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Exploration of the Wechsler Memory Scale Fourth Edition and Measures of Executive Function Combined Components Model

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Exploration of the Wechsler Memory Scale Fourth Edition and Measures of Executive Function Combined Components Model

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While memory is the faculty that affords us learning, adaptation and development, it is our executive function that oversees, manages and organizes these abilities. Still, there is limited research on the interaction between memory and executive function. The present study investigated this relationship through Principal Components Analysis. Performances on accepted measures of memory and executive function were evaluated in an adult clinical sample. Components were retained using three criteria: a predetermined four-component structure, eigenvalues exceeding a value of one, and parallel analysis. Results demonstrated that a four-component model most accurately represented the data. Analyses also revealed that measures of immediate and delayed memory did not uniquely assess memory but instead loaded onto components associated with visual and verbal processing. The findings were shown to be in support of the brain working in an integrated, systematic manner in which abilities hierarchically ascend from arousal to tertiary function. Consequently, several accepted measures of memory and executive function failed to measure cognitive capacity unique from visual and verbal processing, placing their construct validity and efficacy in question.

Chapter I: Statement of the Problem

"If one does not remember a tree falling in the woods, does it matter whether it made a sound?" Memory is crucial for everyday life. It is what ties us to the past, lets us plan for the future and, more importantly, understand the present. Many philosophers, theologians and neuroscientists have pondered what defines our humanity and separates us from animals; the answer may be memory. Memory facilitates rational thought and frees one from being dependent on physiological urges or situational demands for pleasure seeking (Lezak, 2004). Despite the great importance of memory and the large body of literature which has sought to elucidate its intricate functions, there is still much unknown. Specifically, the presentation of memory in instances that deviate from normal function, such as in clinical populations with dementia or a history of head trauma, remains an important area for empirical investigation.

The value of memory becomes most apparent during those everyday instances where the simplest of facts may elude our retrieval or as we witness others struggle against debilitating conditions that strip them of their personal narratives. Memory impairment can isolate a person from meaningful contact with the world about them and deprives the person of a sense of personal continuity. "Without the glue of memory, past and future lose meaning and self-awareness is reduced or even lost."-Hans Markowitsch (Halligan & Wade, 2005). Although the examination of memory function in impaired individuals contributes substantially to our understanding of this important faculty, exploration of this cognitive function in isolation is insufficient. Just as medical and biological research has shown that the brain is a nonlinear entity in which specialized parts interact in a dynamic, bidirectional manner, so too, cognitive and neuropsychological research must evaluate and measure the interaction between memory and other systems. A significant factor to consider when studying memory would then be its interaction with executive function, which is regarded as the system that oversees, manages and organizes cognitive function. The goal of this paper is to consider the relationship between memory and executive function and determine whether these cognitive elements group onto specific components based on their underlying anatomical mechanisms and conceptual features. In order to understand the role of memory and executive function, one must first define these distinct functions, explore their underlying anatomy and physiology, review the measurements used to evaluate them, and examine the overlapping conceptual and anatomical features shared by these two vital cognitive functions.

Chapter II: Review of the Literature

Theories of Memory

The study of memory began with inferences made from animal experiments, by the German philosopher, Herman Ebbinghaus, who was among the first to demonstrate that human memory could be studied empirically through list learning (Baddeley, 2009). Later, Clark Hull studied the learning behavior of white rats and attempted to use his results to build a theory of memory learning that closely resembled those of physicists such as Isaac Newton by incorporating postulates and equations. With the emergence of Gestalt psychology in Germany, the study of memory moved from observing responses to stimuli to the importance of internal representation. The idea of cognitive maps as mental representation was first explored by Edward Tolman (1948), through his research with rats. Behaviorists and learning theorists further expanded on the empirical understanding of memory by exploring stimulus association. Later, lesion studies advanced memory research by exposing the biological correlates, through such famous cases as Henry Molaison (H.M.), which demonstrated the importance of the hippocampus to memory acquisition (Scoville & Milner, 1957).

By the late 1960s, memory was described by a two component model which divided memory function into short-term and long-term components. Atkinson and Shiffrin (1968) also proposed the Modal Model that illustrated that information flows from the environment into a limited capacity store through a series of brief sensory memories that are best regarded as part of the perceptual system. These authors proposed that the longer an item remained in these stores, the greater its probability of transfer into long-term memory. This model differed from those preceding it because it established a three structure system comprised of a sensory register, short-term memory and long-term memory. Short-term memory was then comprised of several control processes, i.e. rehearsal, coding, decision, and retrieval strategies. Although the Modal Model was influential, some theorists felt that it described memory as being too static and began arguing that greater empirical focus should be placed on processes associated with memory rather than memory stores. Baddeley (2009) emphasized that researchers should seek to explore both stores and processes as well as the relation between them.

Memory Structures

Sensory memory refers to the brief store within a specific modality of the human perceptual system. Bell Laboratories in the 1960s explored sensory memory specific to visual input, which is termed iconic memory (Baddeley, 2002; Neisser, 1967; Sperling, 1963; Averbach & Sperling, 1961), while echoic memory was the term coined for auditory sensory memory. *Short-term memory*, then, is the temporary storage of small amounts of material over brief delays. Thus, short-term memory is seen as the initial internal holding of information after an individual's first confrontation with it (Halligan & Wade, 2005).

By the 1970's, studies showed that merely holding information in short-term memory did not guarantee learning. Craik and Lockhart (1972) suggested levels of processing in which the probability of subsequent recall or recognition was a direct function of the depth (i.e. multimodally versus unimodally, etc.) to which an item was processed. Subsequently, Baddeley and Hitch (1974), further defined the relationship between short-term memory and long-term memory through a series of experiments. They proposed that short-term memory be replaced with the term working memory. A model was espoused which subdivided working memory into an attentional control (i.e., the central executive), which was assisted by 2 subsystems: the phonological loop and the visuospatial sketchpad. Working Memory was therefore the system which provides temporary maintenance and manipulation of information. In this capacity, working memory acts much like a mental workspace, providing the basis for thought. It is assumed to be linked to attention and draws on short-term as well as long-term memory stores (Miyake & Shah, 1999). While, the phonological loop holds traces of information for seconds and is mediated verbally, the visuospatial sketchpad allows for temporary storage and manipulation of visual and spatial information.

In the Baddeley and Hitch model, the central executive organizes and coordinates the subsystems for efficient execution, which is similar to Noman and Shallic's (1986) description of the supervisory attentional system (SAS). Baddeley and Hitch proposed that much activity is controlled by well-learned habits and schemata, guided by environmental cues. Novel actions that are needed to respond to unexpected situations, therefore, depend upon the intervention from the limited capacity SAS, which was assumed to be capable of overriding habits. In patients with frontal lobe damage, impairments such as perseveration would be attributed to a deficient SAS, which was unable to inhibit environmentally dependent responses. Baddeley, Kopelman, and Wilson (2002) hold that frontal lobe function and executive ability play a substantial component in memory function, since the selection of strategy and stimulus processing, two distinct executive functions, play a crucial role in effective learning. A fourth component of working memory, the episodic buffer, allows one to take advantage of prior knowledge to package information more effectively, thereby enhancing one's storage and retrieval abilities.

Long-term memory is the system or systems that underlie the capacity to store information over extended periods of time (Baddeley, 2009). It can be subdivided into explicit (declarative) and implicit (non-declarative) memory. Explicit or declarative memory refers to memory that is open to intentional retrieval and can be further divided into facts (semantic memory) and events (episodic memory). Semantic memory refers to knowledge of the world; goes beyond meaning of words; and incorporates sensory attributes such as taste and smell (Baddeley, 2009). While explicit memory is contingent on a conscious process in which knowledge and facts are brought into one's awareness, implicit memory tends to operate outside of consciousness and is comprised of various motor skills and habits, e.g. movements that comprise riding a bicycle, as well as association and conditioning (Baddeley et al, 2002; Squire, 1992). Research has shown that many amnestic patients are unable to learn new information or retrieve past information, yet have preserved implicit memory as evidenced by their ability to engage in overlearned behaviors, such as using language. Classical conditioning has also been spared for such patients, indicating that implicit learning persists for many so-called amnestic patients. For example, Weiskrantz and Warrington (1979) showed that amnestic patients learned to associate a puff of air with a specific tone and began to blink whenever the tone was played.

Stages of Memory

Through research in clinical neuropsychology the examination of memory has progressed from the description of different "types" of memory to a three-stage model of memory that is comprised of: encoding, storage, retrieval. Encoding is described as the processes whereby information is registered while storage pertains to the maintenance of information over time.

Retrieval, then, is the accessing of information by recognition, recall, or the demonstration that a relevant task is performed more efficiently as a result of prior experience. Although the three stages of memory are interrelated and depend on one another for adequate memory function, studies have shown that patients can present with deficits at any one stage, exclusive of others. Korsakoff patients, for example, have been shown to exhibit impaired memory during information processing (Butters and Cermak, 1980). The famous case of H.M. showed that a deficit can also occur during transfer from short-term memory to long-term memory (Scoville & Milner, 1957; Milner, 1964). Patients can also present with impaired retrieval as often seen in patients diagnosed with Alzheimer's Disease (AD) (Baddeley, 2009).

Neurobiology of Memory Function

Research has shown that the entire brain is devoted to memory (Baddeley, Kopelman, Wilson, 2002) with learning via experience producing a relatively permanent change in neuronal performance. In 1949, Hebb proposed that when an axon is near enough to excite another neuron or repeatedly and persistently takes part in firing it, some growth or metabolic change takes place in both cells, such that the first cell's efficiency is increased in firing the second cell. Kandel's (1967) research with sea slugs supported Hebb's principle and showed that habituation was accompanied by alterations in the morphology of electrophysiologically identified synapses (Kandel, 1967; Kandel and Schwartz, 1982). In 1973, the concept of long-term potentiation (LTP), which is described as a lasting increase in the synaptic efficacy following high frequency stimulation of afferent fibers, was discovered (Bliss & Lomo, 1973). Richard Morris and colleagues (1990) further showed that the proportionality of LTP was associated with the functional aspects of learning, where less LTP was correlated with insufficient learning and more LTP was correlated with greater learning. At a neurological level, this process can be seen as follows: First, information storage is intrinsic to sensorimotor pathways mediating a particular learned behavior. Second, information storage is an alteration in the efficacy of existing neural pathways. Third, the detection of contiguity in classical conditioning is a biological property of neurons. A G protein is believed to represent the unconditioned stimulus in classical conditioning and calcium calmodulin is believed to be the conditioned response. Allosteric modulation of the denylate cyclase is that its subsequent activation by the unconditioned stimuli will result in greater production of cAMP and enhance phosphorylation of presynaptic K+ channels (Ropper, 2005).

The hippocampal system has been shown to have only a temporary role in the formation and maintenance of some aspects of declarative memory and permanent memory appears to be established in other brain regions, most likely the neo cortex (Alvarez & Squire, 1994; Squire, 1992; Zola-Morgan & Squire, 1993). This is supported by studies with patients with bilateral hippocampal damage who have a temporally-graded defect in retrograde memory, with greater retention of more latent autobiographical information. It should be noted that retrograde memory refers to the memory-access to events that occurred, or information that was learned, before an injury or the onset of a disease. The most famous example is the case of H.M., who endured bilateral resection of his temporal lobes due to intractable seizures. After the surgery, H.M. developed an inability to learn new, declarative information, but exhibited fairly intact working memory and was able to retrieve information from his past. In contrast, another patient known by the name of Boswell, developed both retrograde and anterograde amnesia following herpes simplex encephalitis which damaged all of the mesial and anterolateral parts of the temporal lobes. Research has also shown that there is lateralization in the mesial temporal lobes with the left side mediating verbal information and the right side mediating visual information (Milner, 1997).

The hippocampal complex has been shown to be vital to declarative, factual information (Baddeley, 2002). Studies in this area have suggested that the right-sided non-mesial temporal structures operate in concert with the right prefrontal cortices to subserve the retrieval of unique, factual information, especially for autobiographical knowledge (Calabrase et al, 1996; Fletcher et al, 1997). It has been proposed that the frontal cortices play an important role in the connectedness of unique memories and the methods of memory search utilized in effortful retrieval, whereas the temporal lobes are suspected to hold specific knowledge of facts and events (Baddeley, 2002).

Frontal Lobes and Executive Function

Although views on the exact nature of executive function(s) vary, it is generally agreed that this aspect of brain function includes the abilities of abstraction, shifting of response patterns, planning, working memory, and response suppression (Trans-NIH Executive Function Workshop, 2003). Executive functions are regarded as the most complex behaviors and are associated with the ability to respond in an adaptive manner to novel situations. More specifically, executive functions appear to be the basis of many cognitive, emotional, and social skills where "all [executive functions] are necessary for appropriate, socially responsible, and self-serving conduct" (Lezak, 2004, p.35). Lezak (2004) conceptualizes executive function as having four components: planning, volition, purposeful action, and effective performance. Conversely, Baddeley (1992) regards executive functions as higher cognitive activities by which performance is optimized in situations requiring the simultaneous operation of divergent cognitive processes. In this conceptualization, executive functions (EF) depend greatly on short-term working memory which allows information to be held and manipulated in the mind during effortful tasks including learning, reasoning and comprehending (Baddeley and Hitch, 1974). Executive control deficits will then lead to difficulty coordinating the simultaneous operation of the phonological loop and visual sketchpad which are important aspects of the working memory system. Despite limited agreement among clinicians and researchers regarding these concepts and their localization, there has been a historical linkage of these "higher-level" processes with the frontal lobes. Many investigators often use the term "frontal functions" synonymously with "executive functions" despite evidence that contradicts this synonymous usage (Baddeley, 2002).

Three neural circuits have been identified between the frontal lobes and other cortical and subcortical areas which play an important role in cognitive, emotional, and motivational processes (Duke and Kaszniak, 2000; Sbordone, 2000; Stuss and Benson, 1984). These circuits are: dorsolateral, ventromedial, and orbitofrontal. The dorsolateral frontal cortex projects primarily to the dorsolateral head of the caudate nucleus and has been linked to verbal and design fluency; the ability to maintain and shift a cognitive set; planning; response inhibition; working memory; organizational skills; reasoning and problem-solving; and abstract thinking (Cummings, 1993; Duke and Kaszniak, 2000; Grafman and Litvan, 1999; Malloy and Richardson, 2001; Milner, 1971). Conversely, the ventromedial circuit, which begins in the anterior cingulate and projects to the nucleus accumbens, appears to be involved in motivated behavior. Lesions to this region often produce apathy, decreased social interaction, and psychomotor retardation (Sbordone, 2000). Finally, the orbitofrontal cortex projects to the ventromedial caudate nucleus and appears to influence social behavior. Lesions to this area have been shown to cause disinhibition, impulsivity, and antisocial behavior (Blumer and Benson, 1975; Cummings, 1995).

Memory and Executive Function

Several theories have been proposed regarding the interaction of the executive function components of the frontal lobes with other areas of the brain. Work from Goldman-Rakic's group (1994) suggests different areas of the Prefrontal Cortex (PFC) encode different types of content using the same basic processing functions of working memory to hold and compare information. Dias, Robbins, and Roberts (1997), on the other hand, suggested that different areas of the PFC subserve different processing functions such as abstraction versus inhibition (O'Reilly, Noelle, Braver, & Cohen, 2002). Other theorists suggest that there is a dissociation of functions in different regions of the PFC using lesion, electrophysiology, and fMRI studies (Freedman, Black, Ebert, & Binns, 1998; Kubota & Niki, 1971; Nakahara et al., 2002; Petrides, 2000; Wallis et al., 2001; Wilson, Scalaidhe, & Goldman-Rakic, 1993). The working memory model of PFC function describes working memory as the process of maintaining information through continual neural firing, which can be rapidly updated by changing the activation state of a set of neurons (Kubota & Niki, 1971; Miller & Cohen, 2001; O'Reilly et al., 2002). These activation-based working memories, although unstable, are flexible and can be altered to accommodate new information to allow for abstraction and set shifting.

Lesion studies have shown that executive functions and the frontal lobes play an important role in memory. For instance, patients with frontal impairments exhibit significant memory deficits on tasks involving free recall of word lists (Balbo et al, 2002; Dimitrov et al, 1999; Stuss, 1994). These deficits are most pronounced on tests of delayed recall, but can also be observed on tests of cued recall in which participants are presented with a cue such as a category. However, when information is embedded within a rich, well organized task, such as learning a story, frontal patients show relatively good recall (Incisa della Rocheta & Milbner, 1993;

Janosky et al 1989). Finally, tasks that put minimal demands on effortful retrieval, such as word stem completion and category exemplar priming, do not appear to be sensitive to frontal lesions (Gershberg & Shimamura, 1998; Shimamura et al, 1992).

Baddeley (2002) stated that recall deficits in frontal patients are related to their reduced use of semantic and subjective organization, both at encoding and retrieval, indicating that the learning process itself may not be impaired. Instead, the monitoring and control of information during encoding and retrieval may be what is compromised. Deficits in recognition have also been observed in frontal patients. Baddeley (2002) espoused that these deficits are most evident when distractors are semantically related to target items. Evidence suggests these impairments are secondary to general deficits in strategic encoding and retrieval rather than a fundamental learning deficit. The left frontal lobe is thought to be more involved in the retrieval of highly typical associations, while the right frontal processes support more remote idiosyncratic associations (Baddeley, 2002). Overall, frontal patients exhibit marked impairment on a variety of long-term memory tests, but these deficits are attenuated when they are provided with retrieval strategies and/or the attention demands are reduced. Collectively, these results suggest how cognitive rehabilitation aimed at improving frontal/executive functions can also positively impact memory function, further illustrating the interaction between the two systems.

Through their participation in attention, encoding, and problem solving, the frontal lobes can be thought of as playing a secondary role in memory function (Baddeley 2002; Shimanura, 1991). Indeed, the dorsolateral prefrontal region appears to play an important role in working memory as functional imaging studies have shown that performance on working memory tasks consistently activate the dorsolateral prefrontal cortex (PFC) and, in particular, Brodman areas 6, 44, 9 and 46 (Baddeley, 2002). Studies have also shown lateralization with the left dorsolateral

PFC being activated by verbal working memory tasks and the right dorsolateral PFC being activated by spatial working memory tasks (Smith et al, 1996). While the manipulation of information shows greater activation of Brodman areas 9 and 46, areas 6 and 44 show greater activation during tasks that require the maintenance of information (Baddeley, 2002). It is therefore presumed that the anterior dorsolateral PFC is involved in higher processing and may exhibit deficits in tasks such as Arithmetic, which require manipulation of information. The posterior dorsolateral PFC, then, would be expected to show greater activation during tasks such as Digit Span, which require the participant to maintain numeric information. Further lateralization has been demonstrated in which the left PFC is associated with retrieval of general information and the encoding of novel events while the right PFC has been shown to specialize for retrieval of episodic memories (Nyberg et al, 1996,1998; Tulving et al, 1994, 1996). The ability to judge recency and frequency has also been associated with the dorsolateral PFC (Smith & Milner, 1988).

Given the aforementioned research, memory deficits can occur with associated prefrontal lesions because patients are unable to select relevant information or inhibit distracting or interfering items that occur during the encoding or retrieval process (Luria, 1966, 1973; Perret, 1974). Patients with prefrontal lesions do not appear to spontaneously organize information or make use of effective organizational strategies during unstructured encoding or retrieval tasks (della Rochetta and Milber, 1993; Stuss et al, 1994; Greshberg and Shimamura 1995; Alexander et al, 2003; Blumenfeld and Ranganath, 2007).

Neuroimaging studies of working memory and cognitive control also suggest that regions within the ventrolateral PFC and regions in the dorsolateral PFC may impact control processes that support memory encoding (Blumenfeld and Ranganath, 2007). Specifically, the ventromedial PFC plays an important role in behavioral regulation and response selection, which is similar to the dorsolateral PFC influence on memory encoding and retrieval. The ventromedial PFC essentially links factual knowledge to pertinent emotions and feelings, thereby providing the connection between the propensities for various actions and the individual emotional experiences. Rolls (2000) opined the orbitofrontal cortex is also crucial for learning associations between various stimuli and their primary reinforcers.

A review by Blumenfeld and Ranganath (2007) concluded that different areas of the PFC implement cognitive control processes that support successful long-term memory encoding by supporting controlled selection of goal-oriented item information and organization. Their review of neuroimaging studies revealed that the ventrolateral PFC is more involved in controlled selection of item information and the dorsolateral PFC is more involved in organizational processing such as "chunking" information. The ventrolateral PFC may support long-term memory formation through selecting relevant item information. The dorsolateral PFC is then believed to be associated with building the associations among items that are active in memory. Kawasaki, Kitajo, and Yamaguchi (2010) showed there is dissociation in regards to localization during working memory tasks with frontal theta activity being mainly observed during the manipulation period and posterior [temporal and parietal] alpha activity observed in the manipulation period and in the maintenance period. Duarte, Henson, Knight, Emery and Graham (2010) revealed that the orbitofrontal cortex (OFC) contributed to encoding and retrieval of associations between objects and their temporal components but not to their spatial contexts. It was found that OFC patients exhibited impairments in temporal but not spatial source memory accuracy suggesting that the OFC plays a critical role in the formation and subsequent retrieval of temporal context.

Studies have also shown that in degenerative disorders, such as Parkinson's, Alzheimer's, and fronto-temporal dementia, there is a relationship between executive dysfunction and memory deficits (Higginson, King, Levine, Wheelock, Khamphay, and Sigvardt, 2003). Godefroy, Roussel, Leclerc and Leys (2008) found that episodic memory deficits in nonaphasic stroke patients was due to lesions of the medial temporal region, thalamus, frontal lobes, centrum semiovale and striatum, with a deficit of immediate recall being predictive of left thalamic lesions, and the presence of false recognitions being a predictor of frontal damage.

For a better understanding of the relationship among brain function, particularly between memory and executive function, it is important to briefly review Alexander Luria's theory of functional systems. According to Luria (1973) there are three functional units, comprised of the arousal unit, the sensory-input unit and the organizational and planning unit with each further divided into primary, secondary and tertiary processing areas. Each of these units work simultaneously in unison as well as independently. This results in a complex bidirectional relationship between different brain areas that give rise to both localized function at each site and complex emergent qualities from their interaction. Behavior is therefore considered the result of the interaction of the brain as a whole with each area contributing to a specific skill. Primary areas of processing receive and send impulses. Secondary areas process incoming information and program information for execution. Finally, the tertiary areas are responsible for complex function through association and projection onto primary, secondary and other tertiary areas.

Factor Analytic Studies of Memory and Executive Function

While no study has explored the integrative composition of memory and executive function, previous studies have sought to identify the factor structures of memory and executive tests independently. Aside from the standardization studies, research such as Hunkin, et al (2000) have advanced the literature by combining accepted measures of memory function to identify underlying factors which comprised of Recall, Visual Recognition, and Verbal Recognition.

Tests, Bennett, and Ponsford (2012) explored the underlying factor structure of 19 executive function measures using a clinical sample. The study found weak correlations among the 19 tests which separated out into the following six factors: Prospective Working Memory, Set-Shifting/Interference, Task Analysis, Response Inhibition, Strategy Generation, and Self-Monitoring. This study expanded on previous research which showed that measures of executive function can load on four or five factors, illustrating the complexity among the structure and function of these tests (Shute and Huertas, 1990; Robbins and colleagues, 1998; Pineda and Merchan, 2003).

Clinical Relevance

Clinical evaluation in the area of memory dysfunction is intended to address issues regarding diagnosis; severity and types of damage; and prognosis. The possibility of rehabilitation and the monitoring of change associated with an intervention fall within the purview of clinical evaluation, as these assessments contribute to the understanding of adaption and improvement.

The World Health Organization (WHO) defines impairment as damage to a physical or mental structure. Disability refers to a reduction or loss of functional activity in daily life, which occurs as a result of the impairment (Halligan & Wade, 2005). Interventions that focus on memory impairment attempt to alter the internal neurobiological or cognitive state of the individual with the expectation that such a change will have general benefits for memory in a range of everyday situations and, thus, reduce disability. The method often used is repetitive practice and exercise with the goal of stimulating or activating damaged cognitive and neural processes that are involved in memory so as to restore their function. Interventions that focus on disability tend to intervene directly at the behavioral level without the expectation of internal change or generalization (Halligan & Wade, 2005).

Patients with frontal deficits, although they may be able to learn new strategies may not be able to initiate them spontaneously and not exhibit generalization. Strategy training should therefore be beneficial to those with relatively preserved frontal function and limited damage to medial temporal lobe structures. Through the use of strategic encoding processes, patients can associate the elements of a new experience together and relate them to similar information in the knowledge system. The information delivered to the temporal lobes is likely to be well integrated and meaningful, placing less of a burden on the binding processes of the hippocampus and surrounding brain regions (Halligan & Wade, 2005).

Overall evidence for successful treatment of memory impairment is weak with strategies showing little generalization. Duncan (1995, 2000) proposed that there is general intelligence which is encompassed by the frontal lobes in what is termed 'g'. In regards to rehabilitation, improvement or intervention with this general ability would, in turn, lead to generalized improvement which would directly affect functions such as memory (Halligan & Wade, 2005). Therefore a more integrated method for rehabilitation may yield efficacy and allow for more generalization. Still, before such rehabilitation programs are designed and implemented, a better understanding of the interplay between areas that play a role in memory and executive function must be established.

Purpose

Memory acquisition and retention result from the interaction of multiple networks. Many theories of memory consolidation propose a gradual transfer of memory that requires processing from the hippocampal and medial temporal lobes to the neocortex for long-term storage (Lezak, 2004; Kapur & Brooks, 1999). Others suggest that there is no single site for stored memories; instead memories involve neuronal contributions from many cortical and subcortical centers with different brain systems playing different roles. Within this view, encoding, storage, and retrieval of information in the memory system appear to take place according to both principles of association and characteristics that are unique to the particular stimulus (Lezak, 2004).

With such a strong emphasis on the abilities to give structure, organize and relate information, it would follow that the executive functions would play a vital role in all three stages of memory function. Yet, in the field of neuropsychology there is uncertainty regarding the relationship between executive function and memory. While some studies have demonstrated a significant relationship between memory and executive function in clinical populations (Bondi, Kaszniak, Bayles, & Vance, 1993; Pillon, Deweer, Agid, & Dubois, 1993), other studies have discounted this relationship; describing it as spurious and dissociable (Mohr et al., 1990; Owen et al., 1992; Paolo, Troster, Axelrod, & Koller, 1995). Some authors have also suggested that both memory and executive function may be mediated by a third variable such as the construct of General Intelligence (Troster & Fields, 1995). In sum, past research has been inconclusive regarding the relationship of memory and executive function. Thus, research is needed to clarify how these complex functions interact, particularly in diverse clinical samples where accurate evaluation and treatment planning is paramount.

The goal of this study is to examine the relationship between memory and executive function through exploration of the combined component structure of the Wechsler Memory Scale-Fourth Edition (WMS-IV), the newest edition of the most accepted measure of general memory function, and the Wisconsin Card Sort Test (WCST), the Category Test, the Trail Making Test (TMT), the Conner's Continuous Performance Task (CPT-2), and the Tactual Performance Test (TPT), which are accepted measures of executive function. The proposed study is warranted because there is conflicting evidence from previous research regarding memory and executive function. With regard to cognitive rehabilitation, having a more clearly defined association between executive function and memory would promote more accurate intervention efforts, which can have a direct impact on prognosis.

Hypothesis. It was hypothesized that a Principle Component Analysis of executive and memory measures would yield four correlated components, with two components reflecting facets of memory function and the other two components reflecting facets of executive function.

Research concerning the relationship between executive function and memory has been inconclusive with much disagreement among researchers regarding whether they measure similar underlying constructs. Studies utilizing advanced neuroimaging techniques have shown increased activation of the right and left prefrontal regions during encoding and retrieval, which are sites also highly activated during executive function tasks (Nyberg, Cabeza, & Tulving; 1998). There has also be shown to be differential activation of the dorsolateral regions of the frontal lobe. While the left dorsolateral frontal cortex is more highly activated during encoding, the right dorsolateral cerebral cortex is more highly activated during retrieval. (Nyberg, Cabeza, & Tulving; 1998)

Still, the great majority of research on the relation of memory and executive function has almost exclusively focused on executive function's association with verbal working memory. Working memory is conceived as one of the functions responsible for goal-directed problem-solving behavior, in addition to inhibition, shifting, planning and other processes (Pennington & Ozonoff 1996), which are considered to be prominent abilities associated with executive function. Lyon and Krasnegor (1996) indicated that tests such as Digit Span, TMT, and Stroop were interchangeably used to measure executive function and memory, illustrating no distinction or consensus on their construct validity.

Factor analytic studies during the WMS-IV standardization resulted in a three-factor model, Immediate, Delayed and Visual Working Memory (Wechsler, 2009). The portioning of the subtests into these three factors can be related to the activation of different areas of the PFC. In relation to measures of executive function, factor analytic studies have illustrated that although different measures evaluate distinct abilities, they can be grouped into factor models ranging from four to six, depending on the study. For example, studies such as Tests, Bennett, and Ponsford (2012), Shute and Huertas (1990), Robbins and colleagues (1998), Pineda and Merchan (2003) have shown that these tests group into four, five or six factor models.

Although no previous study has sought to explore whether measures of memory and executive function assess the same underlying constructs, it was expected that through Principal Components Analysis, the 17 selected measures for the present study would load into a minimum of four components. These components would be similar to what has been shown in previous studies, with measures grouping into components associated with working memory (CPT Commissions, Trails B, WMS-IV Spatial Addition, and WMS-IV Symbol Span), immediate memory (WMS-IV Logical Memory I, Verbal Paired Associates I, Visual

Reproduction I, and WMS-IV Designs I), delayed memory (WMS-IV Logical Memory II, Verbal Paired Associates II, Visual Reproduction II, and WMS-IV Designs II), and executive function (Category total errors, WCST Total Errors, WCST Perseverative Errors, TPT Total Score, and CPT Perseverative Responses). Such a presentation would support the notion that although similar areas of the brain are activated during tasks of executive function and memory, these constructs are emergent in quality and, as a result, are mutually exclusive. Related primary, secondary, and tertiary areas are activated, such as in recalling a semantic memory to answer a question or when using overlearned information efficiently to organize and strategize to solve a novel problem. The resulting ability or construct is therefore dynamic and dependent on the interplay between these locations in the brain rather than a being the linear result of their stimulation. Furthermore, it was believed that measures of working memory would also separate from measures of executive function as well as immediate and delayed memory, which would support the three components model utilized for the WMS-IV standardization, which classifies working memory as an independent function.

Chapter III: Method

Participants

This study involved analysis of archival data. Participants consisted of 114 adults, aged 18 to 69 that were referred for testing services at the Neuropsychology Assessment Center at Nova Southeastern University. Participants who had previously completed a specific battery of neuropsychological tests (in addition to undergoing a clinical interview) were selected for inclusion into the study. Informed consent, when necessary, was obtained. Assessments were conducted by clinical psychology graduate students trained in the standard administration, scoring, and interpretation of testing instruments. Students were expected to complete supervised training prior to test administration. Testing results were reviewed by supervisors who were licensed, board certified, clinical psychologists. Diagnoses met by participants were made by supervisors abiding by DSM-IV-TR criteria (APA, 2000) and based on acquired history, behavioral observations, and concordant testing results obtained by the testers. Because of the referral nature of the testing, no tests were administered in a predetermined order of administration.

Inclusion and exclusion criteria for the study primarily revolved around age, clinical status, and completion of the requisite neuropsychological tests. Participants included into the study were between the ages of 18 and 89 years of age who have been diagnosed with a neurological and/or psychiatric disorder. Exclusion criteria included participants being below the age of 18 years or above the age of 89 years and failure to complete the requisite measures. Participants were also excluded if no diagnosis of either a neurological and/or psychiatric disorder was made by the licensed clinical psychologist and/or hearing or visual impairment. Common comorbid disorders were allowed to covary naturally and did not serve as exclusionary criteria. Because of the retrospective nature of the study, information about language acquisition is not known for all participants. Thus, language did not serve as exclusionary criteria. Demographic variables, such as educational level, ethnicity, race, socioeconomic status, or geographic location, also did not serve as exclusionary criteria. Demographic information from the sample appears in Tables 1 and 2.

Table 1

Mean and Standard Deviations (SDs) of the Demographic Variables for this Sample (N=114)

	Age	
	Number	Percent
18-19	7	6.1
20-29	50	43.9
30-49	34	29.8
50-69	23	20.2
	Education	
	Number	Percent
Less Than 12	6	5.3
High School	32	28.0
College	70	61.4
Graduate School	6	5.3

Table 1 shows age and education date for the clinical sample used in this study.

Table 2

Mean and Standard Deviations (SDs) of the Demographic Variables for this Sample (N=114)

	Handedness	
	Number	Percent
Right	87	76.3
Left	25	21.9
Mixed	1	.9

	Race	
	Number	Percent
Caucasian	77	67.5
African American	9	7.9
Latino-Hispanic	22	19.3
Other	5	4.4

	Gender	
	Number	Percent
Male	55	48.2
Female	59	51.8

Table 2 shows handedness, race and gender information for the sample.

Memory Measures

The measures selected involved standardized scores characterized as quantitative in nature, with each subscale yielding scores that have been gender and age-corrected. The measures yield index scores with a mean of 100 and a standard deviation of 15, scaled scores with a mean of 10 and standard deviation of 3, and T-Scores with a mean of 50 and standard deviation of 10. These measures are discussed in more detail below.

Wechsler Memory Scale. The Wechsler Memory Scale-fourth edition is an individually administered battery designed to asses various memory and working memory abilities in individuals aged 16-90. It is a revision of the Wechsler Memory Scale-Third Edition. Two batteries are contained within the WMS-IV, an adult battery for individuals aged 16-69 and a shorter older adult battery developed for use with individuals aged 65-90. The WMS-IV contains a total of seven subtests: three subtests retained from the WMS-III (Logical Memory, Verbal Paired Associates and Visual Reproduction) and four new subtests (Brief Cognitive Status Exam, Designs, Spatial Addition, and Symbol Span). Four subtests are divided into two conditions: the immediate condition and the delayed condition, which are administered about 20-30 minutes apart. Several subtests also include optional tasks that are used to derive process scores. Of the seven WMS-IV subtests, six are considered primary subtests and are used to derive index scores and one subtest is optional. The primary subtest scaled scores are used to derive five index scores: Auditory Memory, Visual Memory, Visual Working Memory, Immediate Memory and Delayed Memory.

The WMS-IV provides a detailed assessment of clinically relevant aspects of memory functioning commonly reported in individuals with suspected memory impairment or diagnosed with a wide range of neurological, psychiatric and developmental disorders. It is designed to provide relevant information for general clinical and neuropsychological evaluations as well as for rehabilitation evaluations. As a clinical assessment instrument, the WMS-IV provides measures of important memory functions. Considering that the Wechsler Memory scales have been the standard for research, the use of these measures will provide the examiner with a wealth of information about memory functioning and processes.

Reliability. The WMS-IV normative sample data are based on a national sample representative of the US population of adults aged 16-90 years. A stratified sampling plan ensured that the normative sample included representative proportion of adults form selected demographic variables. An analysis of data gathered in 2005 from the US census bureau provided the basis for stratification according to age, sex, race/ethnicity, education level and geographic region. All examinees were required to sign consent forms to participate in the study. One thousand four hundred examinees were included with 100 in each age cohort. 900 completed the adult battery and 500 completed the older adult battery.

Test reliability is an indication of the degree to which test scores provide a precise and stable measure. A reliable test will have relatively small measurement error and produce consistent results across administrations. The reliability of a test refers to the accuracy, consistency and stability of test scores across situations. Internal consistency reliability coefficients were calculated utilizing the split-half and alpha methods. The split-half coefficient is the correlation between the total scores of the two subtests, corrected for length of the test, using the Spearman formula. The internal consistency reliability coefficients for index scores were calculated with the formula recommended by Nunnally and Bernstein (1994). The average coefficients were calculated suing Fisher's z transformation (Silver & Dunlap, 1987; Strube, 1988). The results of the reliability studies indicated that most of the WMS-IV subtests have moderate to high internal consistency with an average range of coefficients from .74 to .97 across all age groups. The individual index scores exhibited high internal consistency across all age groups with and average range of .93 to .97.

Validity. The validity of test measure is the single most fundamental and important aspect of test development and evaluation (Sattler, 2008) with researchers allocating significant time to evaluate construct, content and convergent validity. Evidence of content validity is not based on statistics or empirical testing but rather on the degree to which the test items adequately represent and relate to the trait or function that is being measured. Data collected during the pilot and tryout phases of test development is used to determine final subtest and composition. The most relevant data for establishing construct validity are the correlational data obtained from convergent validity studies with other measures of memory functioning and from special group studies. The average correlations were computed using Fisher's z transformation. Statistically, all inter-subtest correlations were significant. The highest correlations were observed between the immediate and delayed conditions of the same subtest. The correlations between the subtests and their corresponding process scaled scores were moderate to high. The data supported the claim that subtests of similar functioning correlate more highly with each other than with the subtests measuring different types of functioning.

Factor Analysis. Confirmatory Factor Analysis is designed to evaluate the factor structure specified by researchers a priori. The relations between observed variables and latent variables are specified in advance and that model is tested to determine if the specified variance/covariance model fits the data. It if does, this is supporting evidence for the validity of model. Overall, factor analytic studies of the previous versions of the WMS have yielded inconsistent results, supporting 4 and 5 factors. The authors of the WMS-IV tested a two factor model (Verbal and visual memory) and a three factor model (verbal, visual and visual working memory). Model 1 and Model 2 yielded very similar results at each age range and overall. The reported statistics indicated that both models fit the data well with adjusted goodness of fit index (AGFI) values above .95 and root means square error of approximation (RMSEA) values at or below .05. The differences in fit between the two models were not significant. The authors reported that the three-factor model as selected to represent the core WMS-IV index score structure because of the response processes being evaluated.

Convergent Validity. An examination of the relationship between test scores and other related variables provides important information about what a test measures and whether it behaves as expected when related to other measures of similar constructs. The WMS-IV was therefore compared to several neuropsychological measures as part of the standardization. Of specific interest to this dissertation were the comparisons with the Wechsler Adult Intelligence Scale-fourth edition (WAIS-IV) and the Delis-Kaplan Executive Functioning System (D-KEFS). The WAIS-IV was administered to all 1250 examinees who took the WMS-IV, with a testing interval of 0-79 days and a mean testing interval of 5 days. The correlations between the WAIS-IV and the WMS-IV ranged from .40 to .71. The Matrix Reasoning and Similarities subtests of the WAIS-IV exhibited small to medium correlations with the WMS-IV subtests. The highest correlation with Similarities pertained to Logical Memory 1 (r=.45) and the lowest to Designs II Spatial score (r=.13). The highest correlation with Matrix Reasoning pertained to Symbol Span (r=.49) and the lowest to Designs II Spatial score (r=.20). Similarities correlated highest with Immediate Memory Index (r=.52) and lowest with the Visual Memory Index (r=.39). Matrix Reasoning correlated highest with the Visual Working Memory Index (r=.55) and lowest with the Auditory Memory Index (r=40).

The D-KEFS consists of nine subtests that measure a wide spectrum of verbal and nonverbal executive functions. The WMS-IV and two subtests form the D-KEFS (trail making and verbal fluency) were administered to 90 examinees, ages 16-89. It was expected that the WMS-IV subtest and index scores would show low to moderate correlations with the D-KEFS. Relative to other WMS-IV subtest and index scores, higher correlations were expected between D-KEFS scores and scores for the Visual Working Memory subtests, as well as the Visual Working Memory Index (VWMI). The Auditory Memory subtests and the Auditory Memory Index (AMI) were expected to demonstrate higher correlations with the D-KEFS letter fluency and categorical fluency scores than the other WMS-IV subtest and the index scores. The following comparisons were attained from Wechsler, D. (2009): Correlations between the D-KEFS and WMS-IV range from .22 to .54. The highest subtest correlation for the Trail Making was Designs I (DE I), and the lowest was Verbal Paired Associates I. The Delayed Memory Index (DMI) had the highest correlation with TMT Number Letter Switching (r=.54) and the VWMI had the highest correlation with the TMT Combined Number Sequencing and Letter Sequencing (r=.50). The lowest Index correlation with Number Letter Switching was Visual Memory Index (VMI) (r=.38), and the lowest for Combined Number Sequencing and Letter Sequencing was AMI (r=.22). The highest subtest correlation for Letter Fluency was Verbal Paired Associates (VPA) II Word Recall (r=.42), and lowest subtest correlation was DE I Spatial (r=.08). The highest Index correlation with Letter Fluency pertained to the DMI (r=.48), and the lowest Index correlation with Letter Fluency was VWMI (r=.23). The highest subtest correlation with Categorical Fluency was DE II Content (r=.34), and the lowest pertained to the DE II Spatial (r=.07). A clinical sample consisting of TBI patients ages 19-45 was also used to compare performance on the D-KEFS and WMS-IV. Overall, there was an increase in correlations due to a general decrease in processing speed and possible fronto-temporal lesions. The highest subtest correlation with TMT Number Letter Switching was VPA II Word Recall (r=.82), and the lowest was Visual Reproduction I (r=.36). The highest Index correlation was DMI (r=.76) and the lowest Index correlation was VWMI (r=.56). The highest subtest correlation with Letter Fluency was DE II Spatial (r=.60), and the lowest subtest correlation was Symbol Span (SSP) (r=.20). The highest Index correlation with Letter Fluency was DMI (r=.52), and the lowest Index correlation was VWMI (r=.29). The highest subtest correlation with Categorical Fluency was DE Spatial I (r=.64), and the lowest subtest correlation was VR I (r=.21). The highest Index correlation with Categorical Fluency was AMI (r=.68), and lowest Index correlation was VMI (r=.44).

Descriptions of WMS-IV Individual Subtests.

Logical Memory. This subtest assesses narrative memory under a free recall condition. Two short stories are orally presented. For older adults, one story is presented twice. The examinee is asked to retell each story from memory immediately after hearing. The delayed condition assesses long-term narrative memory with free recall and recognition tasks. The examinee is asked yes/no questions about both stories.

Verbal Paired Associates. This subtest assesses verbal memory for associated word pairs. After 10 or 14 word pairs are read to the examinee, the first word of each pair is read and the examinee is asked to provide the corresponding word. There are four trials of the same list in different orders. The delayed condition assesses long-term recall for verbally paired information with cued recall and recognition tasks, and includes a free recall task. The examinee is orally presented with the first word of each pair learned in the immediate condition and asked to provide the corresponding word. The examinee is then read a list of word pairs and asked to identify each as either one of the initial word pairs he or she was presented or a new word pair. Finally, during the optional word recall task, the examinee is asked to say as many of the words from the pairs as he or she can recall.

Designs. This subtest assesses spatial memory for unfamiliar visual material. The examinee is shown a grid with four to eight designs on a page for 10 seconds, which is then removed from view. The examinee then selects the designs from a set of cards and places the cards in a grid in the same place as previously shown. The delayed condition assesses long-term spatial and visual memory with free recall and recognition tasks. First, the examinee is asked to recreate the pages shown in the immediate condition with the cards and grid. Then he or she is shown a series of grids and asked to select the two designs that are correct and in the same place as on the pages shown in the immediate condition.

Visual Reproduction. This subtest assesses memory for the nonverbal stimuli. A series of five designs is shown one at a time for 10 seconds. After each design is presented the examinee is asked to draw the designs from memory. The delayed condition assesses long-term visual spatial memory with free recall and recognition tasks and includes a direct copy task. First, the examinee is asked to draw the designs shown during the immediate condition from memory in any order. Second, the examinee is asked to choose which of six designs on a page matches the original design shown during the immediate condition. Third, for an optional copy task, the examined is asked to draw the designs while looking at them.

Spatial Addition. This subtest assesses visual-spatial working memory using a visual addition task. The examinee is shown sequentially two grids with blue and red circles. The examinee is then asked to add or subtract the location for the circles based on a set of rules.

Symbol Span. This subtest assesses visual working memory using novel visual stimuli. The examinee is briefly shown a series of abstract symbols on a page and then asked to select the symbols from an array of symbols, in the same order they were presented on the previous page.

Executive measures.

Wisconsin Card Sorting Test. The Wisconsin Card Sorting Test (WCST) is comprised of either 64-card or 128-card decks. The patient's task is to place the cards one by one under four stimulus cards according to a principle that the patient must deduce from the pattern of the examiner's responses to the patient's placement of the cards. Performance on the WCST can be scored in a number of ways with the computerized version being the most popular and the most widely used scores being: Categories Achieved, Perseverative Responses, and Perseverative Errors.

The WCST was developed in 1948 by Berg and has been widely employed as a test of PFC function in clinical and research since that time. It is generally agreed that the WCST assesses abstract reasoning, cognitive flexibility, and the ability to maintain and shift cognitive set according to changing reward contingencies (Damasio & Anderson, 1993; Heaton, Chelune, Talley, Kay, & Curtiss, 1993; Nagahama et al., 1996). The WCST appears to have first earned its reputation as a measure of frontal ability in the studies of Milner (1963, 1964) in which individuals with frontal lesions exhibited decreased performance. Performance on the WCST by patients with damage limited to the PFC is typically characterized by a high incidence of perseverative errors, an inability to shift set once established, and an inability to use feedback to modify response patterns (Heaton, 1981; Milner, 1963, 1995). Milner (1963) reported that the ability to shift from one mode of response to another is more often impaired by frontal lobe damage than as a consequence of temporal or occipital damage and appears to result from an inability to derive and effectively use feedback to modify response patterns. Studies have also shown that patients with other conditions have difficulty completing the WCST, noting that patients with diffuse brain damage may exhibit high levels perseveration (Robinson et al., 1980).

Category Test. The Category is a test of conceptual and spatial reasoning which consists of 208 visually presented items. There are six item sets, each organized on the basis of different principles, followed by a seventh set made up of previously shown items. The patient's task is to determine the principle presented in each set and signal the answer by indicating whether the visual stimulus infers 1, 2, 3, or 4. Total score corresponds to the number of errors across subtests. Of all the tests in the Halstead Battery, the Category Test is recognized as the most sensitive to brain damage regardless of its nature or location (Cullum & Bigler, 1986; Goldstein & Ruthven, 1983; King & Snow, 1981). The Category test was recognized by its creator as a measure of frontal ability through studies which showed poorer performances by patients with frontal injuries (Halstead, 1947). This measure also evaluates an individual's ability to visually deduce abstract categories and adjust behavior based on positive or negative feedback (Fried & Smith, 2001).

Trail Making Test. This test originated as part of the Army Individual Test (1944) as a measure of scanning, visuomotor tracking, divided attention and cognitive flexibility. It is given in two parts. In part A, the patient draws lines to connect consecutive numbered circles on a worksheet. In part B, the patient is then asked to consecutively connect numbers and letters by alternating between the two sequences. Scores are based on total time to complete task. Originally performance was based on cut-off scores which designated organic impairment (Reitan and Wolfson, 1985). This approach has since been abandoned by most practitioners and authors in favor of normative data established by Heaton's 2004 publication (Strauss, Sherman,

& Spreen, 2006). Test reliability has been shown to be adequate although with significant variability across studies (Strauss, Sherman, and Spreen, 2006). Trails A and Trails B have been shown to correlate moderately with one another, which suggests that they measure similar but different functions (Pineda and Merchan, 2003, Strauss, Sherman and Spreen, 2006). While some studies have shown that executive control plays an important role in Trails B (Arbuthnott and Frank, 2000; Kortte et al, 2002), both Part A and B require processing speed and visual acuity (Strauss, Sherman, and Spreen, 2006).

Tactual Performance Test. The Tactual Performance Tests (TPT) employs a version of the Seguin-Goddard form board, a flat wooden puzzle board into which differently-shaped blocks can be placed. Without using vision (usually a blind-fold is used) the subject must place the blocks in the board using the dominant, non-dominant, and both hands. The time to complete each of these tasks serves as a score and their sum gives the TPT-Total time (TPT-T) score. Afterward, the subject is asked to recall the shape and location of the blocks. These yield TPT-memory (TPT-M) and TPT-Localization (TPT-L) scores. Although several normative studies have been conducted, Heaton (2004) is regarded as the standard for raw score interpretation (Strauss, Sherman, & Spreen, 2006). The TPT can be administered to individuals aged 5 to 85 years. The purpose of the test is to assess tactile form recognition, incidental memory for shapes and spatial location (Strauss, Sherman, Spreen, 2006). Internal reliability scores have been shown to range from .61 to .90 in adults (Richard, 2000; Strauss, Sherman, Spreen, 2006). The TPT is considered to measure executive function because of its requirement that the examinee strategize, plan and monitor and correct self-directed responses (Fried and Smith, 2001). The TPT has also been shown to correlate with measures of nonverbal ability (Berger, 1998) and attention/ working memory (Campbell et al, 1989).

Conner's Continuous Performance Test. The Conner's' Continuous Performance Test II (CPT II) is a task-based computerized assessment of attention disorders and neurological functioning. Results from the CPT II can clarify the nature of attention deficits, quickly identifying problems with impulsiveness, activation/arousal, or vigilance. Appropriate for individuals aged 6 years and up, the CPT II presents target letters on a computer screen. The examinee's task is to press the space bar or click the mouse whenever any letter other than "X" appears. Letters are displayed for 250 milliseconds, at one, two and four second intervals. Administration time is 14 minutes. T-scores and percentile ranks are provided, in relation to both nonclinical and ADHD samples. Normative data are based on results from 2,686 subjects. Of these, 378 were diagnosed with ADHD, 223 had other neuropsychological problems, and 1,920 were classified as nonclinical. Reliability based on the standardization study showed high coefficients for the majority of variables (Strauss, Sherman, Spreen, 2006). Validity comparisons showed that the CPT-II correlates with tests of attention and executive function. Barkley et al. (2001) illustrated that the CPT-II loads on factors of Inattention and Inhibition when included in a factor analysis of multiple tests of executive function.

Procedure

Data collection. For the purposes of this study, data was derived from an archival database. Data were collected from psychological evaluations of adults referred to the Neuropsychology Assessment Center at Nova Southeastern University. All measures were administered by clinical psychology practicum students enrolled in a doctoral level program at Nova Southeastern University and under the supervision of a licensed, clinical psychologist who is a board certified Neuropsychologist. All students completed the Nova Southeastern University Collaborative Institutional Training Initiative (CITI) program. Participants were administered multiple measures, but only the WMS-IV and executive measures described above were included in analysis. Scores for the Trails B, TPT, and Category Test were obtained from the Revised Comprehensive Norms for an Expanded Halstead-Reitan Battery: Demographically Adjusted Neuropsychological Norms for African American and Caucasian Adults (HRB) (Heaton, Miller, Taylor, and Grant, 2004). T-scores and scaled scores were then converted to standardized scores to allow for comparisons across measures.

Institutional Review Board requirements. Prior to conducting analyses of the archival data, approval was obtained from the Institutional Review Board (IRB) at Nova Southeastern University. Following requirements set forth by the IRB, all data were de-identified to ensure that strict confidentiality was maintained.

Statistical Analyses. In an effort to determine the association between memory and executive function, a Principal Components Analysis was performed to determine the number of components that explain the majority of shared variance. The objectives of this analysis were to determine the pattern of associations of the selected tests of executive function and memory and to examine the results and their relation to the empirical support in the literature. It was expected that tests that measure similar constructs would cluster together representing underlying components. Before proceeding with analysis, a Barlett's Test of Sphericity and the Keiser-Meyer-Olkin (KMO) Test were conducted to determine whether the correlation of the different variables and sampling were adequate for Principal Components Analysis. A sphericity of $< .05$ and KMO $> .5$ would be deemed appropriate (Keiser, 1974; Stevens, 1992; Fields, 2000). Data was then analyzed by entering standard scores for the variables. Principal Components Analysis (PCA) was implemented to extract components. Several researchers advise utilizing a PCA as a "first pass" method for establishing how many factors there should be in a data set (Cliff, 1988;

Velicer et al., 2000; Johnson & Wichern, 2002). A PCA is a variable reduction technique that reduces the number of observed variables to a smaller number of principal components. The total variance in a PCA is equal to the number of observed variables being analyzed. The first principal component accounts for the most variance and so on in descending manner. Eigenvalues signify the amount of variance explained by each component (Franklin, Gibson, Robertson, Pohlmann, & Fralish, 1995; Fields 2000). In a PCA, one must first extract components then decide how many components to retain. A rotation is used to transform the data to make such an interpretation easier. In the present study, a Promax rotation method was employed for the PCA to allow for correlations across the components. Component loadings of approximate .50 or greater were regarded as potentially loading on the respective component (Fields, 2000). Components were retained using three approaches: a theoretically driven four-component model, Eigenvalues greater than one and parallel analysis. Utilizing these three methods allowed for greater exploration of the relationship between performances on measures of memory and executive function. The "eigenvalue greater than one rule" is regarded as a simple method that is often the default option of many statistical packages, including the one utilized for the current study (Cliff, 1988). A Parallel Analysis, Monte Carlo simulation approach, was used to determine the number of components to be retained, as it has been found to be one of the most accurate factor retention methods (Fields, 2000; Hayton, Allen & Scarpello, 2004). The percent of variance explained by each of the retained components and the commonality for each variable to determine the relative value to the created component structure was also determined (Huck, 2012). Table 3 demonstrates the hypothesized four-component structure.

Table 3

Hypothesized Component Structure

Immediate Memory	Delayed Memory	Working Memory	Executive Function
Logical Memory I	Logical Memory II	CPT-II Comm	Category Errors
VPA I	VPA II	Trails B	WCST Total Errors
VR I	VR II	Spatial Addition	WCST Per Errors
Designs I	Designs II	Symbol Span	TPT Total Score
			CPT-II Per

Note: Variables under each heading are expected to cluster together. VPA I = Verbal Paired Associates I, VPA II = Verbal Paired Associates II, VR I = Visual Reproduction I, VR II = Visual Reproduction II, CPT-II Comm = CPT-II Commissions, and CPT-II Per = CPT-II Perseverative Responses.

Table 3 illustrates the four-component structure derived from the reviewed literature. While no previous study has sought to explore the manner in which variables associated with performances on measures of memory and executive function load onto shared components, this study hypothesized that measures of memory would separate onto two components associated with Immediate and Delayed Memory. This notion was derived from the WMS-IV standardization study that showed a three-factor model comprised of Immediate, Delayed and Visual Working Memory. Studies reviewed did demonstrate a significant relation between measures of working memory and executive function. It was therefore expected that the Spatial Addition and Symbol Span subtests, which comprise the Visual Working Memory Index would load onto a third component that also featured measures of executive function which significantly assess attention and working memory. The fourth component was therefore expected to be comprised of executive function measures that assessed problem solving and concept-formation.

Chapter IV. Results

Assumptions

In order to conduct a Principal Components Analysis, the variables being evaluated must meet the following assumptions: equal variances among the variables (Sphericity) and correlations across variables (KMO). In order to test sphericity, Barlett's Test of Sphericity was conducted. It was shown to be significant $\chi^2(110) = 995.729$, $p < .01$. A significant result allows one to reject the null hypothesis that the distribution is consistent with an identity matrix in which the individual variables are unrelated. An identity matrix would be one in which the all diagonal elements are 1 and all off-diagonal elements are 0, implying that all of the variables are uncorrelated. In order to proceed with a PCA the variables pertaining to the analysis must be correlated. The KMO was 0.803, which indicated a relatively large proportion of the common variance. The KMO is a measure of sampling adequacy that compares the magnitudes of the observed correlation coefficients to the magnitudes of the partial correlation coefficients. Values for the KMO measuring greater than 0.5 indicate that a PCA of the variables is a good idea (Fields, 2000).

Descriptive statistics for all 17 variables included in the analysis are displayed on Table 4. Mean performance on measures ranged from -.14 to .11 with WMS-IV Designs II having the lowest score and Trails B: Number of seconds having the highest score. Standard deviations ranged from .10 on the WMS-IV Visual Reproduction I to 1.09 on the WMS-IV Logical Memory subtest.

Table 4

Descriptive Statistics

Variable	Mean	Standard Deviation
Category: Number of Errors	.06	.87
Trails B: Number of Seconds	.11	.92
TPT: Total Time	.08	.98
WCST: Total Number of Errors	.08	.93
WCST: Total Number of Perseverative Errors	.10	.98
CPT II: Commissions	.03	1.07
CPT II: Perseverations	.04	1.07
WMS-IV Logical Memory I	.02	1.02
WMS-IV Logical Memory II	.07	1.09
WMS-IV Verbal Paired Associates I	.10	1.01
WMS-IV Verbal Paired Associates II	.08	1.01
WMS-IV Designs I	-.06	.96
WMS-IV Designs II	-.14	.93
WMS-IV Visual Reproduction I	-.00	.10
WMS-IV Visual Reproduction II	-.01	1.00
WMS-IV Spatial Addition	.02	.94
WMS-IV Symbol Span	-.06	.93

Tables 5, 6 and 7 display the correlations among all the variables in the analysis. To facilitate interpretation, the complete correlation matrix was divided into three separate tables.

Table 5

Correlation Matrix for the Principal Components Analysis

Variables	Cat	TMT	TPT	WCSTE	WCSTP	CPTCOM
Cat		.31*	.31*	.39*	.36*	.03
TMT			.26*	.37*	.26*	-.18
TPT				.23	.20	.03
WCSTE					.86*	-.04
WCSTP						-.08
CPTCOM						

Note: Correlations are above diagonal. Cat=Category Number of Errors, TMT= Trails B Number of Seconds, TPT= TPT Total Time, WCSTE= WCST Total Number of Errors, WCSTP= WCST Total Number of Perseverative Errors, CPTCOM= CPT II Commissions, CPTPER=CPT II Perseverations, LM1= WMS-IV Logical Memory I, LM2= WMS-IV Logical Memory II, VPA1= WMS-IV Verbal Paired Associates I, VPA2= WMS-IV Verbal Paired Associates II, DES1= WMS-IV Designs I, DES2= WMS-IV Designs II, VR1= WMS-IV Visual Reproduction I, VR2= WMS-IV Visual Reproduction II, SA= WMS-IV Spatial Addition, SS= WMS-IV Symbol Span. * Correlation is significant at .01 alpha level.

Table 5 showed significant correlations except CPT II amongst all the variables Commissions (CPTCOMM). The highest correlation was between the Wisconsin Card Sort Total Number of Errors (WCSTE) and the Wisconsin Card Sort Total Number of Perseverative Errors (WCSTP). Table 6 displays the correlations among the following variables: Category: Number of Errors, Trails B: Number of Seconds, TPT: Total Time, WCST: Total Number of Errors, and

CPT II: Commissions, CPT II: Perseverations, WMS-IV Logical Memory I, WMS-IV Logical Memory II, and WMS-IV Verbal Paired Associates.

Table 6

Correlation Matrix for the Principal Components Analysis

Variables	CPTPER	LM1	LM2	VPA1	VPA2
CAT	-.22	.28*	.30*	.30*	.10
TMT	-.14	.25*	.27*	.30*	.31*
TPT	-.10	.12	.16	.20	.11
WCSTE	-.27*	-.40*	-.41*	-.44*	.37*
WCSTP	-.25*	.30*	.26*	.33*	.32*
CPTCOM	.51*	-.15	-.10	-.00	.01
CPTPER		-.28*	-.24	.20	-.15
LM1			.90*	.52*	.48*
LM2				.52*	.48*
VPA1					.75*

Note: Correlations are above diagonal. Cat=Category Number of Errors, TMT= Trails B Number of Seconds, TPT= TPT Total Time, WCSTE= WCST Total Number of Errors, WCSTP= WCST Total Number of Perseverative Errors, CPTCOM= CPT II Commissions, CPTPER=CPT II Perseverations, LM1= WMS-IV Logical Memory I, LM2= WMS-IV Logical Memory II, VPA1= WMS-IV Verbal Paired Associates I, VPA2= WMS-IV Verbal Paired Associates II, DES1= WMS-IV Designs I, DES2= WMS-IV Designs II, VR1= WMS-IV Visual Reproduction I, VR2= WMS-IV Visual Reproduction II, SA= WMS-IV Spatial Addition, SS= WMS-IV Symbol Span. * Correlation is significant at .01 alpha level.

Table 7 displays the correlations among the following variables: Category: Number of Errors, Trails B: Number of Seconds, TPT: Total Time, WCST: Total Number of Errors, and CPT II: Commissions, CPT II: Perseverations, WMS-IV Logical Memory I, WMS-IV Logical Memory II, WMS-IV Verbal Paired Associates I, WMS-IV Verbal Paired Associates II, WMS-IV Designs I, WMS-IV Designs II, WMS-IV Visual Reproduction I, WMS-IV Visual

Reproduction II, WMS-IV Spatial Addition and WMS-IV Symbol Span. Negative correlations observed between CPT II and other variables was due to higher scores denoting worse outcomes.

Table 7

Correlation Matrix for the Principal Components Analysis

Variables	DES1	DES2	VR1	VR2	SA	SS
CAT	.43*	.43*	.57*	.47*	.42*	.46*
TMT	.37*	.37*	.46*	.40*	.41*	.32*
TPT	.37*	.31*	.30*	.23*	.11*	.30*
WCSTE	.36*	.35*	.40*	.44*	.37*	.37*
WCSTP	34*	.31*	.27*	.35*	.27*	.27*
CPTCOM	-.08	.01	-.07	-.12	-.05	-.13
CPTPER	-.25*	-.21	-.16	-.26*	-.21	-.28*
LM1	.26*	.23	.36*	.40*	.37*	.44*
LM2	.30*	.31*	.35*	.43*	.38*	.46*
VPA1	.29*	.35*	.34*	.45*	.28*	.40*
VPA2	.16	.24	.32*	.45*	.24	.26*
DES1		.69*	.34*	.40*	.38*	.56*
DES2			.33*	.42*	.38*	.50*
VR1				.73	.43*	.45*
VR2					.44*	.51*
SA						.47*

Note: Correlations are above diagonal. Cat=Category Number of Errors, TMT= Trails B Number of Seconds, TPT= TPT Total Time, WCSTE= WCST Total Number of Errors, WCSTP= WCST Total Number of Perseverative Errors, CPTCOM= CPT II Commissions, CPTPER=CPT II Perseverations, LM1= WMS-IV Logical Memory I, LM2= WMS-IV Logical Memory II, VPA1= WMS-IV Verbal Paired Associates I, VPA2= WMS-IV Verbal Paired Associates II, DES1= WMS-IV Designs I, DES2= WMS-IV Designs II, VR1= WMS-IV Visual Reproduction I, VR2= WMS-IV Visual Reproduction II, SA= WMS-IV Spatial Addition, SS= WMS-IV Symbol Span. * Correlation is significant at .01 alpha level.

Data Analysis

It was hypothesized that Principal Components Analysis of executive and memory measures would yield four correlated components, with two components reflecting facets of memory function and the other two components reflecting facets of executive function. The first proposed memory component would be associated with organization and encoding and comprised of the following variables: WMS-IV Logical Memory I, Verbal Paired Associates I, Visual Reproduction I, and WMS-IV Designs I. The second proposed memory component would be associated with retention and retrieval and be comprised of the following variables: WMS-IV Logical Memory II, Verbal Paired Associates II, Visual Reproduction II, and WMS-IV Designs II. The first proposed executive function component would be associated with working memory and attention and be comprised of the following variables: CPT Commissions, CPT Perseverations, Trails B, WMS-IV Spatial Addition, and WMS-IV Symbol Span. The second proposed executive function component would be associated with problem solving and concept-formation and would be comprised of the following variables: Category total errors, WCST Total Errors, WCST Perseverative Errors, and TPT Total Score. A Principal Component Analysis was ran using SPSS to determine the number of dimensions.

Model One. Component extraction was done by selecting four components based on the hypothesized four-component model. Table 8 shows the Eigenvalues obtained from the Principal Component Analysis. Component loadings are interpreted as correlations between variables and components. In this four-component model the total variance accounted for by the components retained was 63.51, with component one accounting for 38%, component two accounting for 10%, component three accounting for 9%, and component four accounting for 7%. Five components were shown to have Eigenvalues that exceed one.

Table 8

Eigen Values

		Principal Component Analysis	
Component	Total	% Variance	Total % Variance
1	6.37*	37.50	37.50
2	1.72*	10.13	48.62
3	1.47*	8.66	56.28
4	1.23*	7.23	63.51
5	1.01	5.95	69.46
6	.90	5.27	74.73
7	.82	4.83	79.55
8	.71	4.19	83.74
9	.54	3.18	86.92
10	.50	2.94	89.85
11	.42	2.45	92.31
12	.38	2.26	94.56
13	.29	1.17	96.28
14	.22	1.29	97.58
15	.21	1.22	98.79
16	.13	.74	99.53
17	.01	.47	100.00

Table 9 shows the structure matrix for the four-component model based on the hypothesized component loadings. Reliability index was also provided for each individual component. Cronbach's alpha, which is a coefficient of reliability derived as the as a function of the number of tests and average intercorrelation among the items, was calculated for each component. Component 4 had the highest reliability at .926.

Table 9

Component Loading Matrix for 4 Component Model

Variable	Visual Processing	Verbal Processing	Problem Solving	Attention
Reliability (α)	.833	.818	.766	.926
Cat	.733			
TMT	.598			
TPT: Total Time	.509			
WCSTE	.518	.497	.918	
WCSTP	.416		.952	
CPTCOM				.860
CPTPER				.825
LM1	.418	.856		
LM2	.463	.855		
VPA I	.431	.799	.424	
VPA II		.794		
DES I	.763			
DES II	.739			
VR I	.723	.497		
VR II	.716	.606		
SA	.638	.454		
SS	.746	.506		

Note: Cat=Category Number of Errors, TMT= Trails B Number of Seconds, TPT= TPT Total Time, WCSTE= WCST Total Number of Errors, WCSTP= WCST Total Number of Perseverative Errors, CPTCOM= CPT II Commissions, CPTPER=CPT II Perseverations, LM1= WMS-IV Logical Memory I, LM2= WMS-IV Logical Memory II, VPA1= WMS-IV Verbal Paired Associates I, VPA2= WMS-IV Verbal Paired Associates II, DES1= WMS-IV Designs I, DES2= WMS-IV Designs II, VR1= WMS-IV Visual Reproduction I, VR2= WMS-IV Visual Reproduction II, SA= WMS-IV Spatial Addition, SS= WMS-IV Symbol Span. All values less than .40 were omitted. α= standardized Cronbach's alpha.

Component one was associated with Visual Processing and was comprised of the following variables: Category Number of Errors, Trails B Number of seconds, TPT Total Time, WMS-IV Designs I, WMS-IV Designs II, WMS-IV Visual Reproduction I, WMS-IV Visual Reproduction

II, WMS-IV Spatial Addition, and WMS-IV Symbol Span. Component two was associated with Verbal Processing and was comprised of the following variables: WMS-IV Logical Memory I, WMS-IV Logical Memory II, WMS-IV Verbal Paired Associates I, and WMS-IV Verbal Paired Associates II. Component three was associated with Problem Solving and Concept Formation and was comprised of the WCST Total Number of Errors and Total Number of Perseverative Errors. Component five was associated with Sustained Attention and was comprised of the CPT-II Commissions and Perseverations. Ultimately, the four components retained from the analysis failed to match the hypothesized four-component structure.

Model Two. As the hypothesized component structure was not confirmed, a Monte Carlo Simulation was performed to confirm how many components to retain independent of the hypothesis. The MonteCarlo PA exe. program was utilized to run the parallel analysis. Monte Carlo PCA for Parallel Analysis (PA) is an application that computes Parallel Analysis criteria (eigenvalues) by performing a Monte Carlo simulation by processing the specified parameters. The program is designed to speed up the calculations required for generating the values for a parallel analysis. The Monte Carlo method is widely used in statistics and other exact sciences in order to determine the probability of a certain event. It is based on performing multiple experiments and calculating the probability distribution based on the results. This program is available free online. In order to run the analysis the program requires that one input the number of variables in the analysis and how many iterations to run. For the purpose of this analysis, 17 variables were inputted and 1000 iterations were selected (Watkins, 2008). A component was retained using the Parallel Analysis when the Eigenvalue obtained from the Principal Component Analysis exceeded the corresponding Random Eigenvalue obtained from the Monte Carlo Simulation.

Table 10

Eigen Values

	Principal Component Analysis		Monte Carlo Simulation
Component	Total	% Variance	Random Eigenvalue
1	**6.37***	37.50	1.75
2	**1.72***	10.13	1.59
3	**1.47***	8.66	1.46
4	**1.23**	7.23	1.36
5	**1.01**	5.95	1.27
6	.90	5.27	1.18
7	.82	4.83	1.10
8	.71	4.19	1.02
9	.54	3.18	.95
10	.50	2.94	.90
11	.42	2.45	.82
12	.38	2.26	.76
13	.29	1.17	.70
14	.22	1.29	.63
15	.21	1.22	.57
16	.13	.74	.50
17	.01	.47	.43

Note: * represents a component that was retained based on an Eigenvalue greater than the corresponding Eigenvalue obtained from Monte Carlo Simulation. **Bold** components that were retained based on an Eigenvalue greater than 1.

For the purpose of this study it was decided to also select components to be retained based on the default method of selecting components with Eigenvalues greater than one. Such an approach would allow for greater exploration for the underlying component structure and comparisons between the two models obtained. Table 10 shows the Eigen Values obtained from the Principal Component Analysis and the Random Eigenvalues obtained from the Monte Carlo Simulation. Component loadings are interpreted as correlations between variables and components.

As shown on Table 10, the random Eigenvalues obtained from the parallel analysis did not support the hypothesized four-component model. Three components were retained since their respective Eigenvalues were larger than the 95^{th} percentile of the distribution derived from the Monte Carlo simulation. Components were therefore retained if the Eigenvalue determined from the SPSS output were larger than the ones randomly derived from the parallel analysis. Table 11 shows the structure matrix for a three component model based on the Monte Carlo simulation.

Component one was associated with Visual Processing and consisted of the following variables: Category Number of Errors, Trails B Number of Seconds, TPT Total Time, WCST Total Number of Errors, WCST Total Number of Perseverative Errors, WMS-IV Designs I, WMS-IV Designs II, WMS-IV Visual Reproduction I, WMS-IV Visual Reproduction II, WMS-IV Spatial Addition, and WMS-IV Symbol Span. Component two was associated with Verbal Processing and was comprised of the following variables: WMS-IV Logical Memory I, WMS-IV Logical Memory II, WMS-IV Verbal Paired Associates I, and Verbal Paired Associates II. Component three was associated with Sustained Attention and was comprised of the Conner's CPT commissions and CPT perseveration. Fifty-six percent of the variance was explained by the three component model with 37% accounted for by the first component, 10% accounted for by the second component and 9% accounted for by the third component.

Table 11

Component Loading Matrix for 3 Component Model

Variable	Visual Processing	Verbal Processing	Attention
Reliability (α)	.842	.833	.549
Category: Number of Errors	.734		
Trails B: Number of Seconds	.601		
TPT: Total Time	.518		
WCST: Total Errors	.623	.618	
WCST: Total Perseverative Errors	.539	.490	
CPT II: Commissions			.852
CPT II: Perseverations			.836
WMS-IV Logical Memory I		.830	
WMS-IV Logical Memory II	.440	.826	
WMS-IV Verbal Paired Associates I	.448	.813	
WMS-IV Verbal Paired Associates II		.808	
WMS-IV Designs I	.762		
WMS-IV Designs II	.738		
WMS-IV Visual Reproduction I	.704	.490	
WMS-IV Visual Reproduction II	.708	.607	
WMS-IV Spatial Addition	.619	.445	
WMS-IV Symbol Span	.716	.488	

Note: All values less than .50 were omitted. α= standardized Cronbach's alpha.

The main difference between the hypothesized four-component model and the three-component PA model, was the inclusion of the WCST Total Number of Errors and Total

Number of Perseverative Errors variables into the Visual Processing component, therefore eliminating the Problem Solving/ Concept Formation component. While the highest loading for these two variables was on factor one, they both had high cross-loadings on factor two, which made it difficult to discern their true loading.

Table 12 displays the component correlations for the three-component PA model. The components associated with this model were associated with verbal and visual processing and attention.

Table 12

Component Correlation Matrix for 3 Component Model

Components	1	2	3
1	1.00	.54	-.27
2	.54	1.00	-.26
3	-.27	.26	1.00

Components one and two had the highest direct correlation. Components one and three were shown to be inversely correlated. As shown in Tables 5 through 7, the CPT-II Commissions and Perseverations variables had negative correlations with the other variables. It would therefore be expected that these two variables isolate onto their own component but that this component would also be inversely correlated with the other components retained.

Model Three. Table 13 shows the structure matrix for a five-component default model. Component loadings lower than .5 were suppressed.

Table 13

Component Loading Matrix for 5 Component Model

Variable	Verbal	Perceptual	Spatial	Problem	Attention
Reliability (α)	.833	.818	.766	.926	.549
Cat		.722	.574		
TMT		.626	.436		
TPT: Total Time			.610		
WCSTE	.485	.511	.421	.926	
WCSTP				.953	
CPTCOM					.857
CPTPER					.827
LM I	.862	.454			
LM II	.867	.470			
VPA I	.816	.420		.428	
VPA II	.797			.407	
DES I		.489	.874		
DES II		.489	.834		
VR I	.407	.883			
VR II	.539	.830	.445		
SA	.405	.692	.442		
SS	.514	.623	.715		

Note: Verbal=Verbal Processing, Perceptual=Perceptual Reasoning, Spatial=Spatial Organization, Problem=Problem Solving, Cat=Category Number of Errors, TMT= Trails B Number of Seconds, TPT= TPT Total Time, WCSTE= WCST Total Number of Errors, WCSTP= WCST Total Number of Perseverative Errors, CPTCOM= CPT II Commissions, CPTPER=CPT II Perseverations, LM1= WMS-IV Logical Memory I, LM2= WMS-IV Logical Memory II, VPA1= WMS-IV Verbal Paired Associates I, VPA2= WMS-IV Verbal Paired Associates II, DES1= WMS-IV Designs I, DES2= WMS-IV Designs II, VR1= WMS-IV Visual Reproduction I, VR2= WMS-IV Visual Reproduction II, SA= WMS-IV Spatial Addition, SS= WMS-IV Symbol Span. All values less than .40 were omitted. α= standardized Cronbach's alpha.

While multiple variables had cross-loadings only the highest loadings were interpreted. Component 1 was regarded to assess verbal processing. Component 2 was associated with visual/perceptual reasoning. Component 3 was associated with spatial organization. Component 4 pertained to problem solving. Component 5 was associated with sustained attention.

Component one was associated with Verbal Processing/Memory and consisted of: WMS-IV Logical Memory I, WMS-IV Logical Memory II, WMS-IV Verbal Paired Associates I, and Verbal Paired Associates II. Component two was associated with Visual Reasoning and consisted of: Category Number of Errors, Trails B Number of Seconds, WMS-IV Visual Reproduction I, WMS-IV Visual Reproduction II, and WMS-IV Spatial Addition. Component three was associated with Spatial Organization and consisted of: WMS-IV Designs I, WMS-IV Designs II, TPT Total Time, and WMS-IV Symbol Span. Component four was associated with Problem Solving and consisted of: WCST Total Number of Errors and WCST Total Number of Perseverative Errors. Component five was associated with Sustained Attention and consisted of Conners CPT commissions and CPT perseveration. Sixty-nine percent of the variance was explained by the five component model with component one accounting for 38%, component two accounting for 10%, component three accounting for 9%, component four accounting for 7% and component five accounting for 6%. Standardized Cronbach's alpha was calculated for all components in both models to determine internal consistency. While the majority of components exhibited good internal consistency (i.e. alpha > .70), component 3 in model one and component 5 in model two attained an alpha of .549 which falls in the poor range (Fields, 2000).

In comparison to the other models, the five-component model had significant cross loadings, which may it difficult to discern the true meaning of the loadings. Specifically, the Symbol Span subtest of the WMS-IV had significant cross loadings on components one, two and three, which made it difficult to discern its true loading and meaning. Table 14 displays the correlations among the components for model 2.

Table 14

Component Correlation Matrix for 5 Component Model

Component	1	2	3	4	5
1	1.00	.52	.39	.37	-.24
2	.52	1.00	.59	.40	-.24
3	.39	.59	1.00	.35	-.23
4	.37	.40	.35	1.00	-.10
5	-.24	-.24	-.23	-.10	1.00

Similar to the correlations observed on Table 12, component five, which was comprised of the CPT-II Commissions and Perseverations, was inversely correlated with the other components. The inverse correlation of component five is consistent with the other models and expected based on the correlations amongst the variables included in the analysis.

Chapter V: Discussion

The current study sought to investigate the relationship between executive function and memory through exploration of the combined component structure among established measurements of cognitive function. It was hypothesized that the 17 variables utilized in the data analysis would load onto four correlated components, representing the following abilities: Concept Organization/Encoding, Retention/Retrieval, Working Memory/Attention, and Concept Formation/Perseveration.

Four Component Model

The hypothesized four-component model was not supported. Measurements associated with immediate and delayed memory did not load onto separate components as predicted but, instead, grouped onto components associated with visual and verbal processing regardless of whether the measurement was pertaining to immediate or delayed recall. Visual tasks associated with attention and problem solving (Trail Making Test, Tactual performance Test and Category) did not load onto the predicted components as expected either, grouping instead onto the component associated with visual processing. The WCST: Total Number Perseverative Errors and CPT-II Perseveration variables failed to load onto the same components as predicted with the WCST: Total Number of Perseverative Error variable loading onto a component consisting of the WCST: Total Number of Errors variable. The CPT-II Perseverations variable grouped onto a component consisting of the CPT-II Commissions variable.

Analysis of the four-component model demonstrated that the notion that memory tasks measure a unique ability separate from associative sensory perception (i.e. visual and verbal processing) was not upheld. Contrary to research and the hypothesized component structure, visual and verbal memory tasks share more commonalities with measures of visual and verbal processing than they do with memory assessment. Therefore, abilities such as encoding and retention appear to be secondary. The results also demonstrated that established measures of executive function such as the Trail Making Test, Category, and Tactual Performance Task share more in common with visual tasks of memory than they do with novel problem solving (WCST) and sustained attention (CPT).

Analysis of the Four-Component was consistent with the notion of functional systems interacting with one another in a hierarchical manner as posited by A.R. Luria. According to Luria, the brain is organized hierarchically with functional systems interacting through primary, secondary, and tertiary units. As the results demonstrated, component loadings by distinct variables of cognitive function shared more commonalities with aspects of the underlying systems than they did with specialized or localized function.

Components 1 and 2 illustrated that aspects of the second functional system, which receives, analyzes and stores sensory input, are more prominent than whether these measures when assessing memory or executive function. Transition or encoding of sensory information requires integrity of the higher secondary and tertiary zones. When lesion(s) or dysfunction are present, the intended focus of these measurement tools are collapsed from more higher-order functions such as memory to the association aspects of visual and verbal functioning.

Component 3 demonstrated that the WCST may indeed be a measure of executive function as it did not load on to Components 1 or 2 which are, respectively, related to visual and verbal association. The WCST Total Number of Errors and Total Number of Perseverative Errors are therefore considered to be more indicative of the third functional system posited by Luria, which is responsible for programing, regulation and verification of behavior, essentially the executive aspect of cognitive function. Component 4 was comprised of the CPT-II

Commissions and Perseverations. Consistent with Luria's theory, the CPT is regarded as a measurement of sustained attention and impulsivity, abilities that are consistent with the first functional system. Even though the CPT is a visual task that requires both motor ability and memory, its most salient feature was consistent with regulating wakefulness (i.e., sustaining attention).

Cognitive function in real life is a more integrative ability with many interrelated aspects. Evaluations should seek to assess functional aspects of cognitive function rather than focusing on isolated components such as memory and executive function. Specificity and localization are relevant in determining etiology but hold little weight in accounting for underlying function. Consistent with Lurian theory, cognitive function is the result of complex functional systems.

The combined component structure also demonstrated that there was much redundancy with the tests evaluated in this study. A more efficient system for evaluating deficit and function may therefore incorporate shorter batteries based of the measures that had the highest loadings on each component. Design I had the highest loading on Component 1. Logical Memory I had the highest loading on Component 2. WCST Perseverative Errors had the highest loading on Component 3. CPT-II Commissions had the highest loading on Component 4. It should be noted that for Components 1 and 2, the subtests that loaded the highest were measurements of Immediate Memory.

Immediate Memory for both verbal and nonverbal information, consists of proper arousal, focused attention, sensory perception, organization, association, and retrieval of learned information. The abilities evaluated by tasks of Immediate Memory may therefore be the most indicative of the association areas of the brain where input from multiple sensory areas are integrated. Immediate Memory is also often regarded as the encoding stage of memory.

Because Trails, Category, and TPT did not uniquely measure executive function they could be omitted from a battery. WCST uniquely loaded on another component that may or may not be more indicative of executive function. Fewer tests may therefore be more efficient. No neuropsychological measure assesses a specific function or ability. Instead, these measurements assess multiple areas of function, such as the Visual Reproduction II subtest of the WMS-IV, which measures visual perception and processing, construction ability, motor ability, visual/spatial ability, retention and retrieval. Functional analysis of performance through multiple comparisons among tests is important. Proper care should be taken when constructing a battery to account for different components assessed in any particular measure.

Tests scores remain an important part of analysis, but should be interpreted in a more integrative manner to account for aspects of cross-modality. As the data analysis demonstrated, performance on measures pertaining to a specific modality (visual versus verbal processing) accounted for more of the basic aspects of sensory perception than they did for higher order areas of function such as memory or executive function. Scores on a particular test should therefore carry less weight in the determination of deficit and weakness.

These findings should not be interpreted as discounting the presence of memory and/or executive deficits but should alert clinicians to be more cautious when making such determinations. It is often seen in practice, that a clinician will make a determination regarding a patient's status based on the outcome of a brief or simple, fixed battery and allude to specific scores as validation for the presence or lack of a disorder or impairment. Particular notice should be given for neuropsychological practices that are solely based on the administration of screeners and short batteries. Also with the advent of more computerized and portable measures, which are constructed to be brief, misinterpretation may become rampant if not controlled for.

In regards to diagnosis, deficits that are ascribed to be solely related to memory loss would have aspects of visual and verbal processing ingrained. This would be paramount to cognitive remediation and intervention. As research has shown, most cognitive rehabilitation models show poor outcomes with minimal generalization. By incorporating a more integrative approach to intervention, more meaningful intervention can be established leading to, ideally, more efficacious outcomes. Accepted rehabilitation practices such compensatory and restorative intervention will have to activate all memory and processing components rather than focus exclusively on one identified deficit. Target should be underlying ability such as visual and verbal processing rather than memory, executive function, etc. Results from the current study suggested that performance is product of the brain as a whole.

The measurements analyzed in this study failed to make an adequate distinction between visual processing, encoding and retention. Because our brains work in an integrative manner previous or associated information is attached to novel information. To tease apart learning and memory from processing, tests should incorporate stimuli that deviate from established knowledge such as nonsensical terms for verbal information. Visual and verbal tests of memory should also mirror one another more closely in design in order to evaluate whether context or modality is responsible for performance.

Executive function is the brain's ability to coordinate function. It is mental efficiency, organization, and shifting as it pertains to visual/ verbal processing and memory. Commonalities are therefore embedded. Memory is intrinsically an aspect of tests such as Trails (memory for alphabet and numbers, memory for instruction), Category (recognition of shapes, memory for rules), TPT (recognition of shapes, memory for location and designs), and WCST (memory for strategy used and outcome of previous trials).

Three Component Model

The three-component model determined by the Monte Carlo simulation resulted in a similar structure to the four-component model with the exception that Components 1 (visual processing) and 3 (concept formation) were collapsed into one component. While the variables that pertained to Component 3 in the four-component model were shown to assess a unique function that was equated with concept formation and the third functional system posited by Luria, this distinction was lost when the variables were collapsed into three components. The WCST is considered to be a hallmark measure of executive function that requires the individual to organize, strategize and form concepts, the information presented is visually perceived and processed by the secondary and tertiary association areas of the brain as well. Hierarchical and systematic processing of the brain would support the notion that executive function is an ability that requires, and is dependent on, more basic perception and association. When forced to group onto three rather than four components, the visual processing/association aspects of the task became most prominent. It should be noted that the variables WCST Total Number of Errors and Total Number of Perseverative Errors did have high co-loadings on Component 2, which is secondary to verbal strategies being implemented when completing the task. This further supports the notion that the variables pertaining to the WCST assess a tertiary function that cannot neatly be collapsed onto primary and secondary perceptual aspects.

The variables that loaded onto Components 2 and 3 did not shift because, at a primary and secondary level, they are assessing unique aspects of brain function that separate from the variables which loaded onto Component 1. The tasks that pertained to Component 2 were auditory; therefore, primary perception and secondary association were able to separate from those of the tasks in Component 1, which are visually processed. It is expected that if a Two

Component model would have been evaluated, that Component 2 would have collapsed into Component 1 because both correspond to the second functional system asserted by Luria. This would supplant modality of perception.

Component 3, which was comprised of the CPT-II Commissions and Perseverations, remained a distinct component. This validated the notion that, while it is a task that is visually perceived, its main components are not of perception and association but of arousal and alertness, making it a good tool for assessing attention.

The Three-Component Model affirmed the notion that Immediate and Delayed memory as measured by the subtests of the WMS-IV were not distinct abilities as demonstrated by the variable loadings. Similar to the Four-Component model, tasks of visual Immediate and Delayed memory grouped onto Component 1, which was associated with visual perception, processing and association. Tasks of verbal Immediate and Delayed memory grouped onto Component 2.

The grouping of the variables assessing memory function onto their respective components, indicated that memory is an associative process within the brain. The organized process of recall is based on a complete system of concertedly working systems in the cortex and adjacent structures. Each of these systems makes its own specific contribution to the organization of the memory processes. Destruction or a pathological state of any one of these systems may lead to a memory disturbance that will vary depending on which brain system is affected. Results from the Principal Components Analysis indicated that the sensory system associated with the input will become more prominent (i.e. visual memory reduced to visual processing and verbal memory reduced to verbal processing).

The transition from the sensory stage of perception and imprinting of information to the more complex stages of its coding into organized systems of categories, requires integrity of the highest secondary and tertiary cortical zones, some of which are concerned with the synthesis of incoming stimuli into successive or simultaneous structures, while others are concerned with the organization of these stimuli (Luria, 1973). In a clinical sample such organization will be more pronounced due to the underlying pathology. Such was the case in the sample utilized for this study. Even though there was variability in regards to diagnosis and clinical presentation, all the participants had a history of psychiatric and/or neurological diagnosis.

Memory deficits and short-term memory loss are among the most common symptoms reported when there is pathology. This would be due to the assertion that memory is a tertiary, systematic function that requires greater association and integration of sensory input. Any deficits within the system would impact memory to a certain extent prior to affecting a less associated function. Because of the decreased capacity, sensory aspects pertaining to the memory system take on a greater role.

Along with confirming the lack of distinction between tasks of memory function and visual processing, the Three-Component model also supported the Four-Component model finding that tasks of Immediate and Delayed Memory loaded on the same component depending on modality of perception. When one is wishing to recall a certain item of information that person exhibits a certain recall strategy, choosing the necessary means, distinguishing the important and inhibiting the unimportant signs, selecting depending on the purpose of the task, the sensory or logical components of the imprinted material and fitting them into appropriate systems. This approach approximates the process of recall to a complex and active investigative activity, it enables one to use the activities of language and to some provides the link between short-term and long-term memory (Luria, 1967). Immediate Memory is often regarded as the process of organizing and encoding information, and Delayed Memory corresponds to retention and retrieval. Deficits in one or both of these abilities often signify to a practitioner a particular deficit. Similar to aspects of general memory, this distinction was lost when the variables were loaded onto three and four components. While the findings do not dispute the presence of distinct deficits, aspects pertaining to modality specific processing and association become more prominent when pathology is present. Clinically, a localized view of brain function has been discounted in place of a systemic distribution of ability that relies on areas of the brain working in a hierarchical manner.

Contrary to the assertion made when analyzing the Four-Component model, a short battery comprised of the tasks that loaded highest on each component would not be suggested. Such a battery would result in confounding and erroneous information because the meaning regarding the component loadings would be diluted. The highest component loading would therefore not be representative of the underlying component. Also, the three highest component loadings would fail to account for executive function, which is of particular interest and importance when conducting a neuropsychological examination. In regards to clinical practice, consideration should be given to the brevity of cognitive screeners. While the redundant aspects of a long, comprehensive battery may result in inefficient practices that yield greater pathology, short screeners may in-turn fail to identify pathology when present or completely overlook specific areas of function.

Even though the Monte Carlo simulation statistically supported the Three Component model, the component loadings appeared to artificially group the variables pertaining to the WCST, which resulted in a loss of sensitivity for executive function and decreased specificity for visual and verbal processing. The Three Component model was therefore regarded as being theoretically incompatible and clinically impractical.

Five Component Model

The five-component model determined by Eigenvalues greater than one also had a similar structure to the four-component with the exception that the variables that loaded onto the Visual Processing Component (Component 1) in the four-component model now loaded onto two separate components resulting the five-component structure (Component 2 & Component 3). Similar to the three-component model, variables associated with verbal processing and attention did not load onto new component with the respective components observed in the four and three component models retaining their structures. The component associated with Problem Solving in the four-component model also retained its structure.

The Visual Processing component was partitioned into a Visual Reasoning and Spatial Organization. The variables that loaded onto the Visual Reasoning component required visual comprehension and construction but minimal spatial processing. In contrast, the variables that loaded onto the Spatial Organization component required significant visual-spatial abilities such as sequencing and mental rotation. In clinical and research practices, nonverbal abilities are often grouped together as visual-spatial abilities. Based on the current findings, such practices may be diluting our understanding of human perception, performance, and deficit.

Secondary zones of the cortex show a distinct cytoarchitecture in the brain and are regarded as being the locations responsible for the conversion of incoming stimuli into functional organization. Tertiary cortical zones within the posterior regions of the brain that lie where secondary projections from multiple modalities overlap give rise to complex synthesis from multiple modalities resulting in one's ability to visual process information and spatially relate its components. Such processes are therefore the product of association between secondary areas temporal, parietal and occipital lobes wherein vestibular and visual perception may result in spatial understanding. Memory can be encoded with spatial components ingrained as well as more integrative visual organization. This supports the finding that when the variables loaded onto five components, spatial aspects within the variables were teased apart before aspects of immediate versus delayed memory.

Such a finding further supports the assertion that memory is a systemic and integrative ability which depends on multiple areas of the brain working in concert. The role of verbal and visual processing as well as concept-formation, attention and spatial integration must be considered in order to truly assess an individual's memory function. The respective loadings of the variables also indicate that the underlying modality/process aspects of memory have greater significance than is currently espoused in neuropsychological practice and investigation. Memory components are not merely present within a visual/verbal distinction but within those processes such as spatial organization. Finally, the distinction between immediate and delayed memory was not significant based on the loading of the variables. This was consistent with the findings in the four and three-component models.

While a battery comprised of the highest component loadings (i.e. Logical Memory II, Visual Reproduction I, Designs I, WSCT Perseverative Errors & CPT II: Commissions) may not be functional, because of immediate and delayed recall trials, the findings indicated that a battery assessing for verbal processing, visual reasoning, spatial organization, problem solving and sustained attention may be the most efficient. Story and design comprehension as assessed Logical Memory I, Visual Reproduction I and Design I would be adequate measures of verbal and visual processing with the aforementioned variables of the WCST and CPT being incorporated.

General Discussion

The current exploratory study demonstrated that the relationship between executive function and memory is secondary to aspects of visual and verbal processing. The brain operates in a systematic manner, in which primary, secondary and tertiary areas of the brain are in constant communication and interaction. Memory and executive function are therefore qualities that are dependent upon the direct and associative aspects of sensory input with sustained attention appearing to be unique from other cognitive faculties. While all the models evaluated in this study provided useful information, the four-component model illustrated these aspects the clearest and represented the data analyzed in the most logical manner to facilitate clinical interpretations.

All of the models evaluated in this study demonstrated that aspects of memory were less salient than modality specific components, as evidenced by variables associated with memory loading onto components associated with visual and verbal processing. This distinction persisted across the four-, three- and five-component models. This finding elucidated how memory is a systematic ability resulting from the integration of multiple components or capacities across the brain, which supports the notion of a functional systems distribution of the brain posited by A.R. Luria. In a clinical sample, such as the one utilized for this study, the distinction of memory is lost to primary and secondary aspects of processing, i.e. visual/verbal function and attention. Because these primary and secondary processes exhibit cognitive priority, variables associated with Immediate and Delayed memory would therefore not be expected to factor onto the same respective components as observed in the models evaluated. This disputes the notion that unique aspects of brain function are measured when assessing a clinical sample. For example, when evaluating patients who present with visual and/or verbal deficits as well as memory impairments, memory tasks may erroneously characterize such individuals as having memory impairment when the deficits are better accounted for by impairments in their visual and/or verbal processing. Diagnoses that are associated with diffuse cognitive impairments, such as traumatic brain injury and psychiatric presentation, are also expected to result in such presentations. This is because impairments in visual and verbal processing have more gross impact on cognitive function because, through the association of their sensory input, we are able to attain secondary and tertiary function. This is an aspect that was supported by all models involved in the analysis. Furthermore the findings support the two-component model evaluated during the standardization of the WMS-IV, which grouped the variables onto components associated with visual and verbal memory, as opposed to immediate and delayed recall therefore allocating greater weight to the underlying sensory processing.

Immediate memory (IM) is often regarded as an individual's capacity to organize and encode information. Poor performance on measures associated with IM are interpreted to indicate that the individual being assessed may have an attention, executive or motivational difficulty. Conversely, the current findings did not support such an assertion, as indicated by tasks associated with IM failing to load onto the components that were associated with executive function and attention. Therefore, caution is suggested when interpreting poor performance on measures of memory as indicating memory or attention impairment. The results also demonstrated how examiners should also be cautious when interpreting poor performance on measures of executive function.

The four-component model demonstrated that variables of the WSCT most accurately measured executive function, an aspect that was superficially diluted by the three-component model and is often poorly described and understood by clinicians and researchers alike. Often times, tasks such the Trail Making Test, Tactual Performance Task, and the Category are referred to as measures of executive function as well as attention and processing. The four-component demonstrated that while these tasks evaluate aspects of executive function, the concepts that are primarily measured pertain to visual processing.

Research has shown that tasks of executive function may load onto multiple factors (Shute and Huertas, 1990; Robbins and colleagues, 1998; Pineda and Merchan, 2003), particularly in a clinical sample (Tests, Bennett, and Ponsford, 2012), demonstrating inconsistency in what is being regarded as executive function. In the current study tasks associated with executive function, except WCST, did not load onto a unique component but instead presented similar to variables associated with memory, loading onto components associated with visual processing. It should be noted that all the measures of executive function included in this study relied on visual perception rather than verbal. Similar to memory, executive function is a higher order function, which is dependent on the association between primary and secondary areas of the brain. In the clinical sample evaluated in this study, the distinction for executive function was lost except for tasks of the WCST. This finding both supports Lurian functional systems of cognitive function as well as elucidates how most tasks that are regarded as assessing executive function may be simply assessing the underlying primary and/or secondary aspects of cognitive function.

The variables pertaining to the CPT-II were shown to load onto a unique variable in all of the models evaluated in this study. While all psychological measures have attention as a prerequisite, the CPT-II is unique in that it measures vigilance, sustained attention, and focus. Often times in clinical practice and research performance on other measures such as the Trail Making Test are interpreted in regards to examinee's capacity for attention.

The literature is variable when assigning whether a measurement tool is evaluating attention, working memory and/or executive function with abilities such as switching, inhibition, and divided attention being classified as both executive function and attention. Working memory and immediate memory are also held to be largely attention based which is misleading by their names and classification. Similar to the distinction observed with the WCST's ability to measure a unique capacity in the four-and five-component models, the CPT-II was shown to have an even greater property of assessing a unique ability separate from all other measurement tools in this study.

When the five-component model was compared to the three- and four-component models, a distinction was shown to be present between visual variables that required greater spatial organization and those that did not. Respectively, measures of immediate and delayed memory were partitioned based on aspects of spatial organization being present. Visual tasks are often grouped together as being visual-spatial. Courtney, Ungerleider, Keil, & Haxby (1996) showed how the neural systems pertaining to object and spatial working memory are functionally segregated with different areas of the frontal lobes activated during Positron Emission Topography (PET) scans. The findings in the current study expanded on what was posited by Courtney et al (1996) by demonstrating that while the distinction between object and spatial perception is important in regards to our understanding of executive function, it also plays a vital role in memory integration. Even though the five-component model elucidated the notion that uniting visual processing and spatial perception into the aggregate concept of visual-spatial ability may be erroneous, the loadings of the variables was not theoretically sensible. Logical Memory II was shown to have the highest loading on the verbal processing component and Symbol Span had comparable co-loadings on Components 2 and 3, providing an inaccurate account. Still, clinicians should be attentive to the distinction between visual and spatial function when evaluating patients and diagnosing impairments. This distinction should also be incorporated when constructing and interpreting neuropsychological batteries.

Whether one utilizes a fixed or flexible battery, test selection is always an integral factor when evaluating a patient. Findings from the current study support a briefer and efficient battery comprised of fewer tests based on their propensity to measure a specific factor. The three-, four-, five-component models demonstrated that there is much redundancy within components. Reducing the amount of tools incorporated in a battery may lower the 'noise' present in current practices and provide efficient means for assessing an individual and arriving at a diagnosis. With so much overlap between assessment tools, diagnosing memory, attention and executive dysfunction appears to be a challenging undertaking, especially if impairments in visual and/or verbal processing are misconstrued as memory or attention impairments. Conclusively, while understanding the relationship between different cognitive abilities is intrinsically rewarding, the ultimate goal is to determine how these findings can improve the quality of human life. Cognitive rehabilitation has often relied on having a patient achieve proficiency on a task associated with a particular brain function. While the integration of restorative and compensatory strategies has been a significant progress in the field, practitioners and patients are often left with the dilemma of how to attain ecological relevance and generalization to daily living. The findings from the current study suggest that while rehabilitation that utilizes strategies to improve memory and executive function should not be dismissed, a successful rehabilitation and treatment program should incorporate, or perhaps emphasize, the underlying primary and secondary functions which are modality specific but significantly affect memory and executive function. Failing to do so would provide incomplete intervention that may not generalize or persist.

With such great variability in the research and practice of neuropsychology, studies such as the current one seek to explore and expand on the observable components that are interpreted to be objective, but often receive varying subjective interpretations reducing the application and ecological validity of such findings. This study supports research that has shown that the entire brain is devoted to what are denoted as specific abilities, such as memory (Baddeley, Kopelman, Wilson, 2002) with learning via experience producing a relatively permanent change in neuronal performance. Executive function therefore interacts with memory in a bidirectional manner that is dependent on general health and status of the brain. Our bodies, and in this case our brains, are systematic and integrative. Their complexity is a function of localized components communicating with one another in constant and nonlinear fashion. When reduced to its components, the observer sees cells, chemicals, and voltages and often misses the complexity present in its emergent qualities and functional systems.

Limitations

The current exploratory study sought to elucidate commonalities between memory and executive function as they pertain to general cognitive status. While the findings obtained from data expanded on important aspects of neuropsychology, limitations in the scope and structure of the study allow for further research to confirm and expand on conclusions.

The current study was conducted with a clinical sample in order to accentuate differences and provide more extreme results. Utilization of a clinical sample would not be generalizable to the general population. Conclusions derived from such a sample would therefore only be accurate for interpretation in a clinical population. Often times, research studies find significant results using unique samples but seek to extend the implications of such in order to attach more meaning. Such practices lead to erroneous generalizations. Because a clinical sample was used in the analysis, component loadings and the general behavior of the variables implemented in this study must be interpreted in light of damage or injury being present. Therefore the findings should not be generalized to healthy individuals. Absence of a non-clinical, control group limited the implications of this study. Furthermore, damage, disease, and/or arrested development results in different organization, behavior, and function. Differences are therefore expected to be accentuated in a clinical sample versus a normal sample and the omission of a non-clinical, control sample may have therefore inflated the findings reported herein.

The clinical sample used in this study was of multiple diagnoses ranging from psychiatric diagnoses such as depression to neurological diagnoses such as traumatic brain injury. Different diagnoses affect the brain in different ways. For example, traumatic brain injuries result in both focal and diffuse changes in the brain. Emotional diagnoses such as anxiety and depression are often regarded as secondary to biochemical changes in the brain, although the chemical changes can be onset by situational factors, biological predispositions or acquired brain injury. The complexity among the different diagnoses and physical states that result in brain changes can be innumerable. Therefore aggregating the presentations may both accentuate and attenuate important aspects of the relationship between the different faculties of the human brain. This would lead to general conclusions about how the relationship between executive function and memory when deficits or impairment are present, but would fail to describe brain behavior in any particular diagnosis.

While the sample used in this study met the requirements for an adequate Principal Components Analysis, a greater sample size would control for any extreme or extraneous aspects that may not be as evident in a small sample. A small sample size can increase Type II errors. A Type II error is when one retains the null hypothesis and fails to identify an effect when one is present. In the current study that would signify not observing the variables grouping onto a component that would be more indicative of population trends resulting in a false negative.

In regards to the measures used in this study, the WMS-IV is regarded as the standard for evaluation of memory function, which was the reason it was chosen to represent measurement of memory function. The WMS-IV is frequently used to diagnose memory deficits following an acquired brain injury or progressive disorder. It is also used to differentiate between organic memory impairments versus subjective memory difficulties as seen in individuals diagnosed with depression and/or anxiety. While the WMS-IV is a well-accepted and utilized measurement, both clinically and academically, using one measurement tool for memory may have provided an incomplete perception of the combined factor model. Furthermore, because the models observed in this resulted in no distinction between immediate and delayed memory as well as no separation from measures of visual and verbal processing, construct validity of the measures used may have hindered analysis. Test design may have therefore limited the reported findings by not proficiently measuring memory function.

Similarly, the variables analyzed in this study pertaining to executive function were limited to visual tasks (e.g., Trail Making Test B, Tactual Performance Test, Wisconsin Card Sort Test, Category Test, and Conner's Continuous Performance Test). Consequently, the variables associated with the Trail Making Test B, Tactual Performance Test, and Category test loaded onto visual processing components, with variables associated with the Wisconsin Card Sort and Continuous Performance Test loading onto unique variables. Only including measures of visual executive function limited interpretation of results. Therefore assertions cannot be generalized to all executive functions.

The WCST and CPT-II were shown to be the only tests that had variables that loaded onto unique components. The WCST Total Errors and WCST Perseverative Errors variables loaded onto the component associated with problem solving, concept-formation. While the Category test is also often considered a measure of similar capacities, variability among tests of executive function results in only one test and two variables significantly associating to problem solving. More tests of problem solving would therefore be needed to accurately determine the relationship of measures of problem solving, memory and general cognitive function. Furthermore, the variables analyzed from the WCST were limited to two, i.e. Total Errors and Perseverative Errors. This determination was executed secondary to clinical practice in which Total Errors represents an individual's overall difficulty with the test, which in the case of the WCST would denote poor capacity to accurately establish a strategy and problem solve. Perseverative Errors evaluates an individual's capacity to switch the manner in which they responsd according to the problem or stimulus presented, correlating performance with an ability that is widely accepted as being paramount to executive function. Still, by limiting the variables analyzed to only two variables, an incomplete picture of the WCST was provided. Assertions on the construct validity of the WCST or relationship to memory and other measures of executive function could therefore not be accurately generalized to the entire measure but qualified to only pertain to the variables evaluated in this study. This same implication holds for the CPT-II. Only the CPT-II Commissions and CPT-II Perseverations were included in this study, therefore assertions made about the manner in which they loaded onto components and the generalize validity of the CPT-II should be limited to the variables analyzed.

Future Research

The current study was intended to be exploratory, elucidating on aspects of neuropsychology and human cognition that are widely accepted, but rarely scrutinized. A confirmatory analysis would be the natural progression of the research espoused in this paper. Future researchers should test whether the measures of the constructs demonstrated in this study are consistent with our interpretation of the nature of those factors/constructs by replicating the component structure observed in the four-component model and confirming the finding that the brain operates in an integrated, systematic manner in which aspects of high order functions are not as pertinent as visual and auditory processing.

Because a diverse clinical sample was implemented in the current study, exploration of the combined factor model with a uniform clinical sample would provide further elucidation of the interplay and processing of memory and executive function within the modalities of visual and verbal processing. Researchers should attempt to replicate findings utilizing samples comprised solely of one diagnosis, such as depression or traumatic brain injury. This would moderate mediating and moderating aspects that are more prevalent in a diverse sample. Inclusion of a non-clinical, control group would also enrich findings by providing comparisons between 'normal' individuals and those with clinical diagnosis as well truly explored brain behavior and performance. Future research should therefore incorporate comparisons of the combined factor models across a nonclinical sample, absence of psychiatric and/or neurological diagnosis, and multiple clinical groups structured with uniform diagnoses in each group.

Future researchers should also utilize a greater sample size to facilitate inclusion of a diverse sample but partitioning into groups for comparisons. While other researchers may be limited by resources, those with greater access could truly enrich findings and implications by replicating this study with multiple groups consisting of 85 individuals, based on minimum requirement due to variables included in the study. A larger sample would also facilitate a confirmatory factor analysis to support current findings. Comrey and Lee (1992) qualified good to excellent factor analytic studies, confirmatory, to range from 500 to 1000 variables/participants, although the minimum requirement was noted to be at least 100. Future research could also partition the groups based on gender and age to further evaluate the information more intricately. The reason larger samples increase your chance of significance is because they more reliably reflect the population mean, i.e. the sample more accurately reflects the population being evaluated.

Aside from increasing sampled size, future research should consider the use of other tests of memory function such as the Rey Auditory Verbal Learning Test (RAVLT), *Rey-Osterrieth* Complex Figure Test (ROCF), California Verbal Learning Test (CVLT), Memory Assessment Scales (MAS), etc. Utilizing one test may mediate results because of aspects unique to that test or measures. Inclusion of more tests of memory would therefore provide for more accurate statistical analysis and overall understanding of cognitive function.

The RAVLT is a proven tool in evaluating verbal learning and memory, including proactive inhibition, retroactive inhibition, retention, encoding versus retrieval, and subjective organization. It is appropriate for both children and adults (ages 7 through 89) (Lezak, 2004). The standard RAVLT consists of a list of 15 words, which is read aloud to the patient. Their task is to repeat all the words they can remember. This procedure is carried out a total of five times. This is followed by a distracter list of one trial. Immediately following this, the patient is asked to remember as many words as possible from the first list. This followed by a 20 to 30 minute delay. After which the patient is asked to once again freely recall the information. The Rey-

Osterrieth Complex Figure Test (ROCF) is a neuropsychological assessment in which one is asked to reproduce a complex illustration, first by copying it freehand and then drawing from memory (Lezak, 2004). There are often 4 trials: figure copy, immediate recall, delayed recall, and recognition. This measurement tool is standardized for use with individuals ranging from 6 to 93 years of age. The CVLT-II is a measurement similar to the RAVLT, providing a comprehensive assessment of verbal learning and memory for individuals ranging from age 16 to 89 years (Lezak, 2004). It also consists of multiple trials for learning, immediate recall, delayed recall and recognition. Unlike the RAVLT, this test also provides cuing and categorization, which overlaps with what is often regarded as aspects of executive function. The MAS consists of 12 subtests based on the following 7 memory tasks: Verbal Span, List Learning, Prose memory, Visual Span, Visual Recognition, Visual Reproduction and Names-Faces (Williams, 1991).

Similar to tests of memory function, future researchers could incorporate other measures of executive function, particularly ones that assess verbal executive function such as the Controlled Oral Word Association Test (COWAT) and the Stroop Interference task. By including such measures, one would be able to evaluate whether measures of verbal executive function would load onto factors similar to the ones included in the current study, i.e. loading onto factors associated with verbal processing. Because the variables associated with the WCST and CPT-II loaded onto unique components on multiple models, other studies should include other variables from these measures and evaluate their behavior in exploratory models. This would only provide greater understanding of the measures included and cognitive function but would facilitate generalizations about the findings and measures. Future research should also incorporate tasks that are similar to the WCST such as Tower of London Test, i.e. measure of problem solving. The Tower of London test is a well-known measure used for the assessment of executive functioning specifically to detect deficits in planning and problem solving (Lezak, 2004). Future researchers should also seek to include other measures similar to the CPT-II such as the Test of Variables of Attention (T.O.V.A.), i.e. measure of sustained attention. The T.O.V.A. is an objective, neurophysiological measure of attention that measures your responses to either visual or auditory stimuli (Lezak, 2004). Such a measure would further clarify whether the CPT-II's ability to measure sustained attention and focus, faculties which were correlated to Luria's primary processing, is unique feature of the CPT-II or present in similar measures.

Finally, the manner in which the variables assessing memory function loaded onto their respective components, illustrated how memory was not uniquely assessed by the measures incorporated into this study, in particular no distinction was observed between immediate and delayed memory. Aside from utilizing alternate measures of memory function, future researcher should also seek to evaluate the construct validity of current measures. Researchers must establish distinctive observation and measurement of learning and memory processing. Tests should incorporate novel stimuli that departs from established knowledge. For example the use of nonsensical terms for verbal information. Deviation from the established use of list learning for rote memorization and story memory for contextual items would provide a more rich analysis of verbal memory. Visual and verbal tests of memory should also mirror one another more closely in design in order to evaluate whether context or modality is responsible for performance. Future research on memory should also incorporate the different aspects of memory (i.e. encoding, consolidation, retention and retrieval) that work in concert. Designing such measures would result in more accurate evaluation and understanding. Furthermore, our ability to group information and associate to learned information is vital for learning and memory to occur. Such aspects should also be more formally evaluated.

Overall, the nature of an exploratory study, such as the current one, is to elicit more scientific questions and facilitate future research. While the findings illustrated by the current study are of significance, more research is needed to verify its validity and transition the conclusions into practice.

Summary

In conclusion, this study was conducted to examine the relationship between memory and executive function in reference to performances on the WMS-IV and measures of executive function through exploration of their combined factor structure. The analyses resulted in three models with three, four and five components being retained. The hypothesized component structure was not supported. Rather than the variables loading onto components associated with Working Memory, Executive Function, Immediate Memory and Delayed Memory, the observed component structures resulted in Visual Processing and Verbal Processing surmounting immediate and delayed memory and the CPT-II and WCST uniquely loading onto components associated with Sustained Attention and Concept Formation. Similar loadings were observed in the three- and five- component models with the component associated with Concept Formation being collapsed into the Visual Processing component in the three-component model, and the Visual Processing component being separated into a component associated with Visual Reasoning and a component associated with Spatial Organization in the five-component model.

The observed component structures were demonstrated to be in accordance with the functional systems theory posited by Luria (1973), which holds that the brain works in an integrated systematic manner resulting in a hierarchy of function that ascends from maintaining arousal to tertiary association of input. The three-component model was the result of the parallel analysis, Monte Carlo simulation. While this model was the most statically accurate, since selection of components was most stringent, the component structure was deemed to not be theoretically accurate because Component three from the four-component model was suppressed, causing high co-loadings with the variables that it was comprised of. The five-component model was comprised of components selected because their eigenvalues were greater than one. This component structure partitioned visual processing from spatial organization, illustrating that these two types of measurement evaluate unique functions. Still, when analyzing the highest loadings, variables associated with delayed memory and immediate memory were shown to be highest on their respective components, resulting in findings that were not deemed theoretically accurate or clinically meaningful. The obtained four-component model was therefore regarded as being the most accurate and representative of the sample analyzed.

In neuropsychology and neuroscience, much of the research has sought to localize and categorize brain function, seeking to pinpoint where abilities such as memory and problem solving reside. This has spurred colloquial understandings of cognition such as the 10 percent usage of the brain. In clinical practice, clinicians seek to pinpoint deficit and impairment in order to formulate programs of intervention that target a specific deficiency. Restorative treatments comprised of gaining proficiency in office-implemented tasks demonstrate poor generalization and practicality. The exploration of the association of performances on measures of memory and executive function in the current study demonstrated that executive function and memory interact in a bidirectional manner with aspects of primary and secondary processing (verbal and visual) being accentuated when impairment is present. The evaluation and treatment of the brain should therefore be conducted in a holistic manner, in which abilities or anatomical components are not thought of in an isolated way. Construct validity and accuracy of accepted measures of memory and executive function was also called into question; since the combined factor model failed to support the notion that several of these measures assess abilities unique from visual and verbal perception. Component loadings demonstrated redundancy and poor efficiency in regards to battery construction. Along with confirming these findings or replicating the results using larger or nonclinical samples, future researchers should seek to expand upon the functional aspects of cognition and efficiency of evaluation. As long as the clinician and researcher continue to regard brain faculties as being isolated, so too will be the findings and results. Focus should be given on how the underlying functional systems transfer to everyday tasks in regards to perception, processing, learning and abstraction. Rehabilitation and intervention should consequently consider functional integration. The brain has been shown to be immensely malleable with plasticity resulting in compensation even after significant injury. A practical understanding founded on the individual will facilitate greater understanding and allow for generalization of proficiency within that individual when undertaking rehabilitation tasks.

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