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DISTINCT MEMORY PROFILES IN CHILDREN WITH LEARNING DISABILITIES:

A NEUROPSYCHOLOGICAL PERSPECTIVE

by

Beth Pollock

A Dissertation
Submitted to the Faculty of Graduate Studies
through the Department of Psychology
in Partial Fulfillment of the Requirements for
the Degree of Doctor of Philosophy at the
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Distinct Memory Profiles in Children with Learning Disabilities:

A Neuropsychological Perspective

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Abstract

A great deal of research has focused on memory dysfunction in children with learning disabilities. However, findings have been inconsistent which may be attributed to the limitations inherent in the approaches previously used in this area. Given the heterogeneous nature of learning disabilities, the current study examined performance on the Wide Range Assessment of Memory and Learning- Second Edition (WRAML2) to identify reliable and meaningful memory profiles in children and adolescents diagnosed with a learning disability. A total of 101 children and adolescents between the ages of 9 and 16 diagnosed with a learning disability were included in this study. Participants' scaled subtest scores on the WRAML2 core subtests and the verbal working memory subtest were subjected to two-stage hierarchical and iterative partitioning cluster analysis. Internal validity of the final cluster solution was established using multiple-method reliability techniques. Comparison of the results obtained using several two-stage cluster analyses strongly suggested the presence of five memory subtypes. Three of the five clusters were differentiated primarily by level of performance (Average, Low Average, and Borderline scores on the majority of subtests). The other two clusters were differentiated by pattern of performance (weak visuospatial short term memory and weak auditory verbal short term memory). The five subtypes exhibited distinct patterns of performance on measures of delayed memory, intellectual functioning, and academic achievement. Also, the groups differed in the rate of co-morbid ADHD, the results together suggesting that the memory profiles are valid and potentially clinically meaningful. The findings indicate that reliable patterns of WRAML2 subtest scores can be identified in children and adolescents with learning disabilities. The implications of the findings are discussed.

Dedication

This dissertation is dedicated to my two boys, Xavier and Lukas, who always forgave me when I couldn't play superheroes because I needed to work on my research. I would also like to thank my husband, Thorin, and my parents, Ruth and Wayne, who provided financial and emotional support throughout my long academic career.

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Chapter 1: General Introduction

The capacity to process, store, retain, and subsequently recall information is crucial to support learning. It seems likely, therefore, that children with poor memory functioning will struggle to succeed in basic learning activities. Not surprisingly, much research has focused on memory dysfunction in children with learning disabilities (e.g., Fletcher, 1985; Howes, Bigler, Lawson, & Burlingame, 1999; Kramer, Knee, & Delis, 2000; Liddell & Rasmussen, 2005; Mammarella & Cornoldi, 2005; O'Neill & Douglas, 1991; Pickering & Gathercole, 2004; Siegel & Linder, 1984; Siegel & Ryan, 1989; Swanson, 1993; van der Sluis, van der Leij, & de Jong, 2005; Vicari, Marotta, Menghini, Molinari, & Petrosini, 2003).

While research into the cognitive correlates of learning disabilities has exploded in recent years, the field is plagued by confusion over a conceptualisation and operational definition of the term "learning disability" (LD). Much of the previous research examining memory in children with learning disabilities has used a traditional model of LD identification, the discrepancy analysis approach, to identify children as learning disabled. Based on this approach, a child is diagnosed as having a LD if the child demonstrates a significant discrepancy between intellectual functioning in the Average range and poor performance in at least one area of academic performance.

Many criticisms of the discrepancy approach to LD identification have been raised (e.g., Berninger, 2001; Francis, Fletcher, Shaywitz, Shaywitz, & Rourke, 1996; Lyon, 1995; Semrud-Clikeman, 2005; Siegel, 1992; Stanovich, 1989; Stanovich & Siegel, 1994; Vellutino, 2001). Classification based on this approach has not facilitated practitioners' or researchers' abilities to communicate about such children, has added to the public's confusion about these disorders, and has provided limited (if any) direction for treatment recommendations. In addition, research based on this limited conceptualisation of LD has tended to view children with learning disabilities as a homogeneous entity.

Studies that have examined the memory functioning of children with learning disabilities using this approach have compared children with generic learning disabilities to non-learning disabled children (e.g., Sheslow & Adams, 2003). These studies have found that children with learning disabilities tend to have memory functioning that is inferior to their normally achieving peers. However, due to the limitations of this approach, these findings provide no information about the prevalence of memory impairments in the LD population and the relationship of memory impairment to specific learning problems.

In contrast, subtyping studies based on samples of individuals with learning disabilities have demonstrated the heterogeneous nature of the LD population. Research based on this perspective has identified a number of distinct LD subtypes that demonstrate specific profiles of cognitive functioning (e.g., Fisk & Rourke, 1979; Rourke & Finlayson, 1978; Sweeney & Rourke, 1978). Two basic approaches to subtyping have been used in the literature. These approaches include a priori clinical subtyping and subtyping based on multivariate (cluster analytic) approaches.

In clinical subtyping schemes, children are identified according to a priori criteria such as patterns of intellectual abilities (e.g., low Verbal IQ and high Performance IQ) or patterns of academic achievement (e.g., poor arithmetic and satisfactory reading). Three groups of children with learning disabilities have consistently been identified using these clinical subtyping schemes: a reading disabled group, an arithmetic disabled group, and a globally learning disabled group (e.g., Ozols & Rourke, 1991; Rourke, 1985, 1989, 1991). Memory research conducted using this method of LD profiling has revealed different patterns of memory functioning for each of these specific LD subtypes (e.g., Censabella & Noel, 2005; Fletcher, 1985; Jeffries & Everatt, 2004; Kibby, Marks, Morgan, & Long, 2004; Swanson, Howard, & Saez, 2006). However, there are a number of limitations to this approach that make it difficult to interpret the results clearly. First, since these subtypes are based on performance on measures of academic achievement, intellectual performance, or both, group membership will differ depending on the measures and cut-off scores being used. Second, the specific LD subtypes typically used in this approach (e.g., reading disabled, math disabled) are limited, as they do not take into account children whose profile does not meet expectations (e.g., children who demonstrate weak spelling and math skills but adequate reading abilities). Third, as this approach groups children according to performance on one set of variables (i.e., academic achievement), it is possible that the children within each subtype differ on another set of variables (i.e., memory performance), thus obscuring within group results. Finally, research based on this approach has failed to take into account memory strengths, which are just as important as the identification of memory weaknesses for treatment planning.

The second approach, multivariate subtyping, uses a clustering method (i.e., Q-sort analysis, cluster analysis) to group individuals into subtypes based on similar patterns of academic or cognitive performance. Using this approach, researchers have consistently identified at least four different LD profiles (e.g., D’Amato, Dean, &

Rhodes, 1998; Waxman & Casey, 2006). Research based on this approach addresses some of the limitations of the discrepancy analysis and clinical subtyping approaches. By grouping the data according to similarities and differences in test performance, it recognises the heterogeneity of the LD population. In addition, as groupings are not set a priori, it allows the data to lead group identification, thereby allowing all possible LD profiles to be included in the analysis. Finally, by grouping individuals on their overall performance profile on certain cognitive measures, this approach to LD identification has paid greater attention to both cognitive assets and deficits within LD subtypes.

Thus, the multivariate subtyping approach addresses the limitations of the discrepancy and clinical profiling approaches. However, while recent research has demonstrated that the multivariate subtyping approach can be successfully used to identify memory profiles within a typically developing population (Atkinson, Konold, & Glutting, 2008) and a population of children and adolescents with dyslexia (Howes et al., 1999), no research to date has used this approach to examine whether a group of children with various learning disabilities can be grouped based on their memory performance patterns.

The present study will examine memory functioning in children with learning disabilities, using a cluster analytic approach. The introduction is divided into three chapters. The first chapter will discuss the construct of memory, including examination of short-term and long-term memory processes. The second chapter will then turn to an examination of assessment batteries available to measure memory in children and adolescents. The third chapter will discuss the results to date of research examining memory functioning in individuals with learning disabilities and will provide a rationale for the current study.

Chapter 2: Memory

Childhood constitutes a time of rapid skill and knowledge development. Children are exposed to vast amounts of information, both inside and outside of school, and are expected to retain a large amount of material to achieve proficiency in an immense number of skills. The capacity to attend to, process, store, retain, and subsequently recall information is crucial to support learning. It seems likely, therefore, that children with poor memory functioning will struggle to succeed in basic learning activities. Accordingly, a vast amount of research has been aimed at investigating memory impairments in children with learning disabilities (e.g., Fletcher, 1985; Howes et al., 1999; Kramer et al., 2000; Liddell & Rasmussen, 2005; Mammarella & Cornoldi, 2005; O'Neill & Douglas, 1991; Pickering & Gathercole, 2004; Siegel & Linder, 1984; Siegel & Ryan, 1989; Swanson, 1993; van der Sluis et al., 2005; Vicari et al., 2003). The results from this research reveal a complex relationship between memory and learning. Part of the complexity is that fact that memory is not a simple concept.

The term 'memory' is misleading as researchers have demonstrated that there is no single memory store or system that underpins all mnemonic experiences. Many separable memory systems have been found that can function relatively independently of one another. A commonly used method of classifying these memory functions is by temporal storage ability. Short-term memory is memory for events that have occurred in the very recent past, in which the delay between presentation of the material to be remembered and remembering is measured in terms of seconds. It also has limited storage capacity of only about seven items and these small bits of information quickly disappear forever unless we make a conscious effort to retain the material. Long-term memory is memory for events that occurred in the past, beyond short-term memory. Its capacity seems unlimited, and it can last days, months, years, or an entire lifetime. What follows is a more in-depth exploration of the current understanding of the concept of memory in the research literature.

2.1 Short-Term Memory

Short-term memory is thought to be supported by a set of distinct memory systems. The most complete current specification of short-term memory is the working memory model of Baddeley and Hitch (1974) revised by Baddeley in 1986 and 2000. Although originally devised to account for adult short-term memory performance, this model has also proved useful in characterising the development of memory during the childhood years (Alloway, Gathercole, Willis, & Adams, 2004; Gathercole, Pickering, Ambridge, & Wearing, 2004).

Working memory is the mental process involved when we say we are "thinking about something" and it allows us to reflect on the present and the past (Baddeley, 1992). Baddeley (1986) described working memory as a limited-capacity central executive system that interacts with a set of two passive slave systems used for the temporary storage of different classes of information: the speech-based phonological loop and the visuospatial sketchpad. At the core of this model is the central executive, a supervisory system responsible for controlling, regulating, and monitoring complex cognitive processes (Baddeley & Logie, 1999). The two specialised slave systems, the phonological loop and the visuospatial sketchpad, are used for the storage of auditory-verbal and visuospatial information, respectively (Baddeley & Logie, 1999). Both storage systems are in direct contact with the central executive system and all three processes are subsumed under the heading of working memory.

Substantial evidence for the basic tripartite model of working memory is provided by experimental and neuropsychological findings of dissociations between the presumed components (Baddeley & Logie, 1999). The working memory model has been further supported by neuroimaging studies which have identified distinct neuroanatomical loci for working memory systems (Vallar & Papagno, 2002). Furthermore, recent evidence suggests that the tripartite separation of working memory remains more or less constant over the childhood years (Gathercole et al., 2004).

To complicate matters, however, Daneman and Carpenter (1980) adopted Baddeley and Hitch's (1974) term "working memory" to differentiate a more active view of memory from the more classical "slot" conception of short-term memory. The distinctions made between the central executive and the passive slave systems in Baddeley's (1986) model parallel the distinction made between working memory and short-term memory in Daneman and Carpenter's model. Due to the overlap in terms provided by these two models, there is a lack of clarity in the operational definition of these concepts in the research literature. To simplify matters, when referring to memory for information presented in the very recent past, the present study will focus on Baddeley's model of working memory, encompassing the central executive, phonological loop and visuospatial sketchpad.

2.1.1 The Central Executive

The central executive (CE) is a flexible system responsible for the control and regulation of cognitive processes such as the co-ordination of multiple tasks (Baddeley, Della Sala, Papagno, & Spinnler, 1997), shifting between tasks or retrieval strategies (Baddeley, 1996), and selective attention and inhibition (Baddeley, Emslie, Kolodny, & Duncan, 1998). Consistent with the co-ordinating and inhibiting roles of the CE, activities linked with the CE have been found to be associated with the dorsolateral prefrontal cortex and some posterior (mainly parietal) areas (Collette & Van der Linden, 2002).

Individual differences in the capacity of the CE are commonly assessed using complex memory paradigms. According to Baddeley's (1986) working memory model, the CE is flexible and domain general. Thus, the majority of studies do not differentiate verbal from visual working memory processes, and typically use verbal complex memory tasks to assess CE functioning. Well known measures of CE capacity are complex span tasks such as digit span backward, reading span (Daneman & Carpenter, 1980), listening span (Siegel & Ryan, 1989), and counting span (Case, Kurland, & Goldberg, 1982). In these tasks, the stimuli that have to be remembered are not simply presented to the participants but have to be manipulated before recall.

However, there has been much controversy in the literature over whether the CE actually reflects a distributed model in which capacities are task specific or a general model in which capacities reflect a single factor. In support of the modality-specific perspective, Carpenter and Just (1988) state, "Working memory capacity cannot be viewed as some general property or fixed structure… In this view, it would not be surprising if working memory capacity measured in one task was not predictive of performance in a different kind of task" (p.22). In support of their theory, Seigneuric, Ehrlich, Oakhill, and Yuill (2000) investigated the relationship between working memory (CE) capacity and reading comprehension in French-speaking children in the fourth grade. While verbal and numerical working memory tasks were both predictors of reading comprehension, a spatial working memory task did not reach significance. The authors suggest that the working memory (CE) system is divided into two separate components, one for the processing of symbolic information, i.e., linguistic and numerical, and the other for the processing and storage of visual-spatial information.

In contrast, other researchers have suggested that the central executive is a domain general system that operates across "a range of tasks involving different processing codes and different input modalities" (Baddeley, 1986, p.35). In support of this assertion, numerous studies have demonstrated that CE capacity is not dependent on the particular strategy used to accomplish the task at hand, suggesting that various CE tasks tap the same underlying process (e.g., de Jonge & de Jong, 1996; Swanson, 2003; Turner & Engle, 1989).

Regardless of whether the storage capacity of the CE is domain-specific or domain-general, developmental analyses of performance on measures conventionally associated with the CE have provided evidence for an increased capacity in older children to conduct CE operations (Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005; Case et al., 1982; Gavens & Barrouillet, 2004). However, the extent to which processing and storage factors influence this development has been another topic of considerable debate. Three models have been proposed to account for this development. In the first theory, the total processing space available to an individual can be flexibly deployed as either processing or storage space. The suggestion is that total storage space remains constant over development, but that the operational efficiency of an individual increases, releasing storage space and improving CE functioning (Case et al., 1982). A second model proposes that development is due to resource-related phenomena such as increased processing efficiency and a greater amount of available cognitive resources (Bayliss et al., 2005). A third possibility is that the development of other cognitive variables, such as attention, may play a role in improving CE capacity (Gavens & Barrouillet, 2004).

2.1.2 The Phonological Loop

The phonological loop (PL) is specialised for the maintenance of verbally coded material and is estimated to retain as much material as can be articulated within 1.5 to 2 seconds (Baddeley, 1986). The PL is hypothesised to consist of two parts: a phonological store that holds speech-based information and an articulatory control process that is based on inner speech (mental verbalization). The phonological store retains phonological representations of verbal information that decay over time. Information enters the phonological store either directly, via auditory presentation of speech stimuli, or indirectly via internally generated phonological codes for nonauditory inputs, such as printed words. The articulatory control process refreshes the memory trace by means of subvocal rehearsal (Baddeley, 1986).

Given the linguistic nature of the PL, it is not surprising that research investigating the neuroanatomical origin of PL capacity has implicated known language areas. Neuroimaging research has suggested that the PL is served by a neural circuit in the left hemisphere spanning inferior parietal areas (serving phonological storage) and more anterior temporal frontal areas (associated with rehearsal), including Broca's area, the premotor cortex, and the sensory motor association cortex (Henson, Burgess, & Firth, 2000).

PL capacity is typically measured using simple span tasks for digits, words, pseudowords, or sentences. In these tasks, participants are presented with a series of verbally presented stimuli and are required to repeat them back in the order of presentation. Children's level of performance on these tests of the PL increases dramatically over the early and middle years of childhood. Verbal memory span (a measure of the maximum number of unrelated verbal items that can be remembered in correct sequence) shows an average two- to three-fold increase from between two and three items at 4 years of age to about six items at 12 years of age (Hulme, Muir, Thompson, & Lawrence, 1984).

However, research into the development of the individual subcomponents of the PL has suggested that the two processes do not develop in parallel. While the phonological store component appears to be present even in young children, studies have suggested that the subvocal rehearsal process does not emerge until about 7 years of age (Gathercole & Hitch, 1993; Johnston, Johnson, & Gray, 1987). According to Baddeley's (1990) phonological loop hypothesis, further increases in the rate of subvocal rehearsal within the phonological loop mediate any further increases in PL capacity. Kail (1992) elaborated on this model by predicting that developmental increases in rehearsal rate are, in turn, mediated by global processing speed. Research examining the link between these processes and PL capacity suggest that both processing speed and rehearsal rate are important factors in explaining development in PL capacity in children (Ferguson & Bowey, 2005; Kail, 1997).

2.1.3 The Visuospatial Sketchpad

The Visuospatial Sketchpad (VSSP) has been defined as the "work space for holding and manipulating visuospatial information" (Baddeley & Hitch, 1994, p. 489), with its functions including executing spatial tasks, keeping track of changes in the visual field over time, maintaining orientation in space, and directing movement through space. Logie (1994) proposed that the VSSP has two primary subcomponents: a visual store and a spatial mechanism. The physical characteristics of objects and events are thought to be represented in the visual store. The spatial mechanism is purported to be used for planning movements and may also serve a rehearsal function by activating the contents of the visual store.

The dissociation between visual and spatial stimuli in the VSSP has been supported in neuroanatomical and neuropsychological studies. For example, DeRenzi (1982) found that patients with parietal occipital lesions could not use vision to guide their movements, suggesting that damage to this area of the brain results in impairments in spatial processing. Conversely, patients with inferior temporal lesions were found to have difficulties with identifying items: a deficit in visual processing. Furthermore, Pickering, Gathercole, Hall, and Lloyd (2001) tested 5-and 8-year-old children on conventional measures of visual span, spatial span, and digit span. Scores on each task were uncorrelated with one another, suggesting that phonological, visual, and spatial memory capacities may be dissociable even in young children.

Due to evidence suggesting a distinction between VSSP functions, study of the VSSP has been largely dominated by the use of two specific kinds of tasks. The Corsi blocks task involves the presentation of a visuospatial sequence by tapping a randomly placed set of nine blocks. Each block is tapped one at a time and can only be identified on the basis of its spatial location. In contrast, visual short-term memory has been measured using pattern recall type tasks, such as the visual pattern task. Tasks of this type typically involve the presentation of an abstract visual figure or design, and the examinee is required to identify aspects of the stimuli immediately after it is removed.

Although the manner in which the operation of the VSSP changes with age has not been as extensively researched as other working memory processes, there is now a body of research providing a basic understanding of some significant developmental changes in functioning. For example, Pentland, Anderson, Dye, and Wood (2003) used the Nine Box Maze Test, a measure of visual-spatial short-term memory, to address VSSP capacity development in a sample of healthy children aged 5 to 12 years. Their results suggest a developmental spurt in VSSP capacity at around seven years of age, with capacity tending to remain relatively stable between the ages of 8 and 12.

However, if the VSSP is composed of separable subcomponents, it is possible that the two functions do not mature at the same rate. Logie and Pearson (1997) investigated the separability of visual and spatial short-term memory in children of 5 to 6, 7 to 9, and 11 to 12 years of age by administering a visual patterns task and a Corsi block type task and observing the age-related increase in performance for each task. They found that although performance increased with age for both tasks, there was a much steeper age-related increase for the visual pattern task, suggesting that the visual subcomponent of the

VSSP develops faster than the spatial subcomponent in children. Similarly, Pickering, Gathercole, and Peaker (1998) used versions of the visual pattern span and Corsi blocks task to investigate the relationship between visual memory and spatial memory span. While there was an age-related increase in span in both tasks, a much steeper developmental incline was evident for the pattern span than spatial span. The authors propose that the steeper increase in pattern span with age may reflect the increasing use by older children of non-visual strategies to supplement their memory for the visual patterns but not for the temporal order of the elements in the spatial task. The theory that improvements in pattern span may be due to increasing use of non-visual strategies in older children is supported by experimental research (Hitch, Halliday, Schaafstal, & Schraagen, 1988), performance on psychometric testing (Sheslow & Adams, 1990), and electrophysiological findings (Licht, Bakker, Kok, & Bouma, 1992).

2.1.4 The Episodic Buffer

A new component of working memory, the episodic buffer (EB), has been fractionated from the CE in the most recent revision of the working memory model (Baddeley, 2000). The episodic buffer is proposed to use multidimensional codes to integrate representations from components of working memory and long-term memory into unitary episodic representations that may correspond to conscious experience. As it is thought to provide direct inputs into episodic long-term memory, it is possible that this component of working memory may provide an important gateway for learning. Although the neural evidence is limited regarding possible localization of this buffer, there is some suggestion that the dorsolateral prefrontal cortex plays a role (Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000; Zhang et al., 2004). However, a detailed structure of the episodic buffer and methods of assessing its capacity have yet to be identified.

2.2 Long-Term Memory

The term “long-term memory” is used to refer to memory for events that occurred hours, days, months, or years ago. Two distinct memory systems or processes appear to support long-term memory for previous events: implicit (nondeclarative or procedural) and explicit (declarative). Implicit memory retrieval does not carry with it the internal sensation of ‘remembering’ something. The contents of implicit memory are often procedures or skills (frequently motor-based) and are evidenced by more skilled or precise behaviour as a result of experience (Bauer, 2004). Explicit memory, on the other hand, permits recall and recognition of names, dates, places, and events, and its operation is conscious: individuals are aware that the memory representation is based on a past experience. The current research discussion will focus on this conscious aspect of long-term memory.

Research investigating the neural substrate of explicit memory in adults has localised its origins to a multi-component network involving medial temporal and cortical structures (Eichenbaum & Cohen, 2001; Markowitsch, 2000; Zola & Squire, 2000). Different areas seem to be involved at each step of the process during which memories are formed and subsequently retrieved. The processing that turns immediate perceptual experiences into a memory trace is described as involving integration and stabilisation of the various inputs from different cortical regions. These tasks, collectively termed consolidation, are thought to be performed by medial temporal structures (including the hippocampus), in concert with other cortical areas (Abel, Martin, Bartsch, Kandel, 1998;

Eichenbaum & Cohen, 2001; Zola & Squire, 2000). Medial temporal consolidation processes begin with initial encoding and continue for days, weeks, and even years. It is thought that, to the extent that new experiences make contact with memories of old ones, memory representations are continuously activated and re-activated with the result that consolidation continues virtually for a lifetime (Kandel, 1989). However, eventually, the bonds between and among elements are strengthened sufficiently that hippocampal activity is no longer necessary for the maintenance of the memory representations and the association areas assume the responsibility for storage of the trace.

Long-term explicit memory has been further subdivided into verbal versus nonverbal memory with neuroimaging studies revealing different patterns of neural activation depending on the modality of the stimuli presented (Bauer, Kroupina, Schwade, Dropik, & Wewerka, 1998). The specific pattern of firing, the energy contained within a certain neural net profile of activated neurons, contains a representation. The visual system is able to represent visual stimuli whereas the auditory system is able to create representations of sounds. Furthermore, specific regions may carry out different forms of information processing. Thus, circuits primarily within the left hemisphere may mediate language processing, whereas nonverbal representations may be carried out primarily within the right hemisphere (Bauer et al., 1998).

Tasks typically used to assess explicit memory involve participants seeing or hearing a list of words, listening to a story, or seeing an enactment of an event. The examinee is asked to recall the stimuli immediately after the presentation and then following a delay (typically 10-15 minutes) in which intervening tasks are administered. After the delay, the examinee is asked to freely recall the initial stimuli (i.e., “What words were on the list?") or is provided with cues to assess recognition of aspects of the initial stimuli (i.e., "Was the girl in the story named Sally, Lucy, or Suzy?"). As poor performance on a memory task could reflect failure to encode an appropriate memory trace (encoding deficiency), trouble retaining that trace (storage deficiency), or difficulties with accessibility during retrieval (retrieval deficiency) all three recall processes are used to index different aspects of explicit memory. Immediate recall is often used as an index of initial encoding and storage. Free recall after a delay is typically used as a method of assessing consolidation and retrieval. To separate whether a difficulty with free recall is due to encoding, storage or retrieval processes, cued recall is used as it is seen to enhance an individual's ability to access appropriate codes in long-term memory (Tulving & Thompson, 1973). If cued recall increases performance to average levels, one may conclude that performance difficulties are associated with a retrieval deficiency.

The development of long-term explicit memory is thought to differ depending on the modality of stimuli presentation and recall. During the early stages of the acquisition of language, infants and young children typically encode information in a nonverbal way (Bauer et al., 1998; Hayne & Rovee-Collier, 1995). Even children as old as four rely more heavily on nonverbal representations than on their emerging language skills (Simcock & Hayne, 2003). By school age, the typical child shows good skills both at verbally recalling details of prior experiences and at organising those details into a coherent narrative form (Bauer et al., 1998). Further developmental increases in long-term explicit memory capacity are thought to be due to increased usage of strategic processing, which are conscious activities that a learner uses to facilitate memory, such as specific strategy use (Murphy, McKone, & Slee, 2003).

Now that I have completed an examination of some of the components of memory, I will now turn to an exploration of the assessment tools commonly used to assess memory functioning. As the goal of this project is to examine memory in school-aged individuals, I will focus on assessment tools used within the child and adolescent population.

Chapter 3: Assessment of Memory Functioning

Spreen and Strauss (1998) recommend that a thorough investigation of memory functioning for diagnostic hypotheses testing and to facilitate rehabilitation planning should include the assessment of “immediate or short-term retention, rate and pattern of acquisition of new information, efficiency of encoding under both explicit and implicit conditions, rate of decay of information, and proactive and retroactive interference” (p. 260). These processes should also be evaluated for both verbal and nonverbal abilities and using both recall and recognition techniques. In addition, they recommend that the assessment of memory should attempt to establish which aspects of memory are compromised and which are spared, and whether memory function is complicated by problems in other domains, such as in the area of attention and information processing. Therefore, in order to examine the complexity and multifactorial structure of memory, a battery of tests is often used. The use of a single battery of memory and learning tests allows a more coherent evaluation of memory functioning, as well as the potential to identify memory profiles that can be interpreted and compared because the same standardized sample is used for all tests. A number of relatively comprehensive memory batteries have been developed for children and adolescents and will be discussed in turn below.

3.1 Children's Memory Scale

The Children’s Memory Scale (CMS; Cohen, 1997) is an individually administered instrument developed to evaluate learning and memory in individuals ranging in age from 5 to 16. The CMS was developed using the "Milkjug of Memory" model (Cohen, 1997), a sequential model in which directed attention promotes short-term immediate memory, which is divided into the Auditory-Verbal and Visual-Nonverbal domains. Data from each domain are maintained in working memory, which leads to new learning. Information is then stored in long-term memory, which is further divided into declarative and procedural memory. Declarative memory is again subdivided into episodic memory and semantic memory, whereas procedural memory is subdivided into skills learning and classical conditioning. Procedural memory is not assessed by the CMS.

Consistent with this model, the complete CMS consists of nine subtests that assess functioning in three domains: auditory/verbal, visual/nonverbal, and attention/concentration. Each subtest in the auditory/verbal domain and the visual/nonverbal domain contains both an immediate memory component and a delayed memory component. Subtests are combined to yield eight index scores: Verbal Immediate, Verbal Delayed, Delayed Recognition, Learning, Visual Immediate, Visual Delayed, Attention/Concentration, and General Memory. Each domain is assessed through two core subtests and one supplemental subtest. Core subtests include: Stories, Word Pairs, Dot Locations, Faces, Numbers, and Sequences. Supplemental subtests consist of Word Lists, Family Pictures, and Picture Locations.

The CMS is individually administered and can be used as a part of psycho-educational, psychological, neuropsychological, or other clinical evaluation requiring the evaluation of learning and memory. The core battery may be administered in approximately 30-35 minutes and the supplementary battery adds an additional 10-15 minutes of testing time. As this memory test was designed with children and adolescents in mind, the tasks are engaging and child friendly.

The standardization sample consisted of 1000 children in 10 age groups from 5 through 16 years of age, matched to the 1995 U.S. Census report. Using confirmatory factor analysis, a three-factor model consisting of the attention/concentration subtests and the delayed subtests of the verbal and visual subtests was the best model. However, it should be noted that the immediate memory subtest scores, not the delayed subtest scores, are used in the calculation for the General Memory Index score. Reliability coefficients are generally acceptable for the core battery subtest scores and indexes (ranging from .61 to .94) but fall to .47 on some supplemental subtests (i.e., immediate word pairs). Test-retest coefficients for ages 5 to 8 were .54 to .85, for ages 9 to 12 were .56 to .89, and for ages 13 to 16 were .29 to .85. The lowest stability over time was in the delayed recognition subtests across the age groups. Decision consistency reliability coefficients are relatively stable over time with index scores generally showing greater decision consistency then the subtest scores. Correlations between subtests within domains were found to be low to moderate. The visual memory subtests had the lowest correlation across the age groups (.06 to .16). The General Memory Index exhibited moderate-to-high correlations with all of the indices.

3.2 Test of Memory and Learning

The Test of Memory and Learning (TOMAL; Reynolds & Bigler, 1994) was designed to provide an in-depth of analysis of memory functioning in the preschool to high school age range. The TOMAL is a battery of 18 immediate memory, repeated trials learning, and delayed recall subtests that yield a Composite Memory Index, Verbal Memory Index, Nonverbal Memory Index, and Delayed Recall Index. Each of these domains provides additional data beyond memory functioning that are important in educational interventions and programming, with respect to specifying manner of recall (i.e., sequentially, free, or associative), attention and concentration, and ability to learn a novel task. Verbal memory subtests include Memory for Stories, Word Selective Reminding, Object Recall, Digits Forward, Paired Recall, Digits Backward, Letters Forward, and Letters Backward. Nonverbal subtests are Facial Memory, Visual Selective Reminding, Abstract Visual Memory, Visual Sequential Memory, Memory for Location, and Manual Imitation. Delayed recall tests are Memory for Stories Delayed, Word Selective Reminding Delayed, Facial Memory Delayed, and Visual Selective Reminding Delayed. Although the manual presents a historical and theoretical overview of the evaluation of memory, it does not provide a clear theoretical rationale outlining the TOMAL test construct.

The norming sample (N = 1342) was based on the 1990 and 1992 United States Census. Population proportionate sampling was used, with consideration of age, gender, ethnicity, socioeconomic status, geographic region of residence, and urban/rural residence. Because the standardization sample data did not match the U.S. Census in terms of geographical region of residence, weighting was used to correct for the lack of representativeness. The reliability of the instrument was determined using internal consistency, reported by age, and test-retest methods. Median internal consistency coefficient alphas ranged from .84 to .97 for the Verbal and Nonverbal subtests and .67 to .88 for the Delayed Recall subtests. The Core Index reliabilities ranged from .85 to .96, whereas the Supplemental Indexes ranged from .90 to .99.

3.3 Wide Range Assessment of Memory and Learning- Second Edition

The Wide Range Assessment of Memory and Learning, Second Edition (WRAML2; Sheslow & Adams, 2003) is the update to the 1990 instrument that was first designed to assess memory in children, but that now has norms from age 5 to 90. This instrument is administered individually and contains six core subtests: Story Memory, Verbal Learning, Design Memory, Picture Memory, Finger Windows, and Number/Letter. Optional subtests include Verbal Working Memory, Symbolic Working Memory, Sentence Memory, and Sound-Symbol. Delayed-recall subtests are included for Story Memory, Verbal Learning, and Sound-Symbol subtests in order to assess forgetting over time. Also available is a recognition format for delayed retention of the Story Memory, Verbal Learning, Picture Memory, and Design Memory subtests so that the examiner can explore issues of storage versus retrieval for the verbal subtests and delayed recognition for the visual subtests. From the six core subtests, three Index scores can be derived: Verbal Memory (Story Memory and Verbal Learning subtests), Visual Memory (Design Memory and Picture Memory subtests), and Attention/Concentration (Finger Windows and Number/Letter subtests).

The updated version of the WRAML2 was based on information from cognitive sciences, neuropsychology, and developmental research and includes elements of all of the following memory and learning concepts: primacy and recency effects, immediate and delayed recall, recall of rote versus meaningful material, visual and verbal memory, semantic versus acoustic memory errors, working memory, sustained attention, short-term memory, recognition versus retrieval systems, incremental trial learning, learning curve, and memory decay. The time required to administer the WRAML2 is about 45 minutes and may extend to 1 hour if all Delayed Recall tasks are presented.

The WRAML2 was standardised on 1200 children and adults, with 80 individuals allotted to each of 15 age groups, matched to the 2001 U.S. Census in terms of gender, race/ethnicity, educational attainment, and geographical area. Slight variations in the normative sample from census data were corrected with a statistical weighting procedure. Internal validity was assessed via investigation of item content, subtest intercorrelations, exploratory factor analyses, confirmatory factor analysis, and differential item functioning. Results from factor analysis studies support the internal validity of the WRAML2. Reliability data from the WRAML2 indicate excellent person separation reliabilities with Rasch statistics ranging from .85 to .94 on the core subtests. Internal consistency is also shown to be very good, with Cronbach's alpha coefficients ranging from .82 to .96 on the core index scores, and from .71 to .95 across the six core subtests.

The advantages of the above three batteries are that they review a number of different components of memory and allow for intersubtest comparisons. While a battery of memory tests can be time consuming to administer, the number and variety of tasks presented allows greater confidence when speaking to an individual's memory strengths or weaknesses. This information is particularly helpful when designing an intervention or rehabilitation program to ensure that memory strengthening activities and compensatory strategies are targeted at the appropriate memory processes and take into account areas of strength.

While clinicians have a few options in terms of memory batteries when attempting to identify potential memory deficits, the strengths and weaknesses of each of the individual memory assessment battery must be kept in mind. For example, while the CMS is engaging and child-friendly, and has adequate reliability and validity, it can take a great deal of time to administer, especially with elementary-age children with neuropsychological problems, which may compromise the proper administration of delayed tasks. The TOMAL allows for the assessment of multiple memory processes, but it lacks psychometric evidence of validity. This is particularly troublesome as the manual states that the content validity was determine by the test authors themselves. Finally, the test does not appear to be based on any clear theoretical framework. The WRAML2 is attractive to children, has adequate reliability and validity, and can typically be administered within the standardized time frame. In 2005, the Wide Range Assessment of Memory and Learning (WRAML; Sheslow & Adams, 1990) was identified in a survey of clinical neuropsychologists as being one of the most commonly used neuropsychological instruments (Rabin, Barr, & Burton, 2005). The WRAML2 is largely an update of the original WRAML but extends the usefulness of the measure from 5-17 years to 5-85 years of age. The recent update makes it the most up-to-date battery of memory and learning in children and adolescents, and incorporates the most recent findings from research in the field of memory and learning.

Now that I have completed an examination of some of the batteries available for the assessment of memory and learning in children, I will now turn to an exploration of the findings from research examining memory functioning in children and adolescents with learning disabilities.

Chapter 4: Memory and Learning Disabilities

It seems likely that children with poor capacities to process, store, retain, or subsequently retrieve information will struggle to succeed in the learning activities that represent crucial steps in the acquisition of knowledge and complex skills. For example, preschool children are expected to learn the names and sounds of the letters of the alphabet, and subsequent literacy development requires this basic knowledge. Accordingly, the role of memory dysfunction as a cause of problems in academic performance is receiving increased attention in the assessment of children's cognitive functioning.

The term learning disability (LD) is a classification for academic learning difficulties in one or more core academic area (e.g., reading, writing, mathematics), given adequate intelligence and educational opportunity. The incidence of specific LD in North America is between 3-10% (Statistics Canada, 2002). However, despite the high prevalence of learning disabilities and the associated abundance of research into learning difficulties, there remains a state of confusion regarding the definition of learning disabilities in the literature. A formal LD definition continues to be contentious because of its failure to provide closure on "two critical elements: understanding—a clear and unobscured sense of what a LD is—and explanation—a rational exposition of the reasons why a particular student is learning disabled" (Kavale & Forness, 2000, p. 240). Although a number of alternative LD definitions have been proposed, none has been universally accepted, meaning that there is no single statement describing the LD condition. Clinicians and researchers have tended to use one of two methods to define learning disabilities, one that views learning disabilities as a homogeneous entity and one that views learning disabilities as heterogeneous. I will examine the rationale and research emerging from each of these approaches below.

4.1 LD as a Homogeneous Concept

The central component of the LD construct is the historically prominent notion of “unexpected underachievement,” representing children and adults who should be able to learn yet do not attain levels that would be expected based on their apparent abilities. Based on this conceptualisation, children with learning disabilities have been identified according to the presence of a discrepancy between their measured intelligence (IQ) and their level of attainment in academic achievement, an approach termed the ability-achievement discrepancy method. According to this approach, an individual is identified as having a LD based upon the difference between the individual’s presumed potential for reading, spelling or performing arithmetic, as indicated by an IQ score, and his or her actual academic achievement, as indicated by the individual’s score on standardized measures of reading, spelling or arithmetic. As identification based on this approach can be easily determined based solely on the administration of a measure of intelligence and a measure of academic achievement, this method of LD identification is frequently used within school boards. In fact, measures of intelligence and tests of academic achievement are commonly normed together to provide the clinician with a simple statistical method of determining whether a significant ability-achievement discrepancy exists.

While this approach is seemingly reasonable, researchers and clinicians have noted six serious problems with discrepancy-based classifications (Berninger, 2001; Francis et al., 1996; Lyon, 1995; Semrud-Clikeman, 2005; Siegel, 1992; Stanovich, 1989; Stanovich & Siegel, 1994; Vellutino, 2001). Firstly, this approach to LD identification is based on the conceptualization that the underlying cognitive problems affecting reading, spelling, or arithmetic (language skills, working memory, visual processing) somehow have no impact upon performance on an IQ test. A second problem noted is that poor reading skills and reduced exposure to information in print will, over time, likely lower measured IQ, reducing any measurable discrepancy. Thirdly, discrepancy definitions assume that IQ is a good predictor of reading, spelling, or arithmetic skill, although in actuality the relationship is not so clear. For example, Aaron (1995) found that IQ predicts only 16 to 25% of the variance in reading skill. A fourth criticism is the floor effect of many academic achievement tests, making it very difficult to find a statistically significant discrepancy between ability and achievement in young children. A fifth criticism of this approach is that it leads to assessments that are too narrow, ignoring the cognitive factors that are impacting poor academic achievement and failing to provide specific information to guide remediation. Finally, a sixth criticism is that discrepancy strategies have been found to under-identify children with learning difficulties from ethnic minorities, who may score lower on IQ tests due to cultural differences (Siegel, 1989, 1992) and thus will not display the discrepancy required for a learning disability diagnosis. The problems associated with this approach to LD conceptualisation and identification have led to the recommendation by many researchers to abandon this method (Francis et al., 1996; Fuchs, Mock, Morgan, & Young, 2003; Semrud-Clikeman, 2005).

In addition to clinical problems associated with this simplistic approach to LD classification, research emerging from this tradition has resulted in comparison of “the learning disabled child” to non-learning disabled children on different cognitive factors.

Children who display a statistically significant discrepancy between ability and achievement are termed learning disabled, with no differentiation between children based on the type of difficulty shown. They are then compared to non-learning disabled children (i.e., children who do not display a statistically significant discrepancy) and any differences between the groups are interpreted as either determinants or outcomes of having a learning disability. This approach to research on children with learning disabilities was used almost exclusively in the literature prior to the late 1970s (Rourke, 1989) and can still be found in current research studies (e.g., Sheslow & Adams, 2003).

Due to the problems inherent in research based on this approach, little attention will be devoted to an exploration of the memory research emerging from this tradition. It is sufficient to say that researchers utilising this approach have demonstrated that children with learning disabilities score significantly below their peers in all areas of memory functioning (Sheslow & Adams, 2003). As can be concluded from our previous discussion, memory research based on this “generic” view of learning disabilities does not help to increase understanding of the role of memory impairment in learning disabilities or guide specific remediation for individuals with memory impairment. It is probable that grouping children with diverse learning difficulties into one group contributes to uneven results that restrict interpretability and obscure within-group differences (Tsatsanis, Fuerst, & Rourke, 1997). In addition, research based on this approach fails to reveal whether children with specific learning disabilities are more likely to display memory impairment, whether specific memory problems are related to specific academic difficulties, and how memory impairment might change with development and interact with other cognitive factors. Due to all of the problems associated with this type of research, the majority of studies investigating learning disabilities today have abandoned this approach to take a more heterogeneous view of children with learning disabilities.

4.2 LD as a Heterogeneous Concept

A primary focus of research within the discipline of neuropsychology of learning disabilities has centred on the variability of neuropsychological skills within the LD population. Using a "process" approach and based on a neuropsychological perspective, Rourke, Hayman-Abello, and Collins (2003) described learning disabilities as "specific patterns (subtypes) of neuropsychological assets and deficits that eventuate in specific patterns of formal (e.g., academic) and informal (e.g., social) learning assets and deficits" (p. 630). In general, the neuropsychology of learning disabilities literature suggests that the LD population is not homogeneous but rather consists of a number of distinct subgroups that have varying patterns of abilities (e.g., Fisk & Rourke, 1979; Rourke & Finlayson, 1978; Sweeney & Rourke, 1978). On an interindividual level, different cognitive functions, such as language (reading, writing, spelling and/or speaking), thinking and problem solving, mathematical abilities, social interaction, and communication, can be affected to varying degrees. On an intraindividual level, the disability can be very specific (e.g., language performance is fine but math performance is poor) or global, involving all academic areas.

The growing recognition among researchers that learning disabilities represent a heterogeneous group of disorders rather than a unitary phenomenon has elicited a change in research methodology. As a result, significant attention has been paid to the identification of distinct subtypes of children with learning disabilities. Two methods of subtyping have been used in the literature: 1) subtyping based on clinical inferences about symptom presentation and 2) subtyping based on the results of multivariate statistical models that separate children according to patterns of test scores. I will now turn to an examination of these two approaches to LD subtyping and examine the memory research that has emerged from each of these classification schemes.

4.2.1 *Clinical Subtyping*

In clinical subtyping schemes, children are identified according to a priori criteria such as patterns of intellectual abilities (e.g., low Verbal IQ and high Performance IQ) or patterns of academic achievement (e.g., poor arithmetic and satisfactory reading). These subtypes are then examined for neuropsychological differences. The goal of this examination is to delineate homogeneous subtypes of children with learning disabilities who seem to have similar neuropsychological strengths and weaknesses that may account for their academic problems. Following the identification of homogeneous subtypes, these children theoretically can be grouped for instructional purposes and remedial activities tailored to their specific needs.

Rourke and his colleagues found that Wechsler Intelligence Scale for Children Verbal IQ- Performance IQ (VIQ-PIQ) discrepancy (e.g., Fuerst, Fisk & Rourke, 1990; Rourke, Young & Flewelling, 1971) and patterns of Reading, Spelling, and Arithmetic performance (Rourke, 1985, 1989, 1991) were associated with reliable patterns of performance on a number of neuropsychological measures. Three groups of children have consistently been identified using these clinical subtyping schemes: a primarily reading disabled group, a primarily arithmetic disabled group, and a heterogeneous group of children displaying global academic difficulties (e.g., Ozols & Rourke, 1991; Rourke &

Finlayson, 1978; Rourke & Strang, 1978). Various investigations have demonstrated the considerable consistency of these general academic subtypes. For example, Rourke and his colleagues reported subtype characteristics in one of their initial studies of academic subtypes (Rourke & Finlayson, 1978) that were generally supported in subsequent studies (Rourke & Strang, 1978; Strang & Rourke, 1983). Rourke and colleagues also established the consistency of subtypes across age groups (Ozols & Rourke, 1991). Moreover, subtyping efforts have revealed that similar proportions of children fall into these general subtypes including a) a very large subtype of children with reading disabilities associated with language-based deficiencies, b) a substantial subtype of children with mixed neuropsychological deficits, and c) a relatively small subtype displaying visually-based deficiencies. These consistencies have lent a great deal of credence to clinical classification schemes. I will now turn to a brief examination of each of these LD subtypes and examine the findings from studies examining the memory functioning of children classified into each of the subtypes.

The primarily reading disabled (RD) subtype is characterised by “a specific pattern of relative assets and deficits in academic (i.e., poorly developed single-word reading and spelling relative to mechanical arithmetic) and social (e.g., more efficient use of nonverbal than verbal information in social situations) learning” (Rourke, 2005, p. 111). Children with reading disabilities, also referred to as Reading-Spelling Disabled (R-S) or Basic Phonological Processing Deficit (BPPD) in the literature, exhibit relatively deficient psycholinguistic skills in conjunction with very well-developed visual-spatial-organisational, tactile-perceptual, psychomotor, and nonverbal problem-solving skills. Rourke (1989) found that children with this academic profile tend to have verbal abilities significantly less developed than performance abilities (Verbal IQ < Performance IQ) on the Wechsler Intelligence Scales for Children -Revised (WISC-R).

Consistent with their underlying difficulties with language processing, research investigating the memory functioning of children with reading disabilities has revealed generally impaired performance on verbal long-term explicit memory tasks. When compared to same-aged non-reading disabled controls, children with reading disabilities have been shown to have inferior performance on story recall (O’Neill & Douglas, 1991), paired-associate learning (Helfgott, Rudel, & Karam, 1986), verbal list learning tasks (Fletcher, 1985; Kramer et al., 2000), and recall of everyday information (McNamara & Wong, 2003).

However, research attempting to explain the poor verbal memory performance of children with reading disabilities has found mixed results. Kramer et al. (2000) demonstrated that children with reading disabilities have proportionately lower middle-region recall of verbally presented lists and a greater degree of confusion between target items and semantically similar foils, suggesting that children with reading disabilities exhibit primarily an encoding impairment. In contrast, Fletcher (1985) found that subjects with reading and spelling difficulties did not differ from controls on a storage measure, but were poorer on a retrieval index, suggesting that the locus of memory impairment in reading disabilities is at the level of retrieval. Consistent with this finding, Swanson, Reffel, & Trahan (1991) found that when children with reading disabilities were provided with cues, their ability to recall previously learned verbal stimuli increased to the level of their peers without learning disabilities, again suggesting a difficulty with retrieval. Further support comes from McNamara and Wong (2003) who demonstrated that when students with learning disabilities with impaired reading scores were provided with cues that their recall of everyday tasks increased to the level of their non-learning disabled peers.

In contrast to the relatively consistent finding of impaired verbal long-term memory in children with reading disabilities, research findings have been less consistent for measures of working memory. Children with reading disabilities have been shown to have inferior PL capacity (Howes et al., 1999; Jeffries & Everatt, 2004; Swanson, 1999; Watson & Willows, 1995) and central executive capacity (de Jong, 1998; Jeffries & Everatt, 2004; Swanson, 1993, 1999; Swanson & Ashbaker, 2000) in studies that did not take into account their scores on tests of mathematics. Thus, it is probable that these studies combined children from the RD and global learning disability subtypes. In studies that classified children with reading disabilities as having specific impairment solely in reading and spelling, the results have been inconsistent. A number of studies found that children with reading disabilities performed significantly below age-matched peers on tasks assessing PL capacity (Kibby, 2009; Kibby et al., 2004; Swanson et al., 2006), while others found no difference (van der Sluis et al., 2005). This inconsistency of findings is also present in research examining VSSP and CE capacity in children with reading disabilities. Several researchers have found intact VSSP functioning in children with reading difficulties (e.g., Jeffries & Everatt, 2004; Kibby, 2009; Kibby et al., 2004), whereas others have found VSSP impairment even when using stimuli that cannot be verbally coded (e.g., Howes et al., 1999; Kaplan, Dewey, Crawford, & Fisher, 1998). Although studies have found significantly lower performance on measures of the CE in children with reading disabilities (Siegel & Ryan, 1989; Swanson, 1993) others have found no difference (Geary, Hamson, & Hoard, 2000; Kibby et al., 2004; van der Sluis et al., 2005).

Therefore, although these studies have attempted to find specific memory impairments that co-occur with RD, either as a cause of or as a result of their learning difficulty, few consistencies in the literature have been found. Thus, a predictable pattern of memory and learning difficulties associated with reading problems is challenging to infer from the existing literature. One explanation for the discrepancies among findings is that subtypes of LD readers are often combined to form a general "reading disabled" group. According to Boder (1973) children with reading disabilities can be separated into at least two groups, exhibiting primarily dysphonetic or dysdeidetic difficulties. Although larger study groups theoretically increase statistical power, combining two or more subgroups that have dissimilar patterns of deficits is likely to obscure critical differences between study and control groups.

The second subtype, the primarily arithmetic disabled subtype (AD), is characterised by "a specific pattern of relative assets and deficits in academic (well-developed single-word reading and spelling relative to mechanical arithmetic) and social (e.g., more efficient use of verbal than nonverbal information in social situations) learning" (Rourke, 2005, p. 11). Children with arithmetic disabilities, also known as having a Nonverbal Learning Disability (NLD) in the literature, exhibit outstanding problems in visual-spatial-organisational, tactile-perceptual, psychomotor, and nonverbal problem solving skills within a context of proficient rote psycholinguistic skills (Rourke, 1989, 1993; Rourke & Conway, 1997). Rourke (1989) found that children with this academic profile tend to have verbal abilities that significantly exceed their performance abilities (Verbal IQ > Performance IQ) on the WISC-R.

Consistent with their impairment in processing nonverbal material, research investigating memory functioning in children with arithmetic disabilities has revealed generally impaired performance on visual memory tasks. Children with arithmetic disabilities have been shown to demonstrate storage and retrieval difficulties on a visual selective reminding task (Fletcher, 1985), difficulty organising visual information and developing an efficient encoding strategy (Brandys & Rourke, 1991), and impaired memory for faces (Liddell & Rasmussen, 2005). On the other hand, verbal memory in children with arithmetic disabilities has consistently been found to be intact (Liddell & Rasmussen, 2005; Mammarella & Cornoldi, 2005).

In terms of working memory functioning, when compared to their non-arithmetic disabled peers, children with arithmetic disabilities have demonstrated significantly lower performance on measures of VSSP capacity (Cornoldi, Rigoni, & Tressoldi, 1999; Gathercole & Pickering, 2000; Mammarella & Cornoldi, 2005; McLean & Hitch, 1999; Siegel & Linder, 1984; van der Sluis et al., 2005). While some studies have revealed central executive impairment in children with arithmetic disabilities (Bull & Scerif, 2001; Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Keeler & Swanson, 2001; Mayringer & Wimmer, 2000; Passolunghi, Cornoldi, & De Liberto, 1999; Passolunghi & Siegel, 2001; Siegel & Ryan, 1988; Swanson, 1993), more recent research has indicated that once intelligence is controlled for, the AD group does not differ from controls (Geary et al., 2000; van der Sluis et al., 2005). Another possible explanation for the inconsistency is the finding that specific visual-spatial deficits may be implicated in only some instances of arithmetic disabilities (Rourke, 1993). Research has focused on at least three sources of mathematical disability: difficulty in retrieving basic arithmetic facts from long-term memory, use of developmentally immature calculation procedures (Barrouillet, Fayol, & Lathuliere, 1997; Geary, Brown, & Samaranayake, 1991; Jordan & Montani, 1997), and difficulty with visuospatial representation of numerical information (Geary, 1993). Thus, it is possible that CE impairment is a contributing factor in only some children with arithmetic disabilities, depending on their specific arithmetic deficit.

A third group has also been consistently found in research utilising groups based on patterns of academic performance. This globally learning disabled group, known as Reading, Spelling, and Arithmetic Disability (R-S-A) or Reading and Arithmetic Disabled (RAD) in the literature, exhibit much of the cognitive profile of the RD group. They demonstrate relatively poor psycholinguistic skills in conjunction with relatively better developed visual-spatial-organisational, tactile-perceptual, psychomotor, and nonverbal problem-solving skills and abilities. Academically, this group exhibits a pattern of uniformly deficient reading (word recognition), spelling, and mechanical/arithmetic skills. This group is thought to be composed of several different subgroups of children with learning disabilities (Rourke, 1991) but has not been the focus of much research.

No research was found that compared a globally learning disabled group to either non-disabled controls or other LD subtype groups on measures of long-term memory. Research comparing children with global learning disabilities against their non-disabled peers has revealed inferior performance on measures of the PL (Geary et al., 2000; Pickering & Gathercole, 2004; Siegel & Linder, 1984; Siegel & Ryan, 1988), VSSP

(Pickering & Gathercole, 2004; Siegel & Linder, 1984), and CE (Censabella & Noel, 2005; Geary, Bow-Thomas, & Yao, 1992; Geary et al., 1991; Geary et al., 2000; Pickering & Gathercole, 2004; Siegel & Ryan, 1988).

Although the clinical subtyping approach to memory research has improved our ability to examine the role that memory plays in specific learning difficulties, there are a number of limitations to this approach. First, since these subtypes are based on performance on measures of intellectual ability or academic achievement, group membership will differ depending on the measures and cut-off scores being used, resulting in variability of group membership across studies. In addition, results are also affected by whether the researcher takes into account the performance pattern of the individual (i.e., scores on reading and math) or whether they focus solely on one area of impairment (i.e., reading only). Second, LD subtypes based on this approach are limited as they do not take into account children whose profile does not meet expectations. Thus, a child who demonstrates impaired spelling but whose reading and arithmetic skills are within the average range for their age would not be included in the investigations. Third, as this approach to LD subtyping groups children according to performance on one set of variables (i.e., academic achievement), it is possible that the children within a group differ on another set of variables under study (i.e., memory performance), thereby obscuring within group results. Finally, an additional problem in the interpretation and practical application of the previously discussed research is the selection of memory measures. The typical research design in this area includes the use of two or three specific memory tasks, with the memory tests selected for use being conceptually related to the primary variable under investigation. This has led to the use of various experimentally derived measures to examine specific memory processes, which differ across studies, making comparisons between research findings difficult. In addition, this means that measures being used in studies are often entirely different from those administered in a neuropsychological, psychological or educational investigation of LD. This makes it difficult for clinicians to draw parallels from the research to their clinical practice. A review of the literature failed to uncover a single study that compared children with learning disabilities, differentiated by subtype, on a clinically administered battery of memory and learning. Thus, while the clinical subtyping approach to LD research is an improvement over the discrepancy based method, this approach has failed to yield memory research that can be used to enhance our understanding of LD and increase our ability to remediate specific learning difficulties.

4.2.2 Cluster Analytic Subtyping

A second method used to develop classifications of children with learning disabilities focuses on patterns of performance on neuropsychological and cognitive tests. This empirical classification approach involves the statistical manipulation through factor analysis of correlations among participants (i.e., Q-factor) or multivariate procedures (i.e., cluster analysis) to increase homogeneity. This method clusters persons (rather than test variables) with similar test score patterns.

Clusters of persons with similar profiles have served as empirical evidence for clinicians' hypotheses regarding the neuropsychological basis for learning disabilities (Fisk & Rourke, 1983). Research conducted to date clearly indicates that there is no single pattern of test results that characterises all children with learning disabilities (e.g., D'Amato et al., 1998; Joschko & Rourke, 1985; Waxman & Casey, 2006). The proposition that that profile analysis can actually reveal reliable and meaningful patterns of intellectual strengths and weaknesses has spawned a host of investigations regarding learning disability subtypes.

Using cluster analysis, researchers have consistently identified four clusters or subgroups of children with learning disabilities. The first consistent cluster, similar to the RD group already discussed, comprise a group demonstrating global language impairment in the face of relatively well developed visual-perceptual skills (D'Amato et al., 1998; Lyon, 1985; Snow, Cohen, & Holliman, 1985) and somewhat better developed mathematical skills than reading and spelling skills (Waxman & Casey, 2006). A second cluster consistently found, similar to the AD group previously discussed, demonstrates impaired visual-spatial skills in relation to relatively well developed verbal skills (Lyon, 1985; Snow et al., 1985) and somewhat stronger reading ability than arithmetic skills (Waxman & Casey, 2006). Consistent with the global learning disabled group previously discussed, a third group with mixed language and perceptual impairment has consistently been found (D'Amato et al., 1998; Lyon, 1985; Snow et al., 1985) with globally low academic performance (Waxman & Casey, 2006). A fourth group with high verbal and perceptual-reasoning skills and no identifiable impairments has also been consistently identified (D'Amato et al., 1998; Lyon, 1985; Snow et al., 1985). Children found in this cluster appeared to have problems that were not clearly related to the neuropsychological, intellectual, or achievement measures utilised in these studies.

Research based on this empirical approach is an improvement to the traditional LD classification method as it recognises the heterogeneity of the LD population. In addition, as groupings are not set a priori, it allows the data to lead group identification, thereby allowing all possible LD profiles to be included in the analysis. Finally, by grouping individuals on their overall performance profile on the variables under investigation, this approach has paid a greater amount of attention to both cognitive assets and deficits within LD subtypes.

Recent research has demonstrated that a multivariate approach can be used to group individuals into memory subtypes based on their performance on a battery of memory and learning. Atkinson, Konold, and Glutting (2008) attempted to identify a normative taxonomy of profiles likely to be found among typically developing individuals using the six core subtests of the WRAML2 that serve as measures of Verbal Memory, Visual Memory, and Attention/Concentration. They applied cluster analysis to data from the WRAML2 standardization sample of individuals ranging from 5 to 85 years of age. Their analysis revealed nine profiles thought to represent the natural variation of individual memory disparity typical among the general population. While four of their groups presented with above average memory skills in specific areas with the remainder of the memory scores falling within the Average range, more than half, five, of the groups displayed some memory impairment.

To date, little research has been conducted that has used a multivariate approach to examine specific memory profiles in individuals with learning disabilities. One or two variables assessing memory (i.e., Digit Span, Letter-Number Sequencing) have been included in previous empirical studies attempting to identify individual subtypes of learning disabilities (D’Amato et al., 1998). However, these measures were usually included due to convenience (i.e., subtests within the WISC) and memory was not the focus of the study. In a review of the literature to date, only one research paper was found that was primarily concerned with memory profiles in children with learning disabilities, using a standardised battery of memory and learning. Howes et al. (1999) conducted two studies to examine the performance of specific reading disability subtypes on the Test of Memory and Learning (TOMAL). In the first study, children diagnosed with either dysphonetic dyslexia or dysdeidetic dyslexia, classified by Boder (1973) criteria, were compared to age and reading-level matched controls on the Composite Memory Index (CMI) score from the TOMAL. The CMI scores were significantly lower for children with dyslexia when compared to matched controls, with nearly identical memory profiles in the two dyslexia groups. The plotting of mean subtest score profiles for all readers revealed auditory sequential memory impairments for both types of readers with dyslexia and multiple memory strengths in the good readers.

The TOMAL subtest scores from Study 1 were then subjected to cluster analysis. Six clusters emerged. Cluster One, the “Good Readers”, was composed of children with no reading deficits, no memory deficits, and a relative strength in memory for meaningful verbal narratives, tests associated with verbal learning using drill and practice, and motor sequences. Cluster Two was composed of children with reading disabilities, the majority of whom were classified as having dysphonetic dyslexia. While their nonverbal memory skills on the TOMAL were average, they demonstrated generally depressed scores on verbal memory subtests. Additionally, they demonstrated weak verbal working memory/attention skills. Seventy-six percent of cluster three consisted of children with reading disabilities. Like the children in Cluster 2, children with reading disabilities in this group demonstrated auditory sequential memory impairments and weak performance on verbal working memory/attention tests. However they evidenced poorer performance on a measure thought to be related to memory for abstract visual/spatial relationships, and they exhibited verbal strengths similar to those of Cluster One on memory for verbal narratives and learning verbal information over repeated trials. Normal readers in this cluster performed quite similarly to children with reading disabilities, except that none of their memory subtest scores were in the impaired range. Cluster Four was quite small and was comprised of two-thirds (66.7%) of children with reading disabilities. Children with reading problems in this group were very similar to those in Cluster Two, showing generally depressed verbal memory scores and nonverbal memory performance in the average range. Poor readers in this cluster showed impaired memory performance for verbal learning tasks, auditory sequential memory, and delayed recall of learned verbal material with weak skills in verbal working memory/attention. Cluster Five was composed of only two subjects with dyslexia who displayed severe impairment on tests related to nonverbal learning and memory for visual spatial relationships with an additional moderate impairment on verbal tasks involving learning word associations. Auditory sequential memory/discrimination was also weak. The final cluster was composed of 81% children from the control group who were 2 years younger, on average, than the readers with dyslexia who were captured in this cluster. They demonstrated memory strengths on nearly all nonverbal tests and had additional strengths on verbal learning tasks. Children with reading disabilities mirrored their performance, but at a lower level, showing impairments in auditory sequential memory but normal nonverbal memory scores. This finding suggests a possible developmental memory pattern characteristic of normal children at an early stage of reading development. Overall the results of the Howes et al. (1999) study demonstrates that readers with dyslexia can be characterized into distinct, qualitatively different subtypes by their performance on a battery of memory and learning tests.

Although the multivariate method of LD conceptualisation is clearly an improvement on the homogeneous conceptualisation and addresses some of the limitations of the clinical subtyping approach, a number of methodological difficulties exist in research studying memory functioning in individuals with learning disabilities from this multivariate approach. Most research in this area has utilised a limited range of measures and rather small sample sizes (Rourke, 1985). In relation to the former criticism, the use of a select number of measures chosen from a neuropsychology battery offers methodological concerns. These concerns relate to the narrow band of skills assessed, or the inherent bias in the post-hoc selection. In relation to the latter criticism, McKinney (1985) has argued that cluster analysis is inappropriate in studies for which the ratio of subjects to the number of variables is less than 10 to 1. Furthermore, only one study to date has used a memory battery to investigate subtypes of children with learning disabilities, and this study focused solely on children with reading disabilities (Howes et al., 1999).

The purpose of the present investigation was to investigate the extent and nature of memory impairments in children with learning disabilities. The performance of children with learning disabilities on a battery of memory and learning was submitted to a multivariate analysis to identify individual subgroups with specific memory profiles. Specifically, data reduction was completed by cluster analysing subtest scores of a group of children with learning disabilities on the WRAML2. In essence, cluster analysis allows the characterization of children's performance deficits according to their pattern of responses by increasing the homogeneity of groups.

As discussed above, although we have some knowledge based on the literature of how individuals with specific learning disability profiles should function on memory tasks, the findings to date have been inconsistent. The current research extends our knowledge in this area by correcting for limitations in previous research. Evidence from the multivariate approach to LD classification suggests that there may be more LD profiles than are recognised using the common LD clinical classification schemes. Therefore, the multivariate approach to the present study allowed for a more inclusive examination to ensure that children with varying cognitive and academic profiles are included. Additionally, a large sample was used to allow the appropriate use of advanced statistical procedures that require a student-to-variable ratio of 10 to 1. Finally, although experimentally derived measures have revealed distinct memory deficits in the various LD subtypes, the present study utilized a battery of memory and learning tests commonly used clinically to examine memory functioning in children and adolescents with learning disabilities. The WRAML2 was selected following consideration of the strengths and weaknesses reviewed above of the various memory batteries available for children and adolescents. The goal of this research is to improve our understanding of memory functioning in children with learning disabilities.

Based on the results from the Atkinson et al. (2008) study that found specific memory subtypes within the standardization sample for the WRAML2 and results from the Howes et al. (1999) study that identified distinct subtypes of memory performance in a group of children with dyslexia, it was hypothesized that the present study would yield a reliable memory typology. However, while four of the nine memory subtypes identified in the Atkinson et al. (2008) study presented with above average memory skills, it is not predicted that such a high prevalence of subtypes with well developed memory skills would be found in the present sample of children and adolescents with learning disabilities, owing to the body of research identifying various memory deficits in individuals with learning disabilities (e.g., Bull & Scerif, 2001; Censabella & Noel, 2005; Geary et al., 2000; Howes et al., 1999; Passolunghi & Siegel, 2001; Pickering & Gathercole, 2004). In addition, given the different demographic (Atkinson et al., 2008) and learning profiles (Howes et al., 1999) identified in the various memory subtypes identified in the previous memory subtyping studies, it was hypothesized that variables that were not used to form the clusters but would be expected to vary across the clusters, such as prevalence of ADHD comorbidity, delayed memory performance, intellectual functioning, and academic achievement, would differ amongst the clusters.

Chapter 5: Method

5.1 Participants

In order to be considered for this study children had to be first diagnosed with a LD, as verified through their psychological report. The sample included 101 children (57 boys, 44 girls) between the ages of 9 and 16 years inclusive. To operationalize the diagnosis, each participant also had to meet the following criteria: 1) deficient in at least one school subject area, defined as an age-adjusted score on a subtest of the WIAT-II below the 25th percentile; 2) obtain a Wechsler Intelligence Score for Children- Fourth Edition Full Scale IQ, Verbal Comprehension Index, or Perceptual Organization Index score within the standard error of measurement for the Average range (i.e., 95% confidence interval); 3) did not present with significant mental health issues (e.g., anxiety or depression) that could account for their depressed academic scores; 4) had adequate visual and auditory acuity to enable standardized assessment with the WISC-IV, WRAML2, and WIAT-II; 5) attended school regularly since the age of 5½ or 6 years of age; and 6) spoke English as their native language. The screening for English language proficiency was especially important given the high francophone population in the region where the data was collected (40.3% of the population based on the 2001 census by Statistics Canada). Each child received a comprehensive psycho-educational evaluation (by a licensed psychologist, psychological associate, or supervised psychometrist) that included the WISC-IV, WRAML2, WIAT-II and other measures of language and visual-spatial processing. Children diagnosed as having co-existing significant attentional problems consistent with Attention Deficit Hyperactivity Disorder (ADHD) were included in the sample, but were identified as having ADHD within the analysis.

Information about co-morbid diagnoses other than ADHD was not available. The protocol for the current study received approval from the University of Windsor Research Ethics Board, and the parents of all participants gave written consent for their children's participation in the study.

5.2 Procedure

Permission was obtained from the school board administrators and chief psychologists of a large public school board in Eastern Ontario for children identified as having a LD to participate in this study. When a child was assessed with the WISC-IV, WRAML2, and WIAT-II and was subsequently diagnosed as having a LD, a letter was sent by school board personnel to the child's parents inviting them to participate in the study. The letter described the study and requested the parents' permission for the researcher to obtain the child's test scores from their school board psychological file. If the parent agreed to their child's participation, they were asked to sign the permission form and to place the form in the mail to be returned to the researcher. Of the 257 parents contacted, 103 returned the permission form allowing the researcher to access their child's data for coding. This resulted in a return rate of 40%. As the researcher was unable to access data on the individuals who chose not to participate in the study, comparison between the children of responders and non-responders was not possible. The data from two children were excluded from the analyses for not meeting the inclusionary criteria of English being their native language. This resulted in a final sample size of 101 participants.

5.3 Measures

5.3.1 Internal Criteria

5.3.1.1 Wide Range Assessment of Memory and Learning- Second edition. The Wide Range Assessment of Memory and Learning- Second Edition (WRAML2; Sheslow & Adams, 2003) is an individually administered test battery designed for the clinical assessment of memory, including the evaluation of immediate and delayed recall, as well as verbal, visual, and global memory. It has been standardised for use with individuals 5 to 90 years of age. The WRAML2 consists of six core subtests, four optional subtests and seven delayed memory tasks (three free recall and four recognition subtests). Raw scores on each of the subtests can be converted to scaled scores, based on standardization data, each with a mean of 10 and a standard deviation of 3. These standard scaled scores were used for all statistical analyses. The WRAML2 allows for the calculation of six Index scores, as well as a General Memory Index (GMI) and a General Recognition Index score. Each Index score yields a standard score with a mean of 100 and a standard deviation of 15.

The focus of the present study was on the six core subtests that are most often administered during individual clinical evaluation, as well as an additional optional subtest which assesses the central executive (Verbal Working Memory). The brief descriptions of the three primary Indices and their underlying subtests, as well as the verbal working memory subtest, were obtained from the WRAML2 administration and technical manual (Sheslow & Adams, 2003).

The Verbal Memory Index (VBI) score, which provides a global measure of explicit long-term verbal memory, includes the Story Memory and Verbal Learning subtests. In the Story Memory subtest, a participant is read two short stories and is immediately asked to recall as many aspects of the reading passages as possible. Points are earned for verbatim recall of specific words and phrases for most story elements, with some gist recall permitted. The difficulty of the task changes based on the participant's age, with individuals 8 years and younger being read stories consisting of 25 and 36 separate aspects, while those 9 years and older are read stories with 36 and 40 aspects, respectively. The Verbal Learning subtest involves aurally presenting a participant a list of simple words, followed by immediate free-recall. Three additional presentations and recall trials follow. Again the difficulty of the task changes from 13 items for children 8 years or younger to 16 items for those 9 or older (Sheslow & Adams, 2003).

The Visual Memory Index (VMI) score, a global measure of explicit long-term visual memory, consists of Design Memory and Picture Memory subtests. The Design Memory subtest involves the 5 second exposure of a series of five cards with various geometric forms. After this brief exposure, and a 10 second delay, the individual is asked to draw all aspects of the image that they are able to recall. In the Picture Memory subtest, participants are shown four separate detailed scenes of familiar settings, with a 10 second exposure to each image. After each picture, the child is given a similar picture and told to mark the objects that are different (Sheslow & Adams, 2003).

The Attention/Concentration Index (ACI) score consists of Finger Windows and Number-Letter subtests. The Finger Windows subtest presents participants with a vertically resting card containing asymmetrically located holes. In each trial, the examiner demonstrates a pattern by placing the end of a pencil in a sequence of holes and then asking the individual to duplicate the sequence by placing their finger in each hole according to the order of presentation. The length of the sequence increases with each trial. The Number Letter subtest is similar to a digit span task; participants are aurally presented with sequences of alternating numbers and letters and then asked to recall this information in the order it was presented (Sheslow & Adams, 2003).

The optional Verbal Working Memory subtest was also included in the cluster analysis as a measure of the central executive. In the first half of this subtest, the individual is read a list of animals (e.g., tiger, whale, cat) and non-animals (e.g., hat, house, pencil) and is asked to repeat the list back, stating the animals first, in order from smallest to largest, and then the non-animals in any order. The list of animals and non-animals increases with each trial. In the second half of the task, the individual is again read lists of animals and non-animals of increasing length and is required to repeat back both the animals in order from the smallest to the largest, but also the non-animals in order from smallest to largest. This subtest is only available for individuals 9 years of age and older (Sheslow & Adams, 2003).

The participant's obtained Index score (M = 100, SD = 15) for General Memory (GMI), Verbal Memory (VBI), Visual Memory (VMI), and Attention/Concentration (ACI) were used to help describe and interpret the final typology. As prescribed by the WRAML2 manual (Sheslow & Adams, 2003), these values were based on core subtests only, thus excluding the Verbal Working Memory subtest.

The psychometric properties of the six primary subtests are favourable (Sheslow & Adams, 2003). Internal consistency measures were in the high to excellent range (.86-.93) for the majority of subtests. Confirmatory factor analysis (CFA) demonstrated that, consistent with the hypothesized framework, a three-factor model best represents the six core subtests. Multi-group structural analyses provided evidence that the three-factor solution was invariant across groups reflecting gender, ethnicity, age, and level of education. In addition, various subtests of the WRAML2 demonstrated an acceptable degree of correlation with other instruments designed for the measurement of memory, including the Wechsler Memory Scale- Third Edition (r = .60), Children's Memory Scale (r = .49), Test of Memory and Learning (r = .69), the California Verbal Learning Test (r = .64), and the California Verbal Learning Test- Second Edition (r = .68).

5.3.2 External criteria

Unlike deviation Index measures that are actually transformed linear composites of the subtests themselves, certain test measures and variables, such as ADHD co-morbidity, were used both to describe and lend validity to the typology. The test measures included delayed memory WRAML2 subtest scores not used to compute Index measures and results from the WISC-IV and WIAT-II that were co-administered at the time of the WRAML2 assessment.

5.3.2.1 Wide Range Assessment of Memory and Learning- Second edition- delayed memory subtests. Delayed recall subtests from the WRAML2 were used to help describe and validate the typologies created using the core subtests of the WRAML2 and Verbal Working Memory subtest. As the delayed recall subtests are correlated with the immediate recall scores from the core subtests, these scores were not used exclusively to validate the typology and were primarily used to further explore the specific memory subtype characteristics. Two free recall and four recognition memory subtests were used. The Story Memory Free Recall subtest examines the participant's ability to recall details from the two stories presented as part of the Story Memory core subtest, after a delay in which the participant was engaged in intervening memory tasks. In the Story Memory Recognition subtest, the participant is presented with multiple choice questions probing specific details from the stories. The Verbal Learning Free Recall subtest assesses the participant's ability to freely recall the list of words initially presented in the core Verbal Learning subtest after a delay of approximately 10 minutes. In the Verbal Learning Recognition subtest, the individual is read a list of words, some of which were on the initial word list and some of which are not, and the participant is asked to identify the words belonging to the original list. In the Design Memory Recognition subtest, the participant is presented with a series of drawings, some of which were part of the initial designs presented in the core Design Memory subtest and some not. The participant is asked to identify those that were in the initial geometric designs. On the Picture Memory Recognition subtest participants are asked to identify from a series of pictures those which were part of the detailed pictures presented in the core Picture Memory subtest (Sheslow & Adams, 2003).

Raw scores on each of the subtests can be converted to scaled scores, based on standardization data, each with a mean of 10 and a standard deviation of 3, based on age specific technical manual conversion tables. These standard scaled scores were used for all statistical analyses. Average reliability coefficients across age groups are generally good, with scores on the delayed memory subtests for verbal information (ranging from .66 to .96) being somewhat stronger than the average reliability coefficients for the delayed memory subtests for visual information (ranging from .49 to .71). However, the lower reliabilities of the visual recognition tasks are mostly due to the structure of the subtests (yes, no format) and the nature of the task being performed (Sheslow & Adams, 2003).

5.3.2.2 Wechsler Intelligence Scale for Children- Fourth edition. The Wechsler Intelligence Scale for Children- Fourth Edition (WISC-IV; Wechsler, 2003) was used as a measure of intellectual functioning. The WISC-IV consists of 10 core subtests that comprise a Verbal Comprehension Index, Perceptual Reasoning Index, Working Memory Index, and a Processing Speed Index score. The Verbal Comprehension Index score is comprised of tasks that assess vocabulary, verbal reasoning, and knowledge of social conventions. The Perceptual Reasoning Index is comprised of tasks that assess visual-constructional ability, visual reasoning, and visual pattern recognition. The Working Memory Index is comprised of tasks which assess the individual's auditory attention and working memory. The Processing Speed Index score is comprised of two timed visual-motor processing tasks. These four index scores are summed to produce a Full Scale IQ score, reflecting a child’s overall intellectual functioning. Each Index score and the Full Scale IQ score yield a standard score with a mean of 100 and a standard deviation of 15.

Average reliability coefficients across age groups are generally good, ranging from .88 (Processing Speed Index) to .94 (Verbal Comprehension Index). The WISC-IV Index scores were used to validate the typology and to assist with the description of specific subtypes.

5.3.2.3 Wechsler Individual Achievement Test- Second edition. The Wechsler Individual Achievement Test- Second Edition (WIAT-II; Wechsler, 2002) was used as a measure of academic achievement. The WIAT-II is comprised of seven academic subtests including three measures of reading ability, two measures of writing ability, and two measures of arithmetic. The reading subtests include: Pseudoword Decoding, a measure of the ability to read a list of non-words; Word Reading, a measure of the ability to read words presented in isolation; and Reading Comprehension, a measure of the ability to answer questions based on a paragraph. The writing subtests include: Spelling, a measure of single word spelling ability, and Written Expression, which assesses the ability to write sentences, paragraphs, and essays utilising proper grammar, spelling and punctuation. The arithmetic subtests include: Numerical Operations, a measure of the ability to solve paper-and-pencil arithmetic problems, and Math Reasoning, a measure of the ability to solve aurally presented mathematical word problems. All of the subtest scores yield a standard score with a mean of 100 and a standard deviation of 15.

Internal consistency reliability estimates of the WIAT-II subtests are generally high (above .70). Test-retest correlations for the subtests were consistently above .85 (Wechsler, 2002). The WIAT-II subtest scores were used to validate the typology produced by the WRAML2 subtests, as well as assist with the description of the individual subtypes identified. The Written Expression subtest was not included in the analyses due to the low rate of administration by examiners in the study.

5.4 General Rationale of Analysis

5.4.1 Phase 1: Initial Cluster Analysis

Classification can be conceptualized as the process of forming groups from a large set of entities or units based on the similarities and dissimilarities of the individual entities (Morris & Fletcher, 1988). Statistical cluster-analytic techniques provide one empirical approach to the development of classifications. There are two common types of cluster analytic techniques: hierarchical and non-hierarchical.

Hierarchical cluster techniques form groups in successive steps, starting with each individual as its own cluster and building into larger nested clusters. Due to the early determination of grouping rules in this technique, early ineffective combinations of data may mislead the further analyses and the final results. Non-hierarchical cluster techniques, also known as partitioning, require the user to specify the expected number of clusters for the data. On the basis of this information, this method calculates centroids for a set of trial clusters, places each case in the cluster with the nearest centroid, and then recalculates the centroids and reallocates the cases. This process iterates until there is no change in cluster membership. As this approach provides multiple opportunities to assign cases to specific clusters, and thus can compensate for poor initial cluster assignments, the non-hierarchical techniques are less sensitive to outliers than are hierarchical methods (Lange, Iverson, Senior, & Chelune, 2002). However, due to the fact that the number of clusters must be assigned a priori in this approach, non-hierarchical cluster analysis is not recommended as an exploratory technique when the number of clusters contained within a data set is not known (Lange et al., 2002).

Due to the limitations of hierarchical and non-hierarchical techniques on their own, a combination of the two techniques has been recommended as the most appropriate means of determining the cluster structure of a data set (Borgen & Barnett, 1987; DiStefano & Kamphaus, 2006; Lange et al., 2002). First a hierarchical technique is used to identify the number of clusters in a data set. Subsequently, a k-means cluster analysis is employed, whereby the number of clusters requested in the analysis is based on the results from the hierarchical analysis. This method of clustering has been found to be superior to hierarchical methodology alone, and is a procedure that has been validated by numerous researchers in the area of psychology (e.g., Donders, 1996; Fisher et al., 1996).

In this study, each child's profile was based on scaled scores (M = 10, SD = 3) for seven WRAML2 subtests, including the core six subtests, Story Memory, Design Memory, Verbal Learning, Picture Memory, Finger Windows, and Number Letter, and the supplementary Verbal Working Memory subtest. A two-step procedure that combined Ward's method and K-means algorithms was used to attempt to overcome the limitations of each method when selected as the sole method. In the first stage, a hierarchical cluster analysis, Ward's minimum variance method of group linkage, was applied to the data to estimate the number of clusters present in the sample. Ward's method is an agglomerative hierarchical procedure that extracts clusters by minimising error variance within each cluster and maximising the error variance between clusters (Milligan & Cooper, 1987). In other words, Ward's method attempts to maximize the differences among potential clusters by using changes in between and within sums of squared measures to determine the best cluster for an individual profile. This clustering technique has been extensively investigated and has generally been found to be one of the more accurate and effective methods available (Borgen & Barnett, 1987). Squared Euclidean distance was used as a measure of similarity because it is known to be sensitive to profile elevation and pattern, and it preserves the shape, elevation, and scatter of the data (Aldenderfer & Blashfield, 1984; Donders, 1996; Morris & Fletcher, 1988).

Although cluster analysis is a frequently used method for determining subtypes within populations based on test performance, it has been criticized for the lack of clear benchmarks or statistics for determining how well the solution fits the data. As such, the selection of a final cluster solution in cluster analysis is somewhat arbitrary (Vermunt & Magdison, 2002). Thus, several different approaches to deciding on the optimal number of clusters were used that have proven useful in previous studies of children with learning disabilities (e.g., Morris, Balshfield, & Satz, 1981; Morris et al., 1998). These approaches included: a) a review of changes in the clustering coefficients, which measure within and between cluster variability; b) visual inspection of the full hierarchical trees that track the formation of clusters; c) inspection of the changing cluster profiles as clusters are merged; and d) visual inspection of individual child profiles within and across clusters. Additionally, solutions were reviewed to ensure that clusters consisted of a sufficient number of cases to ensure that outlying cases were not exerting undue influence on the cluster solution. Using these methods, two possible cluster solutions were identified.

After possible cluster solutions were identified using the methods listed above, a non-hierarchical clustering approach (k-means) was used to clarify and refine the initial solutions by correcting fusion errors and improper initial assignment. This method re-evaluates each participant within each cluster, and then examines whether a specific child best fits into the original cluster or another cluster. The mean centroids resulting from the initial cluster solutions using Ward's minimum variance method were used as seeds for determining the final cluster centres for the k-means analysis.

5.4.2 Phase 2: Replication and Cross-Classification.

To examine the replicability (internal validity) of the derived solutions, the data were subjected to three additional two-stage cluster analyses. The methods included three hierarchical agglomerative algorithms, which were used to identify the initial cluster solutions (complete linkage, average linkage-within groups, and average linkage-between groups), and were subsequently subjected to an iterative partitioning method (k-means). The latter step was used to clarify and refine the initial solutions produced by the three hierarchical methods. These three algorithms were chosen for replication as they represent some of the most widely used and evaluated methods in the area (e.g., Morris et al., 1998; Waxman & Casey, 2006).

In the complete linkage agglomerative method, the distances between clusters are determined by the greatest distance between any two objects in the different clusters (also known as Furthest Neighbour). This algorithm uses the profile from the most different individuals in a cluster for comparison purposes. This method works well when the plotted clusters form distinct clumps (not elongated chains). Average linkage-within groups method emphasises the mean distance between all possible inter- or intra-cluster pairs. The average distance between all pairs in the resulting cluster is made to be as small as possible. This method is therefore useful when the research purpose is homogeneity within clusters. In the average linkage between groups method, also called UPGMA linkage (unweighted pair-group method using averages), the distance between two clusters is the average distance between all inter-cluster pairs. In other words, a cluster of participants is defined as the average profile of all of the individuals already in the cluster, with individuals being added or removed from the cluster on the basis of the similarity of the individual's profile to the average profile. This method works well for both elongated chain-type and with clumpy type clusters.

Agreement within cluster solutions was calculated by examining misclassification rates between the cluster solutions generated using the hierarchical method and k-means analysis for each method. Participants' cluster membership following hierarchical cluster analysis and cluster membership following k-means analysis were examined and the percentage of participants misclassified was calculated, with lower numbers representing greater agreement between the clusters.

Agreement between the cluster methods was calculated using Cohen's kappa (κ; Cohen, 1960), a chance corrected measure of agreement that captures the degree of consensus between two raters (in this case, four independent attempts at categorization into possible cluster solutions). If the proportion of observed agreements exceeds the expected agreement, kappa is larger than zero and it approaches one if the proportion of observed agreements reaches unity. According to Landis and Koch (1977), kappa values of .41 to .60 can be considered "moderate," values of .61 to .80 can be considered "substantial," and values of .80 to 1.00 are "almost perfect."

As a second measure of agreement between the cluster methods, intraclass correlation coefficients (ICCs) that tested for absolute agreement (*r*- level analyses) were computed to examine agreement between the subtype assignments generated across the different hierachical methods, resulting in larger correlations in situations where test scores are more similar and smaller correlations where they are different. Cluster solutions generated were also examined for theoretical congruity, conceptual distinction, and practical significance. These techniques were used to determine the most replicable and clinically meaningful cluster solution. Once the optimal cluster solution was chosen, descriptive labels summarizing the major features of the WRAML2 profiles were then assigned to each cluster.

5.4.3 Phase 3: Examining the External Validity of the Derived Typology

To determine the external validity of the derived memory subtypes, variables were selected that were not used to form the clusters but would be predicted to vary across the clusters. Without external validation, a clustering solution is no more than a possible hypothesis (Skinner, 1981). ADHD co-morbidity, WRAML2 delayed memory subtests, WISC-IV Index scores, and WIAT-II subtest scores were compared between the groups. In cases where the data were categorical (e.g., ADHD co-morbidity), chi-square analysis was used for comparison. If an omnibus ANOVA test illustrated statistically significant differences among the clusters, follow-up tests were run with Bonferroni's post hoc procedure, controlling the error rate to .05, to identify statistically different (as well as similar) clusters. It should be noted that the goal of these analyses was primarily descriptive, particularly because it is difficult to sketch other than fairly broad conclusions from these comparisons. To ensure that emergent subtype differences reflect more than decisions about alpha levels, effect sizes reflecting the size of the mean group differences were also computed by calculating the pooled within-groups standard deviations for each variable. All statistical analyses were conducted using SPSS Version 11.5 (SPSS Inc., 2002).

Chapter 6: Results

Demographic and participant variables for the sample are presented in Table 1. The overall WISC-IV FSIQ score of the sample was in the Low Average range. The

Table 1

Sample Characteristics

		Overall	Male	Female
N		101	57	44
Age				
	M	142.36	140.89	144.25
	SD	26.93	27.30	26.63
	Range	109-195	109-192	109-195
FSIQ				
	M	87.34	88.04	86.43
	SD	9.01	10.28	7.04
	Range	68-118	68-118	74-105
VCI				
	M	91.77	93.21	89.91
	SD	11.00	12.41	8.62
	Range	55-130	55-130	75-108
PRI				
	M	92.45	93.76	90.70
	SD	12.00	12.23	11.59
	Range	64-120	68-120	64-120
WMI				
	M	85.29	85.44	85.09
	SD	10.90	11.24	10.58
	Range	56-111	56-111	59-103
PSI				
	M	89.71	88.30	91.55
	SD	11.37	11.95	10.42
	Range	68-123	68-121	75-123

Note: N = number of cases; Age = age at testing in months; FSIQ = WISC-IV Full Scale IQ; VCI = WISC-IV Verbal Comprehension Index score; PRI = WISC-IV Perceptual Reasoning Index score mean Verbal Comprehension, Perceptual Reasoning, Working Memory, and Processing Speed Index scores were generally within the Low Average to Average range. Given that the sample was selected due to identified learning difficulties, it is not surprising that the mean academic achievement scores for the sample as a whole were below the 25^{th} percentile, or within the Low Average to Borderline range of functioning, across the WIAT-II subtests, including Phonological Decoding (M = 81.25, SD = 13.43), Word Reading (M = 77.98, SD = 15.64), Reading Comprehension (M = 83.37, SD = 15.76), Spelling (M = 76.72, SD = 14.99), Numerical Operations (M = 75.74, SD = 15.78), and Mathematical Reasoning (M = 78.96, SD = 14.09).

Means and standard deviations for the global Index scores on the WRAML2, as well as the individual subtest scores which were used in the cluster analyses, are presented in Table 2. The mean WRAML2 General Memory Index score for the sample was within the Low Average range. The General Memory Index score is comprised of the Verbal Memory, Visual Memory, and Attention/Concentration Index scores. The mean Verbal Memory Index, Visual Memory Index, and Attention/Concentration Index scores were within the Low Average to Average range. As the subtest scores are already in the same metric (scaled scores; M = 10, SD = 3), no standardization procedure was required. Because the present sample was thought to be characterized by heterogeneity, univariate outliers were considered part of the target population and retained for further analyses.

6.1 Phase 1: Initial Cluster Analysis

Examination of the agglomeration coefficients, dendograms, changing cluster profiles, and individual cluster profiles generated by the Ward's analysis strongly suggested that either five- or eight- clusters would provide the best description of the data. To correct for fusion errors, a k-means relocation pass was applied to the first stage cluster centroids from each solution.

Table 2

Mean WRAML2 Index and Subtest Scores for the Entire Sample

WRAML2 Index and Subtest Scores	*M*	*SD*
General Memory Index	87.10	11.99
Verbal Memory Index	91.41	12.90
Story Memory Subtest	8.51	2.91
Verbal Learning Subtest	8.59	2.48
Visual Memory Index	94.07	13.50
Picture Memory Subtest	9.69	2.48
Design Memory Subtest	8.34	3.15
Attention/Concentration Index	85.97	11.43
Number Letter Subtest	8.37	2.82
Finger Windows Subtest	6.96	2.74
Verbal Working Memory	7.85	2.47

Note. N = 101

6.2 Phase 2: Replication and Cross-Classification

To establish the replicability (internal validity) of the WRAML2 taxonomy, three additional two-stage cluster analyses were performed to enable comparisons of solutions derived through different clustering methods: complete linkage, average linkage-within groups, and average linkage-between groups. Based on the initial Ward’s analysis, five- and eight-cluster solutions were generated for each method. A k-means relocation pass was applied to the first stage cluster centroids from each solution. Each of the four hierarchical methods was then compared separately for five- and eight-cluster solutions and the resulting mean profiles were examined for interpretability.

Comparison of the initial Ward's analysis to the solution generated following k-means analysis resulted in the fewest number of children being reassigned to other clusters (10.9% and 7.9% for the five- and eight-cluster solutions, respectively). Only slightly more children were reclassified when the average linkage-within groups method was used (10.9% and 12.9% for the five- and eight-cluster solutions, respectively). A greater number of children were reassigned with the complete linkage (16.8% and 19.8% for the five- and eight-cluster solutions, respectively) and average linkage-between groups methods (34.6% and 20.1% for the five- and eight-cluster solutions, respectively).

The level of agreement between cluster solutions generated using the various methods was examined using Cohen's kappa. For the five-cluster solution, the highest level of agreement was obtained for Ward's method with substantial agreement with the complete linkage (κ = 0.624, SE = .057), average-linkage between (κ = 0.635, SE = .057), and average linkage within (κ = 0.737, SE = .051) methods. The agreement between the complete linkage method and the average linkage between (κ = 0.653, SE = .058), and within (κ = 0.476, SE = .061) methods was moderate-to-substantial. The agreement between the average-linkage between groups and within groups methods was within the moderate range (κ = 0.536, SE = .060).

The agreement for the eight-cluster solution was poor (ranging from κ = 0.148 to κ = 0.238) and the solutions derived from each method were varied, making matched comparison difficult. The solutions generated by the complete linkage, average linkage-between groups, and average linkage- within groups all generated at least one cluster which contained only one individual. Based on these results, the eight-cluster solution was eliminated from remaining analyses and thus the five-cluster solution was chosen as the best solution for the data.

As a second measure of agreement between the cluster solutions, intraclass correlations were calculated between the cluster assignments derived through the four hierarchical methods. Ward's method demonstrated the highest correlations with each of the other hierarchical methods, with correlations ranging from .626 to .837.

Collectively, these results indicate that all four hierarchical methods produced subtypes with similar WRAML2 profiles for the five-cluster solution. The Ward's five-cluster solution was chosen for subsequent analyses because it demonstrated the greatest correspondence with each of the comparison methods, and because the resultant mean WRAML2 profiles appeared to be clinically meaningful. Due to the moderate agreement with other clustering methods, the five-cluster solution generated by Ward's method, followed by k-means correction, was judged to be internally consistent.

Prevalence, mean age, and mean General Memory Index (GMI), Verbal Memory Index (VBI), Visual Memory Index (VMI), and Attention/Concentration Index (ACI) scores for each subtype are presented in Table 3. There were no differences in gender distribution, $\chi^2(4) = 1.347$, $p = .853$, or age distribution, F $(4, 96) = .669$, $p = .615$, based on cluster membership. Descriptive labels were assigned to the five clusters based on the most salient features of each profile. Mean WRAML2 subtest scores by subtype are presented in Figure 1.

The first cluster, characterizing 22.8% of the participants (n = 23; 14 males, 9 females), demonstrated Low Average performance across the WRAML2 Index scores, with performance on the Design Memory subtest falling two standard deviations below the mean, and performance on the Story Memory, Picture Memory, and Finger Window subtest scores falling at least one standard deviation below the mean. Due to their consistent Low Average performance on the Index scores, the first cluster was labelled Low Average Memory.

The second cluster was comprised of 24.7% of the participants (n = 25; 13 males, 12 females). The profile was characterized by scores within the Average range on all of the subtests with the exception of Extremely Low performance on the Finger Windows subtest. Given the intact functioning across memory subtests, with an isolated weakness on the Finger Windows subtest, which is a measure of attention and short-term memory in the visual domain, this subtype was designated Weak Visuospatial Sketchpad.

Table 3

Prevalence, Age, and Mean General Memory Index (GMI), Verbal Memory Index (VBI), Visual Memory Index (VMI), and Attention/Concentration Index (ACI) Scores for Each Subtype

Cluster	Prevalence n (%)		Age	GMI	VBI	VMI	ACI
1 Low Average Memory	23 (22.8)	*M*	135.57	80.87	86.74	81.26	89.43
		SD	28.91	5.45	7.01	9.33	11.86
2 Weak Visuospatial Sketchpad	25 (24.7)	*M*	140.88	90.84	96.44	97.96	85.96
		SD	25.99	6.47	8.77	7.13	10.13
3 Weak Phonological Loop and Central Executive	26 (25.7)	*M*	146.38	91.27	92.69	103.23	85.81
		SD	26.70	5.23	9.02	7.20	7.98
4 Borderline Memory	17 (16.8)	*M*	143.88	70.65	75.71	82.65	74.18
		SD	24.48	5.52	7.37	9.87	8.99
5 Average Memory	10 (9.9)	*M*	148.60	109.20	112.90	109.40	98.50
		SD	30.81	6.41	9.60	12.18	6.82

Note: N = 101; Age = age at testing in months

The third cluster was comprised of 25.7% of participants (n = 26; 13 males, 13 females). These participants were characterized by a significant discrepancy between the Average Visual Memory Index score and Low Average Attention/Concentration Index score. Examination of the individual subtests revealed that this subtype performed within the Average range on all of the subtests with the exception of performance more than one standard deviation below the mean on the Letter Number and Verbal Working Memory subtests. Due to their weaker performance on measures of auditory attention, short-term memory, and working memory, this cluster was labelled Weak Phonological Loop and Central Executive.

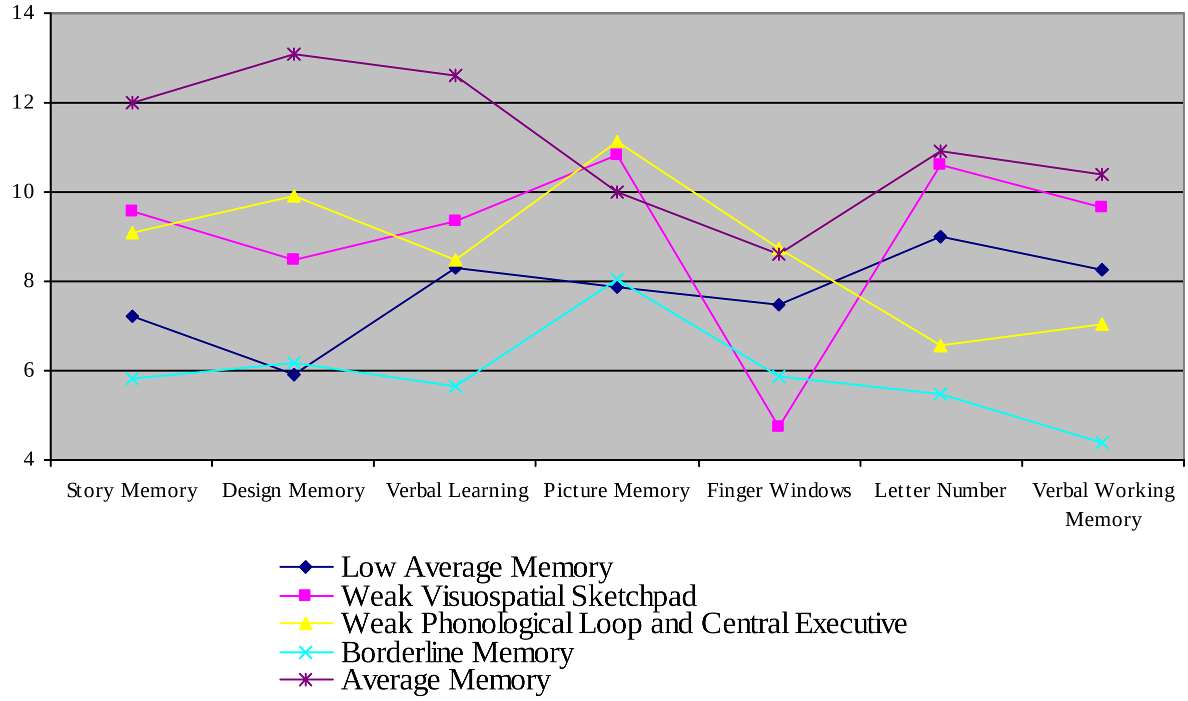

Figure 1: <u>Mean WRAML2 Profile by Subtype</u>

The fourth cluster comprised 16.8% of the participants (n = 17; 11 males, 6 females). Participants in this cluster were characterized by generally poor memory performance. Although the majority of the subtests fell two or more standard deviations below the mean, performance on the Picture Memory subtest fell within the Average range. This cluster was labelled Borderline Memory due to the overall level of performance within the Borderline range of functioning.

The fifth cluster was the smallest and was comprised of 9.9% of the participants ($n = 10$; 6 males, 4 females). This cluster was characterized by Average performance with all of the Index scores falling within the Average range. Due to the unimpaired nature of the memory performance of the participants, the cluster was labelled Average Memory.

6.3 Phase 3: Examining the External Validity of the Derived Typology

ADHD co-morbidity, WRAML2 delayed memory subtest scores, WISC-IV Index scores, and WIAT-II subtest scores were compared between the groups to determine the external validity of the derived memory subtypes, as well as to assist with further description of the specific clusters.

The percentage of children diagnosed with ADHD who were classified in the various subtypes is presented in Table 4. Of note, approximately one-third of the children classified within the Weak Visuospatial Sketchpad and Weak Phonological Loop and Central Executive subtypes had been diagnosed with co-morbid ADHD. In contrast, no children with ADHD were classified into the Average Memory subtype.

A chi-square analysis examined whether the there was a “good fit” between the observed data and an even distribution of children with ADHD across the clusters of children with LD. The chi square statistic was significant X^2 (4) = 9.855, $p = .043$, indicating that the distribution of children with ADHD was different from that which would be expected if there was even distribution of children with ADHD in the five cluster solution.

Table 4

ADHD Co-morbidity for Participants in Each of the Five WRAML2 Subtypes

WRAML2 Cluster	ADHD Diagnosis (% of cluster)
Low Average Memory (n = 23)	3 (13%)
Weak Visuospatial Sketchpad (n = 25)	7 (28%)
Weak Phonological Loop and Central Executive (n = 26)	9 (34.6%)
Borderline Memory (n = 17)	1 (5.9%)
Average Memory (n = 10)	0 (0%)

Note: N = 101

The second group of variables examined was performance on the WRAML2 delayed memory subtests. An ANOVA revealed significant differences between the subtypes on all of the WRAML2 delayed memory subtests, with the exception the Picture Memory Recognition subtest. See Table 5 for mean scores, *F* statistic, and effect size. The mean delayed memory subtest scores are displayed by subtype in Figure 2. To control for the high number of comparisons, the Bonferroni correction was applied to specify a minimum level of alpha .008 (.05/6).

Post hoc comparisons between the clusters indicated significant differences between the Average Memory subtype on one hand and the Low Average Memory and Borderline Memory groups on the other hand across the delayed memory subtests, with the exception of the Picture Memory subtest where performance did not significantly differ between the groups. The performance of the Average Memory group also differed significantly from the Weak Phonological Loop and Central Executive subtype on many of the verbal delayed memory subtests (Story Memory Free Recall, Verbal Memory Free

Table 5

Means, Standard Deviations, Univariate F Scores, and Effect Size for Differences in WRAML2 Delayed Memory Subtest Scores Based on Cluster Membership

	Cluster							
WRAML2 Subtest Scores	1	2	3	4	5	F	p	η^2
Story Memory Free Recall								
M	6.60^{a}	9.52^{bc}	8.92^{b}	6.24^{a}	11.70^{c}	14.31	.000	.374
SD	2.19	2.57	2.38	1.75	2.21			
Story Memory Recognition								
M	8.22^{ab}	10.24^{bc}	10.19^{bc}	6.76^{a}	11.30^{c}	7.82	.000	.246
SD	2.71	3.33	2.40	2.31	1.25			
Verbal Learning Free Recall								
M	8.35^{a}	9.24^{ab}	8.00^{a}	6.06^{d}	11.10^{b}	12.13	.000	.336
SD	2.04	1.62	2.51	1.03	2.18			
Verbal Learning Recognition								
M	8.39^{ab}	10.12^{bc}	8.00^{a}	6.24^{a}	11.30^{c}	9.98	.000	.294
SD	2.13	2.30	3.29	1.64	1.77			
Design Memory Recognition								
M	7.22^{a}	8.64^{ab}	9.69^{bc}	7.00^{a}	12.20^{c}	11.08	.000	.316
SD	1.68	2.51	2.36	2.00	3.64			
Picture Memory Recognition								
M	7.70^{a}	8.56^{a}	9.38^{a}	8.71^{a}	10.00^{a}	2.33	.062	.088
SD	2.40	2.00	2.59	2.71	1.94			

Note: Cluster 1 = Low Average Memory; Cluster 2 = Weak Visuospatial Sketchpad; 3 = Weak Phonological Loop and Central Executive; 4 = Borderline Memory; 5 = Average Memory. Means in the same row that do not share superscripts differ at the *p* < .05 in the post hoc comparison.

Recall, Verbal Learning Recognition), as well as the Weak Visuospatial Sketchpad subtype on one of the visual delayed memory subtests (Design Memory Recognition). With the exception of a significant difference between their performances on the Verbal Learning Recognition subtest, the Weak Visuospatial Sketchpad and Weak Phonological Loop and Central Executive subtypes performed similarly, scoring significantly above the Borderline Memory group across the majority of the delayed verbal memory subtests

(Story Memory Free Recall, Story Memory Recognition, and Verbal Learning Free Recall).

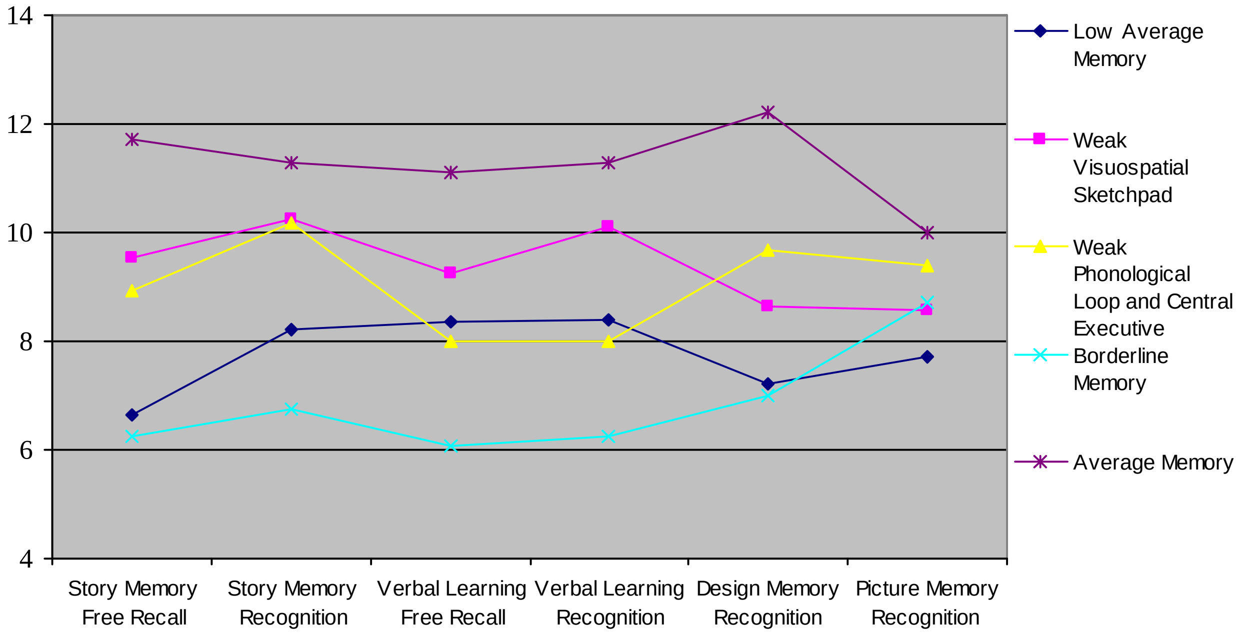

Figure 2: Mean Profile for Each WRAML2 Subtype on WRAML2 Delayed Memory Subtests

The third group of variables to be examined comprised the Index scores from the WISC-IV. The mean WISC-IV Index scores for each subtype are presented in Table 6. Mean WISC-IV Index scores are plotted by subtype in Figure 3. ANOVAs were used to compare WISC-IV Index scores across the individual memory subtypes. To control for the high number of comparisons, the Bonferroni correction was applied to specify a minimum level of alpha .01 (.05/5). Significant differences were found among all of the subtypes.

Post hoc comparisons of mean differences between clusters on the various Index scores of the WISC-IV indicated that the Average Memory subtype obtained significantly better scores than the Borderline Memory subtype across the FSIQ, PRI, WMI, and PSI

Table 6

Means, Standard Deviations, Univariate F Scores and Effect Size for Differences in WISC-IV Index Scores Based on Cluster Membership

	Cluster							
WISC-IV Index Scores	1	2	3	4	5	F	p	η^2
FSIQ								
M	84.30[a]	91.08[bc]	86.35[ab]	81.06[a]	98.20[c]	10.31	.000	.301
SD	6.49	8.25	8.43	6.59	8.46			
VCI								
M	88.57[a]	97.60[b]	88.35[a]	89.88[ab]	96.70[ab]	3.91	.006	.140
SD	9.74	10.34	10.67	11.91	10.00			
PRI								
M	87.43[a]	91.88[a]	94.12[a]	89.47[a]	106.10[b]	5.47	.001	.186
SD	7.77	8.66	13.67	13.16	11.30			
WMI								
M	85.30[ac]	93.80[b]	82.23[a]	72.76[d]	93.20[bc]	19.61	.000	.450
SD	8.72	7.02	9.37	7.90	7.39			
PSI								
M	89.52[ab]	89.12[ab]	91.04[ab]	83.12[a]	99.40[b]	3.72	.007	.134
SD	11.87	11.14	9.28	8.84	13.78			

Note: Cluster 1 = Low Average Memory; Cluster 2 = Weak Visuospatial Sketchpad; 3 = Weak Phonological Loop and Central Executive; 4 = Borderline Memory; 5 = Average Memory. Means in the same row that do not share superscripts differ at the $p < .05$ in the post hoc comparison.

scores. In fact, the Average Memory subtype performed significantly above all of the other subtypes on the PRI score. The Weak Visuospatial Sketchpad subtype scored significantly higher than the Weak Phonological Loop and Central Executive subtype on Indices representing the most verbally-mediated tasks, the VCI and the WMI. Consistent with their weaker performance on the WRAML2 subtests assessing auditory attention and working memory, the Weak Phonological Loop and Central Executive subtype scored significantly below the Average Memory subtype on the WMI score. The

Borderline Memory group performed significantly below all of the other subtypes on the WMI score.

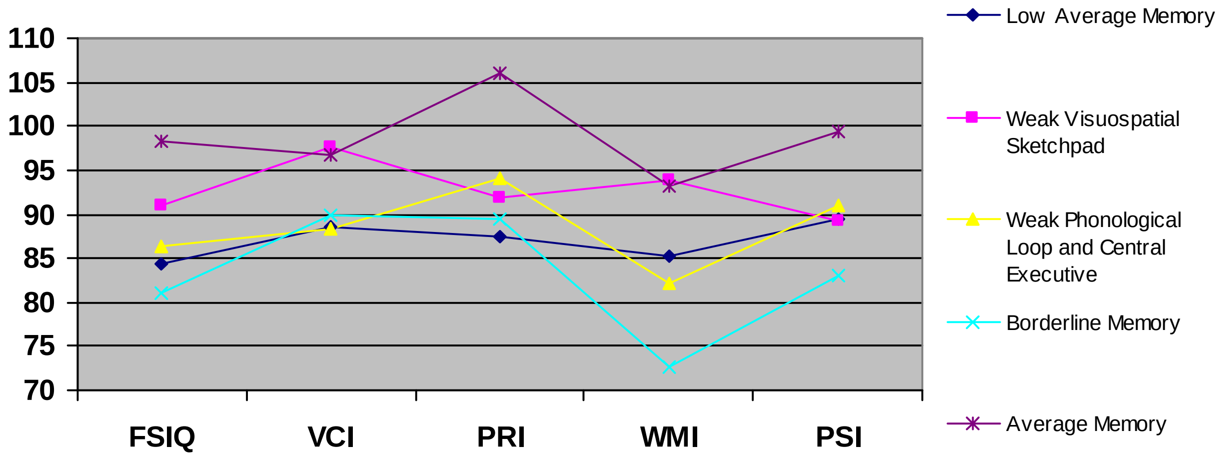

Figure 3: Mean WISC-IV Index Scores by WRAML2 Subtype

The final group of variables used for external validation was academic achievement, as measured using the subtests of the WIAT-II. Mean WIAT-II subtest scores by profile are presented in Table 7. Mean WIAT-II subtest scores by subtype are plotted in Figure 4. Due to the high number of comparisons, the Bonferroni correction was applied to specify a minimum level of alpha of .008 (.05/6). The groups differed significantly on the Reading Comprehension, Numerical Operations, and Mathematical Reasoning subtests.

Post hoc comparison of mean differences between clusters on the various academic achievement subtests revealed a significant difference between the Average Memory subtype and Low Average Memory subtype on the Reading Comprehension subtest. On the Numerical Operations subtest, the Average memory subtype scored significantly higher than the Borderline Memory subtype. The Borderline Memory subtype and the Low Average Memory subtype scored significantly lower than all of the other subtypes on the Math Reasoning subtest.

Table 7

<u>Means, Standard Deviations, Univariate F Scores and Effect Size for Differences in WIAT-II Subtest Scores Based on Cluster Membership</u>

	Cluster							
WIAT-II Subtest Scores	1	2	3	4	5	F	p	η^2
Pseudoword Decoding								
M	78.65[a]	83.00[a]	81.92[a]	76.47[a]	89.20[a]	1.807	.134	.038
SD	14.56	12.54	13.27	10.28	15.84			
Word Reading								
M	75.87[a]	78.08[a]	78.88[a]	75.71[a]	85.80[a]	.936	.447	.133
SD	17.58	17.24	13.22	12.42	17.55			
Reading Comprehension								
M	76.22[a]	84.56[ab]	88.31[ab]	77.94[ab]	93.20[b]	3.693	.008	.070
SD	13.82	17.26	13.52	12.38	18.74			
Spelling								
M	73.00[a]	79.52[a]	80.00[a]	72.53[a]	76.90[a]	1.226	.305	.145
SD	18.00	12.43	14.70	10.28	19.57			
Numerical Operations								
M	70.26[ab]	79.08[ab]	79.96[ab]	66.65[a]	84.50[b]	4.061	.004	.280
SD	15.86	15.64	13.63	12.60	17.38			
Mathematical Reasoning								
M	72.52[a]	84.04[b]	82.88[b]	67.47[a]	90.40[b]	9.314	.000	.049
SD	11.63	13.71	11.45	11.53	12.52			

Note: Cluster 1 = Low Average Memory; Cluster 2 = Weak Visuospatial Sketchpad; 3 = Weak Phonological Loop and Central Executive; 4 = Borderline Memory; 5 = Average Memory. Means in the same row that do not share superscripts differ at the $p < .05$ in the post hoc comparison.

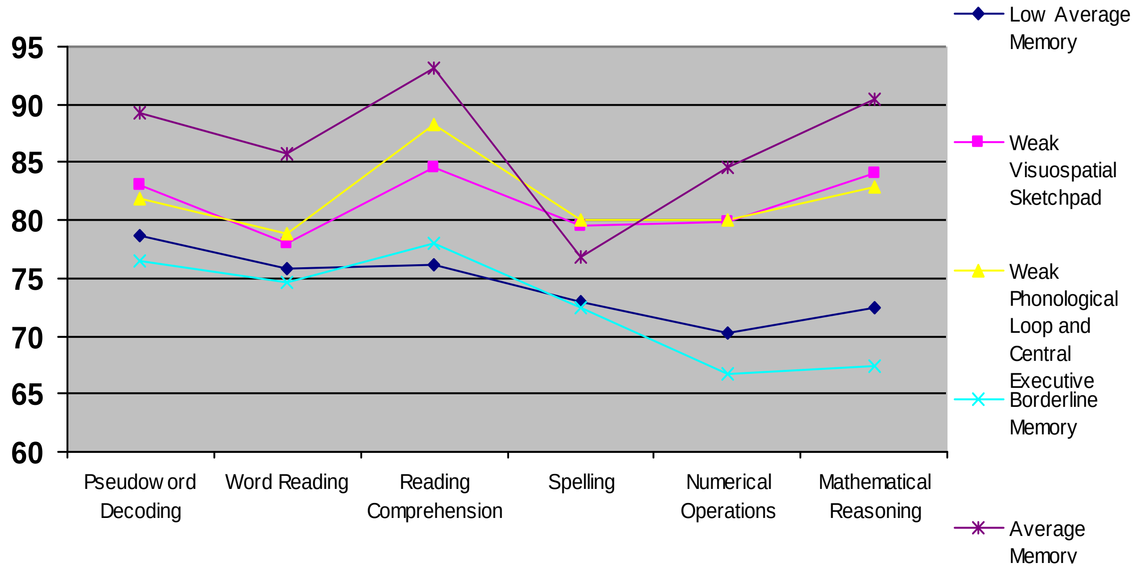

Figure 4: <u>Mean WIAT-II Subtest Scores by WRAML2 Subtype</u>

Chapter 7: Discussion

The objective of the present study was to identify reliable and meaningful memory profiles in children and adolescents diagnosed with a learning disability. Comparison of the results obtained using several two-stage cluster analyses strongly suggested the presence of five distinct memory subtypes. Three of the five clusters could be differentiated primarily by level of performance (Average, Low Average, and Borderline scores on the majority of subtests). The other two clusters, although Average in terms of GMI, were differentiated by pattern of performance (weak visuospatial short-term memory and weak auditory short-term memory and working memory). The finding of multiple memory profiles confirms the heterogeneity of memory functioning in children and adolescents with learning disabilities.

Consistent with the approach used in previous taxonomic research, reliability was assessed through comparison of cluster solutions derived using four different hierarchical clustering algorithms. The Ward's method five-cluster solution demonstrated the highest kappa values and was clinically meaningful and was therefore selected as being most representative of the data. The good agreement between all four clustering methods was taken to suggest that the current five-cluster solution was reliable.

A secondary purpose of this study was to examine ADHD co-morbidity and psychometric test findings from measures of delayed memory, intellectual functioning, and academic achievement associated with subtype membership as a means of demonstrating the external validity of the derived cluster solutions. The five subtypes exhibited distinct patterns of performance on measures of delayed memory, intellectual functioning, academic achievement, and rates of co-morbid ADHD diagnosis, suggesting that the memory profiles are valid and potentially clinically meaningful. Taken together, the findings confirm the hypothesis that a reliable memory typology can be identified in a sample of children and adolescents with learning disabilities.

7.1 Memory Subtypes

The Average Memory subtype was characterized by Average to High Average performance across the memory subtests. Similar subtypes were identified in the Atkinson et al. (2008) study, based on the WRAML2 standardization sample, and in the Howes et al. (1999) study that identified a subtype of 'good readers' with no memory deficits. This finding is important as it suggests that not all children with learning disabilities demonstrate impaired memory functioning. At the same time, this group was comprised of only 10% of the sample, suggesting that intact memory functioning is not typical of children with learning disabilities. As hypothesized the low percentage of individuals with Average memory skills in the current study was much smaller than the approximately 40% of individuals with average memory abilities found in the WRAML2 standardization sample (Atkinson et al., 2008).

It was interesting to note that this group also scored within the Average range on measures of delayed memory and intellectual functioning, although they performed below age level expectations on measures of academic achievement, including Pseudoword Decoding, Word Reading, Spelling, and Numerical Operations. This suggests that a processing deficit not assessed by the WISC-IV or WRAML2 accounted for their fairly global academic deficits. Interestingly, a group with high verbal and perceptual-reasoning skills and no identifiable impairments has also been consistently identified in previous cluster analytic studies based on samples of children with learning disabilities (D'Amato et al., 1998; Lyon, 1985; Snow et al., 1985).

The current five-cluster solution included a subtype with Low Average performance across the WRAML2 Index scores, which was accordingly named Low Average Memory. In evaluating the patterns of memory performance in the WRAML2 standardization sample, Atkinson et al. (2008) identified a similar subtype that was described as having generally below average performance on measures of memory. An examination of the demographics of the individuals within the generally below average cluster in the Atkinson et al., study showed that more than twice the expected proportion of participants with this profile attained less than a high school diploma and significantly fewer than would be expected attended college or at least completed a college degree. Given that individuals with learning disabilities drop out of high school at higher rates than the general population (U.S. Department of Education, 2007) and a much lower percentage of students with a LD attend a four-year post-secondary program within two years of leaving high school (National Longitudinal Study II, 2003), it is possible that individuals with learning disabilities were overrepresented within this cluster in the Atkinson et al. study.

Consistent with their below average performance on the WRAML2 memory subtests, the Low Average Memory group in this study performed consistently below average across measures of delayed memory and intelligence. Academically, this group performed well below age appropriate expectations across measures of reading and spelling, with the most pronounced deficits in the area of mathematics. A group with mixed language and perceptual impairment has consistently been found in previous cluster analytic studies (D’Amato et al., 1998; Lyon, 1985; Snow et al., 1985) with globally low academic performance (Waxman & Casey, 2006).

The current memory typology also revealed a subtype with generally poor performance across the memory subtests, with performance within the Borderline range across all of the subtests save for the Picture Memory subtest, which corresponded to the low end of the Average range. A similar, but somewhat stronger, performance profile was identified in the WRAML2 standardisation sample that was described as having slightly below average memory with elevated picture memory skills (Atkinson et al., 2008). The individuals who demonstrated this profile within the Atkinson et al. study had less than half of the expected percentage of participants who had attained at least a college degree, while a greater proportion had yet to attain a high school diploma. This finding again raises the question of whether the individuals who comprised the slightly below average memory with elevated picture memory skills in the Atkinson et al. study may have included a greater than expected proportion of individuals with disabilities.

The Borderline Memory subtype demonstrated low ability generally across measures of delayed memory, with the exception of their stronger performance on the Picture Memory Recognition subtest. These findings suggest that in contrast to their poorly developed short-term memory, working memory, verbal memory, and memory for abstract visual designs, individuals within this cluster demonstrate an isolated strength in their immediate and long-term memory for meaningful visual information. In terms of their intellectual functioning, they generally performed within the Low Average range, with a significant weakness in their performance on the Working Memory Index score. Thus, this group appears to have a substantial deficit in the area of attention and working memory, as evidenced by their poor performance on measures of attention and working memory on both the WISC-IV and WRAML2. Academically, they displayed global academic deficits. This finding is not surprising in light of the large body of research identifying the critical role that working memory plays in academic development (e.g., Alloway, 2009; Alloway & Gathercole, 2006; Gathercole, Lamont, & Alloway, 2006; Kibby et al., 2004; Nation, Adams, Bowyer-Crane, & Snowling, 1999; Passolunghi, 2006; Passolunghi & Siegel, 2001; Pickering, 2006; Swanson & Sachse-Lee, 2001; Swanson & Saez, 2003; Van der Sluis et al., 2005; Vellutino et al., 2004).

It is interesting to note the correspondence between level of performance on the measures of intellectual functioning and academic achievement, on one hand, and performance on the WRAML2 memory subtests used in the initial analysis, on the other, in the three subtypes differentiated by level of performance. Examination of their mean scores on Figure 1, 2, 3, and 4 reveals a strikingly consistent level of performance across the psychometric measures, with little variability. The close correspondence between scores on measures of memory, intelligence, and academic achievement is consistent with research demonstrating the strong association among these factors (e.g., Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Colom & Shih, 2004; Daneman & Carpenter, 1980; Engle, 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Gathercole, Pickering, Knight, & Stegmann, 2004; Kyllonen & Christal, 1990; Williams & Pearlberg, 2006).

Two additional subtypes were identified that exhibited isolated deficits in areas of working memory. Members within the Weak Phonological Loop and Central Executive subtype demonstrated weak performance on the Number Letter and Verbal Working

Memory subtests, whereas they performed within the Average range on the remainder of the subtests. Individuals with dyslexia in the Howes et al. (1999) study displayed a similar subtype that exhibited weak or impaired verbal auditory sequential memory and auditory working memory/attention skills, in contrast to adequately developed visual attention and memory skills. A similar subtype was not identified within the WRAML2 standardization sample (Atkinson et al., 2008). However, it should be noted that the Atkinson et al., study did not include the Verbal Working Memory subtest from the WRAML2 in their clustering procedure. The identification of this subtype within a study based on a sample of individuals with learning disabilities is not surprising given the volume of research demonstrating learning difficulties in children with impaired functioning of the phonological loop (e.g., Geary et al., 2000; Pickering & Gathercole, 2004; Siegel & Linder, 1984; Siegel & Ryan, 1988) and central executive (e.g., Censabella & Noel, 2005; Geary et al., 1992; Geary et al., 1991; Geary et al., 2000; Pickering & Gathercole, 2004; Siegel & Ryan, 1988). Given the verbal nature of the Verbal Working Memory subtest, however, it is unclear whether the deficit displayed on this subtest was related to their poor PL storage capacity or whether it represents an additional deficit in their ability to mentally process the information. Of note in this regard is the 11 point discrepancy between the verbal and visual memory Index scores, as well as a discrepancy between their VCI and PRI (in favour of the latter), and underachievement on all of the academic measures. This profile appears to be similar to a language disordered subtype that has been found in previous cluster analytic studies (Boder, 1973; Guerin, Griffin, Gottfried, & Christenson, 1993; Konold et al., 1999;

Shaywitz, Shaywitz, Fletcher, & Escobar, 1990; Ward et al., 1999; Waxman & Casey, 2006).

A subtype characterized by performance within the Average range on all of the subtests with the exception of performance within the Extremely Low range on the Finger Windows subtest was also identified in the current typology. The Finger Windows subtest appears to assess visual attention and short-term memory, processes thought to be mediated by the VSSP. A similar subtype with a pure deficit on a measure of the VSSP was not identified in previous memory subtyping studies with either the WRAML2 standardization sample (Atkinson et al., 2008) or among children diagnosed with dyslexia (Howes et al., 1999). However, given recent research suggesting that VSSP functioning only impacts on arithmetic development and not on the development of reading (Simmons, Singleton, & Horne, 2008), it is not surprising that a subtype with an isolated impairment in VSSP functioning was not found in the Howes et al. sample, which was comprised of children who exhibited reading deficits only. Although it did not approach significance, there was a trend towards lower scores on the visual delayed memory subtests and the WISC-IV Index scores that are based on visually-mediated measures (PRI and PSI). This subtype performed consistently below age-level expectations on measures of academic functioning. Subtypes demonstrating Average intellectual functioning with somewhat better developed verbal than visual skills have been found in the standardization sample of the WISC-III (Konold et al., 1999) and in a sample of children referred to an outpatient neuropsychological clinic (Waxman & Casey, 2006). Although it might be expected based on previous research that children and adolescents with a VIQ- PIQ discrepancy (in favour of the former) may exhibit somewhat stronger reading ability than arithmetic skills (e.g., Rourke & Finlayson, 1978; Rourke & Strang, 1978; Share, Moffit, & Silva, 1988; Strang & Rourke, 1983; White Moffitt, & Silva, 1992), this was not the case in the present study as the Weak Visuospatial Sketchpad subtype displayed generalized academic deficits in the areas of reading, spelling, and arithmetic. This finding is consistent with recent research that has demonstrated that when children's short-term memory abilities are measured according to the same normative base for all tasks, relative weaknesses in visual short-term memory are not present in children with isolated arithmetic deficits compared to children with co-morbid reading and arithmetic deficits (Silver, Ring, Pennett, & Black, 2007).

7.2 Validation of the Memory Typology

The external validity of the cluster solutions was explored in a number of ways. The five subtypes exhibited distinct patterns of performance on measures of delayed memory, intellectual functioning, and academic achievement. Also, the groups differed in the rate of co-morbid ADHD, the results together suggesting that the memory profiles are valid and potentially clinically meaningful.

First, the various subtypes were compared on the basis of their prevalence of individuals with co-morbid ADHD. This comparison provided the most robust support for subtype distinctiveness. There was a statistically significant difference between the groups, with the highest concentration of students with ADHD in the Weak Visuospatial Sketchpad and Weak Phonological Loop and Central Executive groups, comprising approximately one-third of the participants in these subtypes. Consistent with the finding of isolated deficits in aspects of working memory in contrast to adequately developed long-term memory performance in the groups with the highest concentration of students with ADHD, multiple studies (e.g., Adams et al., 1991; Cahn & Marcotte, 1995; Kaplan et al., 1998) have found strong evidence that individuals with ADHD demonstrate impairments on measures of attention and concentration, while their long-term memories are intact. In contrast, no children with ADHD fell within the Average Memory subtype. This finding is consistent with the recent findings of Mayes and Calhoun (2007), who found that ADHD is unlikely if a child does not display a relative weakness on measures of attention and working memory, such as the WMI or PSI of the WISC-IV.

Performance on measures of delayed memory was also compared across clusters. Statistically significant differences were found on all of the delayed memory subtests, with the exception of the Picture Memory Recognition subtest. This finding was not surprising given the relationship between immediate and delayed memory measures. That is, even though the delayed measures were not used to derive the subtypes, the immediate and delayed measures are correlated. Post hoc pairwise comparisons revealed statistically significant differences between the Average Memory subtype on the one hand and the Low Average Memory and Borderline Memory subtypes on the other hand across the delayed memory subtests, with the exception of the Picture Memory subtest. The performance of the Average Memory group also differed significantly from the Weak Phonological Loop and Central Executive subtype on many of the verbal delayed memory subtests (Story Memory Free Recall, Verbal Memory Free Recall, and Verbal Learning Recognition). This finding is consistent with previous research that has demonstrated that children with weak language processing skills demonstrate impairment on measures of story recall (O'Neill & Douglas, 1991) and verbal list learning tasks (Fletcher, 1985; Kramer et al., 2000). Consistent with the findings of Kramer et al., (2000), the low performance displayed across the verbal delayed memory free recall and recognition tasks seems to suggest that the impairment rests at the level of encoding. The Weak Visuospatial Sketchpad subtype performed significantly below the Average Memory subtype on one of the visual delayed memory subtests (Design Memory Recognition). Difficulty organising visual information and developing an efficient encoding strategy (Brandys & Rourke, 1991) has previously been identified in individuals with a weakness in visual-spatial analysis skills relative to better developed verbal abilities.

The validity of the cluster solution was also explored by comparing the derived subtypes on the Index scores from the WISC-IV. Significant group differences were found across the Index scores. Post hoc comparisons revealed that the Average Memory subtype generally outperformed the Borderline Memory subtype, with significant differences between the groups on the FSIQ, PRI, WMI, and PSI scores. Although the Weak Visuospatial Sketchpad subtype performed similarly to the Average Memory subtype across the verbally-mediated Index scores (VCI and WMI), they scored significantly below the Average Memory group on the Index score representing the most visual-perceptual subtests (PRI). Consistent with their weakness in auditory attention and working memory, the Weak Phonological Loop and Central Executive group scored significantly below the Average Memory group on the WMI.

Comparison of the groups on measures of academic achievement was also used to validate the cluster solution. Although the groups differed significantly on measures of Reading Comprehension, Numerical Operations, and Math Reasoning, no statistically significant differences were found on measures of Pseudoword Decoding, Word Reading, and Spelling. Post hoc pairwise comparisons revealed that most of the statistically significant differences were between the Average Memory group on one hand and the other lower ability groups on the other (Low Average Memory and Borderline Memory). In fact, it appeared that the significant differences were driven mainly by the average performance of the Average Memory subtype on measures that required reasoning as well as basic literacy and numeracy skills (Reading Comprehension, Mathematical Reasoning), in contrast to the poor performance of the Low Average Memory and Borderline Memory groups on these subtests.

The low number of significant differences between the groups on measures of academic achievement and the generally globally impaired performance across the groups on measures of reading, spelling, and mathematics was surprising. It is interesting to note, however, that there was seemingly a correspondence between degree of memory impairment, or number of memory areas impaired, and degree of academic impairment, such that the individuals with no memory impairment displayed the highest academic performance while the individuals with globally impaired memory displayed the lowest academic performance. It has been proposed that children with memory impairment struggle to meet the memory demands of individual learning episodes resulting in a failure to acquire the knowledge and skills necessary for competence in key academic domains, such as reading and math (Gathercole et al., 2006). It is also possible that the memory impairment, per se, does not affect specific literacy or numeracy skill development, but is only related to other factors which may have a direct impact. This finding is consistent with recent research which suggests that factors, such as speech processing skills, have a direct influence on literacy development, while IQ and memory have no direct influence but are correlated with the crucial predictive factors (Shapiro, Hurry, Masterson, Wydell, & Doctor, 2009). Based on the research of Shapiro et al., children with good memory skills would be likely to also perform well on speech and auditory tasks. However, it would be their speech and auditory skills that crucially influenced their literacy development, not their memory skills. It is also noteworthy that 90% of individuals in this sample displayed impairment in at least one area of working memory. Alloway, Gathercole, Kirkwood, and Elliot (2009) recently identified a group of children with low working memory scores. The majority of these children struggled across reading and math tasks.

7.3 Implications

The most consistent finding in cluster analytic studies of children and adolescents with learning disabilities is the heterogeneity of the population. This study extends previous research examining the performance of children and adolescents with learning disabilities by confirming that the heterogeneity in fact also encompasses performance on a measure of memory and learning. This finding helps to explain the inconsistency of findings in previous studies examining the memory functioning of children and adolescents with learning disabilities.

The current study also provides some support for subtypes reported in previous cluster analytic studies of memory performance. A subtype relatively free of any significant memory difficulties (i.e., Average Memory subtype), a subtype with consistently below average performance on memory measures (i.e., Low Average Memory subtype), a subtype with relatively poor memory but a relative strength in memory for meaningful visual stimuli (i.e., Borderline Memory subtype), and a subtype marked with weak auditory attention and working memory (i.e., Weak Phonological Loop and Central Executive) were identified. While the former three subtypes were identified in the WRAML2 standardization sample, which included individuals with disabilities, the latter subtype was consistent with a subtype identified in the Howes et al. (1999) study of children with dyslexia.

In addition, one subtype identified, which exhibited an isolated weakness in the area of visuospatial short-term memory (i.e., Weak Visuospatial Sketchpad), was unique to the current study. It is possible that the inclusion of children and adolescents with both reading and mathematics disabilities, as well as children and adolescents with co-morbid ADHD explained the identification of this subtype in the current study. It is noteworthy, however, that almost one-quarter of the participants in this study were classified into this subtype. Although the Weak Visuospatial Sketchpad cluster performed almost identically to the Weak Phonological Loop and Central Executive subtype academically and included almost the same percentage of children with ADHD, their deficit in one area of working memory would not have been identified if they had not been given a measure of the VSSP. This finding highlights the importance of including a measure of the VSSP in a comprehensive assessment of memory and learning.

Finally, the substantial variability of memory performance in this sample of children and adolescents with learning disabilities reinforces the need to include a thorough battery of memory that examines various aspects of working memory, immediate memory, and delayed memory in the assessment of learning disabilities. Despite research that has attempted to use memory assets and deficits for specific learning disability subtypes (e.g., Basic Phonological Processing Disorder, Nonverbal

Learning Disability) to suggest strategies for intervention (see Rourke & Tsatsanis, 1995), the current findings failed to display memory profiles that were consistent with academic profiles typically used in multivariate studies. While a verbal/visual dissociation in short-term memory was revealed when children were classified by isolated reading disabilities or isolated arithmetic disabilities in early studies (Fletcher, 1985), subsequent research failed to support such a clear-cut distinction (e.g., Geary, Hamson, & Hoard, 2000; Kibby et al., 2004; van der Sluis et al., 2005). Thus, memory strengths and weaknesses cannot be assumed given specific academic profiles and each child should be provided with a complete battery of memory and learning tests to ensure that any recommendations related to memory are individualized to the needs of the specific child.

7.4 Limitations and Recommendations for Future Research

A few limitations must be highlighted when discussing the results of the current investigation. Recommendations for future research are made to address some of the limitations where applicable.

One potential limitation of the present study relates to the statistical methodology employed. Taxonomic research is viewed by some as a promising avenue of inquiry that continues to be hampered by methodological inconsistencies and unresolved questions (Lange, Iverson, Senior, & Chelune, 2002). Controversy over the degree of confidence that can be placed in cluster solutions continues due, at least in part, to the degree of subjectivity involved in conducting cluster analysis (Lange et al., 2002). Although efforts were made to ensure that the similarity coefficient, clustering algorithms, and measures of association used to demonstrate internal validity of the resultant cluster solution followed relatively conventional and empirically derived standards, ultimately some degree of subjectivity is required.

One advantage of this study is that external validation of the derived cognitive patterns was attempted. Even though the groups derived in the current study appeared to be valid because the subtypes were clinically meaningful, the groups were externally validated on measures of intellectual and academic functioning and rates of ADHD co-morbidity. Intervention studies of children with learning disabilities that take into account their memory subtype would provide another way to externally validate the typology derived in the current investigation.

Sample size may have had an impact on the cluster analysis use in this study. As samples become larger, less frequently occurring profiles have the opportunity to be identified as unique subtypes, rather than being subsumed into more general subtypes. Although the current study was based on an adequate sample size to employ cluster analysis, repetition of the study with a larger sample may reveal additional meaningful cluster subtypes. In addition, to ensure that there were an adequate number of cases to meet the minimum criteria necessary for the methodology used, a relatively broad age range was included in the study that ranged from 9 to 16 years of age. Also valuable would be research focussing on the stability of the typology across childhood, adolescence, and adulthood. Although some of the profiles identified in this study are similar to those found in the standardization sample which included individuals across the lifespan (Atkinson et al., 2008), it is possible that the nature of at least some of the students' profiles, and, consequently their cluster membership, change over time. This would be especially interesting given research demonstrating the stability of childhood working memory impairments into adulthood (Isaki & Plante, 1997).

Another possible limitation of this investigation stems from the sample characteristics. Although data on ethnic origin was not available for collection, based on the demographic characteristics of the population sampled, it is probably that the sample consisted of primarily Caucasian participants. Due to the findings of discrepancies in the composition of race/ethnicity within the various memory subtypes in the Atkinson et al. (2008) study, it is possible that replication of the study in a more racially/ethnically diverse sample may reveal a different pattern of results than obtained here. This would be an interesting point of inquiry for future investigations.

Another limitation of the present study is the lack of information available about ADHD subtype and whether the ADHD was being treated with psychostimulant medication at the time of testing. This information may have helped lead to a clearer understanding of why some children with ADHD fell within the various clusters.

Given that this investigation was the first to examine subtypes of WRAML2 scores in children with learning disabilities, it will be necessary to determine the reliability and validity of the five-cluster solution though replication and cross-validation with independent samples. Cluster analysis of WRAML2 data should be conducted on similar samples of children and adolescents with learning disabilities to determine whether the same mean profile patterns are replicated. Inclusion of children and adolescents without learning disabilities will be important to determine clinical versus non-clinical profiles.

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