D. & Nalcioglu, O. (1998). Attention-deficit/hyperactivity disorder: symptom domains, cognitive processes, and neural networks. In: Parasuraman, R. (Ed.). The Attentive Brain. Cambridge: The MIT Press. pp.445-460.

Tannock, R., Purvis, K.L. & Schachar, R.J. (1993). Narrative abilities in children with attention deficit hyperactivity disorder and normal peers. Journal of Abnormal Child Psychology, 21 (1), 103-117.

Tirosh, E., & Cohen, A. (1998). Language deficit with attention-deficit disorder: a prevalent comorbidity. Journal of Child Neurology, 13, 493-497.

Vicari, S., Paspualetti, P., Marotta, L., & Carlesimo, G.A. Word-list learning in normally developing children: effects of semantic organization and retention interval. Italian Journal of Neurological Science, 20, 119-128.

Voelker, S.L., Carter, R.A., Sprague, D.J., Gdowski, C.L. & Lachar, D. (1989) Developmental trends in memory and metamemory in children with attention deficit disorder. Journal of Pediatric Psychology, 14 (1), 75-88.

Waxman, S.R. and Namy, L.L. (1997). Challenging the notion of a thematic preference in young children. Developmental Psychology, 33 (3), 555-567.

Webster, R.E., Hall, C.W., Brown, M.B. & Bolen, L.M. (1996). Memory modality differences in children with attention deficit hyperactive disorder with and without learning disabilities. Psychology in the Schools, 33 (3), 195-201.

Wechsler, D. (1991). WISC-III Manual. San Antonio: Psychological Corporation.

Wilkinson, G.S. (1993) WRAT3 Administration Manual. Delaware: Wide Range.

Willcutt, E.G., Pennington, B.F., Boada, R., Ogline, J.S., Tunick, R.A., Chhabildas, N.A. & Olson, R.K. (2001). A comparison of the cognitive deficits in reading disability and attention-deficit/hyperactivity disorder. Journal of Abnormal Psychology,110 (1), 157-172.

Vita

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