# MEMORY PATTERNS IN CHILDREN WITH READING DISABILITIES, WITH AND WITHOUT AUDITORY PROCESSING DISORDERS

By

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To my parents and friends for their continued understanding and support, to Brook for his stability, love and patience, and to my children

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Researchers in the fields of audiology and education debate the role of auditory processing disorders (APD) in the development of several other language based learning disabilities such as dyslexia. Despite the controversies, certain neurological, cognitive, and behavioral characteristics are apparent among children diagnosed with APD, several of which are shared with the dyslexic population. The current study attempted to illuminate one such characteristic – deficiencies in verbal memory skills. Forty children with moderate to severe reading disabilities, half of whom had a co-morbid diagnosis of APD, between the ages of 7 and 12 years, and twenty normally achieving children matched for gender and age participated in this study. Consistent with previous research, results indicated significantly lower scores on verbal memory tasks among children with reading disabilities. However, whether a diagnosis of APD obtained by behavioral measures was significantly related to more profound verbal memory deficits among children with reading disabilities could not be clearly established. Children with comorbid RD and APD displayed significantly lower IQ scores and significantly lower levels of reading achievement than their reading disabled counterparts without APD diagnoses. These findings help to illuminate the nature of a possible link between APD and more profound reading disabilities and cognitive deficits and may have important implications for educational practice and intervention for these children.

# CHAPTER 1
# REVIEW OF THE LITERATURE

## Auditory Processing Disorders

Debate continues over the definition and diagnosis of Auditory Processing Disorders (APD) as researchers and clinicians have tried to implement valid and reliable assessment methods and to design viable treatment plans for children diagnosed with APD. Likewise, researchers are divided in their acceptance of auditory processing disorders as a possible underlying factor in the manifestation of several other disorders such as dyslexia and language impairments. Children diagnosed with APD display a variety of cognitive, neurological, and behavioral characteristics that could negatively impact learning in school settings. Research continues to examine how these characteristics impact learning and what strategies can be used to ameliorate learning difficulties experienced by these children.

### Characteristics of APD

Auditory processing refers to the ability of the central nervous system to process and use auditory stimuli efficiently. An auditory processing disorder is thought to result from difficulties in the perceptual processing of auditory stimuli by the central nervous system (American Speech, Language and Hearing Association, 2005b). Children with APD usually have normal hearing sensitivity but still have difficulty with the reception and interpretation of sounds. APD has been hypothesized to have a negative impact on listening skills, speech, language and comprehension of auditory signals including speech. APD may manifest as poor performance in one or more of the following: auditory discrimination, sound localization, auditory pattern recognition, temporal processing of auditory information, distinguishing sounds in the presence of background noise, dichotic listening, and processing degraded acoustic signals. These auditory performance deficits are presumed to occur with both speech and non-speech acoustic signals and have both

behavioral and neurological correlates. (American Speech, Language and Hearing Association, 2005b; Bamiou, Musiek & Luxon, 2001; Florida Department of Education, 2001)

Several behavioral characteristics stemming from auditory deficits generally are evident in children with APD and often are reported by teachers and parents in referral and screening questionnaires. Common behavioral observations include apparent confusion over the origin of a sound, confusion over words that sound similar, difficulty hearing in noisy environments, appearing to 'tune out' at times, difficulty remembering what was heard, following multi-step auditory directions, difficulty saying some words correctly, seeming to misunderstand what was said, looking for visual cues to aid comprehension of spoken messages, slowness to respond to verbal information or requests, distracted easily by other sounds, flat or monotonic speech, difficulty with prosodic cues in communication, demonstration of pragmatic language problems, phonological deficits, poor sequencing skills, expressive language and word finding difficulties, and poor musical skills, especially failure to discriminate between different pitch levels (Bellis, 1996; Florida Department of Education, 2001; Gillet, 1993). This array of difficulties could potentially be debilitating academically, emotionally and socially.

**Controversies Surrounding APD**

While the existence of auditory processing disorders is widely accepted (American Speech, Language and Hearing Association, 2005b; Florida Department of Education, 2001), disagreement continues regarding definition, diagnosis, treatment methods, and specific attributes of the subtypes of the disorder (Cacace & McFarland, 1998). In particular, much debate has focused on the differential diagnosis of APD and language disorders, the reliability and validity of assessment methods, and on the modality specificity of APD.

Literature on auditory processing published prior to 1980 often used the general term 'auditory processing' to refer to anything originating with an auditory cue (Richard, 2001). The

use of this general term invited confusion until the term was differentiated into two separate terms: ‘language processing’ and ‘central auditory processing’. The two terms used today are differentiated by the areas of the brain concerned with the type of processing taking place, and by the type of signals being processed. Central auditory processing refers to the processing of sounds within the central auditory nervous system. Language processing refers to the processing of speech/language in the cortical structures, specifically in the left temporal lobe (Richard, 2001). Despite this delineation of terms, confusion about terminology remains.

Professionals have had difficulty arriving at a definition for auditory processing disorders succinct enough to be utilized yet comprehensive enough to be encompassing (see American Speech, Language and Hearing Association, 2005b for a comprehensive definition). This difficulty is due, in part, to a lack of clarity with regards to related or co-morbid deficits and diagnoses such as language disabilities, and to the complexities of neurological structures. “Advances in the understanding of the role of auditory processing in the genesis of language difficulties have been hampered theoretically by a lack of agreement about the relationship between basic auditory skills, speech perception and phonological processing abilities, and also methodologically by frequent uncontrolled group differences in experimental studies” (Bailey & Snowling, 2002, p.143). As a result, researchers and theorists have criticized of the methods and practices used in the diagnosis and treatment of APD.

A primary criticism of the diagnosis of auditory processing disorders focuses on modality specificity and differential diagnosis. Cacace and McFarland (1998) claim the concept of modality specificity has been left unclear and that the field has failed to adequately address how the specificity of auditory deficits will be determined. McFarland and Cacace (1995) argue for the modality specificity of perceptual dysfunctions, claiming that a child diagnosed with an

auditory processing disorder should manifest problems when processing specifically auditory stimuli, and that this deficit should not be evident when processing information using other modalities. Cacace & McFarland (1998) further argue that "the modality specificity of auditory based learning problems has seldom been established" (Cacace and McFarland, 1998, p. 356). They claim that a major reason for this is the inclusive nature of the diagnostic process, meaning that low performance on auditory tests alone constitutes evidence for diagnosis. Individuals with other non-perceptual problems such as attention problems and language problems are at risk for misdiagnosis.

A task force charged by the American Speech-Language-Hearing Association (ASHA) attempted to address this issue in a 2005 technical report, stating that "the requirement of modality-specificity as a diagnostic criterion for (C)APD (central auditory processing disorder) is not consistent with how processing actually occurs in the CNS" (ASHA, 2005b, p. 2). The report refers to literature that indicates the human brain is not compartmentalized in such a way that one area is exclusively responsible for a single sensory modality. The ASHA task force report argued that the "definition and conceptualization of (C)APD must be consistent with the manner in which auditory and related processing occurs in the CNS" (ASHA, 2005b, p. 2). The task force concluded that "(C)APD is best viewed as a deficit in the neural processing of auditory stimuli that may coexist with, but is *not the result of,* dysfunction in other modalities" (American Speech, Language and Hearing Association, 2005b, p. 3). Further, the ASHA task force report (2005a) underscores the importance of comprehensive assessment and diagnosis that fully explores the nature of the presenting issues. This is especially important due to the complexity and heterogeneity of APD, cognitive processes, learning disabilities, and other factors pertaining

to the diversity of individuals and variability in performances of those referred for APD evaluation.

APD test validity and reliability have also been questioned by critics. As pointed out by several authors (American Speech, Language and Hearing Association, 2005b; Bellis, 1997; Cacace & McFarland, 1998; Jerger & Musiek, 2000; Sharma, Purdy, Newell, Wheldall, Beaman, & Dillon, 2006) many factors may impact test performance significantly, thus threatening validity and reliability and increasing the likelihood of false positive diagnoses. These factors include but are not limited to mental age, motivation, fatigability, attentional level, other cognitive factors, language abilities, and hearing ability. For children with a mental age less than 7 years, auditory test results may have questionable validity due to maturational factors and the cognitive demands of the tasks (ASHA 2005b; Bellis, 1997). Likewise, children with attentional problems or language difficulties may perform poorly on selected auditory processing tests for reasons other than what the tests purport to measure. Additionally, certain procedural variables may threaten reliability including ceiling, floor, and practice effects, as well as using too few diagnostic items during testing (Bellis, 1997; Jerger & Musiek, 2000).

Despite these criticisms, considerable evidence supports the likelihood of the existence of auditory processing disorders. Likewise, mounting evidence, especially recent developments in our understanding of the brain, suggests that deficiencies in auditory processing may be part of a causal chain leading to some forms of language based learning disabilities (Ahissar, Protopapas, Reid,& Merzenich, 2000; Bailey & Snowling, 2002; De Martino, Espesser, Ray, & Habib, 2001; Galaburda, 2004; Hood & Conlon, 2004; Sharma, et al., 2006; Tallal, 1980; Waber et al., 2001; Walker, Shinn, Cranford, & Givens, 2002). Researchers continue to examine possible links

between auditory processing skills and the array verbal deficits observed in some children with reading disabilities.

## Auditory Processing and Reading

### Reading Disabilities

A variety of terms are used to describe the failure of some children to learn to read. The term ‘dyslexia’ is used to describe impairment in the ability to read single words. In more recent years the term ‘reading disability’ has become favored over dyslexia as a means to describe children who have difficulty acquiring a wider variety of literacy skills. As a result of waves of research on reading acquisition, we now know that reading disabilities can manifest in one or more of several skill areas in the course of learning to read proficiently. Despite recent clarification on the nature of reading disabilities, the literature predating the current wave of research into the acquisition of literacy skills generally uses these two terms interchangeably.

Children with reading disabilities have difficulty learning to read despite adequate intelligence and instruction and often have concurrent deficits in other cognitive skills such as verbal memory (Ackerman, Dykman, & Gardner, 1990; Cornwall, 1992; Howes, Bigler, Burlingame, & Lawson, 2003; Messbauer & de Jong, 2002; Nelson & Warrington, 1980; O’Shaughnessy & Swanson, 1998; Torgesen & Goldman, 1977; Torgesen, 1985; Wilkins, Elkins, & Bain, 1995), language (Bishop & Adams, 1990; Catts, 1993; Catts & Hogan, 2003; Menyuk, 1999; Roth, Speece, & Cooper, 2002; Snowling, 1981; Snyder & Downey, 1991), phonological skills, and rapid naming skills (Badian, 1982; Catts, 1993; Roth, Speece, & Cooper, 2002; Scarborough, 1990; Snyder & Downey, 1991; Wolf, 1984). Researchers have not found consistent evidence of one underlying biological or neurological cause of reading disability. Several causal pathways and multiple mediating factors are thought to affect reading ability.

Research involving positron emission topography (PET) scans and functional magnetic resonance imaging (fMRI) studies confirms that the left temporal-parietal cortex is active during verbal memory encoding (Casasanto, Killgore, Maldjian, Glosser, Alsop, Cooke et al. 2002; Gupta & MacWhinney, 1997; Lespinet-Najib et al. 2004), auditory signal perception and processing (Bellis, 1997; Burton, et al. 2001), and language processing (Burton, et al. 2001). Phonological analysis appears to take place in Heschel's gyrus in the region of the Sylvain fissure on the superior gyrus of the temporal lobe, while phonological processing appears to take place near by in areas of the posterior temporal–parietal cortex (Gupta & MacWhinney, 1997). The left inferior parietal cortex appears to be somewhat specialized for the temporary storage of phonological information (Gupta & MacWhinney, 1997), a key quality associated with verbal short-term memory. Likewise, the left superior temporal cortex plays an important role in the reading process of normal readers and has been shown to be under activated in dyslexic readers when compared to controls. (McCandliss & Noble, 2003; Salmelin & Helenius, 2004). It seems logical then that auditory processing, phonological analysis and processing, verbal short-term memory, language processing and reading abilities may be neurologically related in complex ways that affect one's ability to read and thus deserves further investigation.

Dyslexia, once thought to be a visually based problem, is now believed to be a language based disorder. Specifically, "dyslexia is characterized by developmental weakness in establishing phonological representations of speech" (Richardson, Thompson, Scott, & Goswami, 2004. p. 215). Much discussion still occurs as to possible sub-types and causes of dyslexia (see Watson and Willows, 1995). Combinations of several underlying neurological and developmental forces are likely to cause dyslexia.

**Auditory Processing Disorders and Reading Disabilities**

Widely accepted theories of language based deficits underlying dyslexia have fostered many studies examining the role of the auditory system as a potential underlying neurological cause of the speech/language, phonological processing, and perceptual problems associated with dyslexia. Although the construct of auditory processing disorders is difficult for researchers to isolate, a link between auditory processing skills and reading development seems likely (Alonso-Bua, Diaz, & Ferraces, 2006; Penney & Godsell, 1999) and is worthy of further investigation. Phonological awareness skills, which have been shown consistently to impact early reading achievement, are likely to be affected by poor auditory processing skills, although the relationship is somewhat unclear. In particular, deficits associated with discrimination between and ordering of sounds within words, discrimination between different words, and auditory closure likely to negatively impact language development, phonological awareness, verbal memory, and reading achievement (Florida Department of Education, 2001).

Most research has focused on establishing and defining relationships between auditory temporal processing and early reading skills, specifically phonological based skills which are known to be important for reading development. Several studies have found links between dyslexia and dichotic (specifically binaural integration) listening skills (Dermody, Mackie, & Katsch, 1983; Moncrief & Musiek, 2002). However, research on temporal processing seems to be the most promising line of research into possible audiological causes of dyslexia. Auditory temporal processing generally is defined as the ability to process time related aspects of acoustic signals. Such time related aspects include the order of presentation of sounds, the duration of different sounds, and the duration of intervals between contiguous sounds. Temporal aspects of auditory information are used for skills such as sequencing, ordering, sound localization and lateralization (ASHA, 1995).

Several researchers have hypothesized that a temporal processing deficit may underlie language and reading difficulties (Ahisser et al. 2000; Heiervang, Stevenson, & Hugdahl, 2002; Reed, 1989; Rey et al. 2002; Tallal, 1980, 1984; Walker et al, 2002). These researchers propose a deficit in neural networks involved in processing rapidly changing auditory stimuli of short duration. It follows that a deficit in the ability to process such sounds would attenuate a child's ability to correctly identify and process rapid speech sounds such as stop consonants, and to process other multiple complex speech sounds. Ample evidence supports the belief that processing phonological sounds is important in learning to read. Thus, the belief that an underlying auditory temporal processing deficit may cause phonologically based reading disabilities is reasonable.

**The rapid temporal processing deficit theory**

The theory suggesting that temporal auditory processing deficits may be a root cause of dyslexia was first proposed by Tallal (1980). Tallal used a variation of a temporal order judgment task known as the auditory repetition task. In this task, two sounds are presented in close succession at differing inter-stimulus intervals and a person is asked to decipher either the order of the sounds or whether the sounds presented were the same or different. Tallal and colleagues conducted a variety of tests similar in nature to the task described above using both speech and non-speech sounds on children with language delays and later with children who displayed reading difficulties. The findings generally indicated that children with language delays and reading disabilities have difficulty discriminating different sounds when they are presented in rapid succession. Tallal found this difficulty was not apparent when there were larger inter-stimulus intervals. Her work with children with dyslexia (Tallal, 1980) gave birth to the rapid auditory processing deficit theory of dyslexia. The premise of this theory is that deficits in the processing of rapid auditory stimuli affect literacy development because the perception of

rapid transient auditory information is necessary for phoneme perception, and phoneme awareness is necessary for reading to develop.

This rapid auditory processing deficit theory gained some popularity and was the subject of many subsequent studies. However, Tallal's findings have been difficult to replicate consistently. Her research and subsequent studies have been the subject of academic debate and criticized for a variety of methodological problems (see Bretherton & Holmes, 2003; Mody, Stuudert-Kennedy & Brady, 1997; Richardson et. al. 2004; Rosen, 2003). The controversies primarily center on the nature of any auditory temporal processing deficit and whether such a deficit is specific to speech or a more general, perhaps even a multi-modal temporal processing deficit (Adlard & Hazen, 2004; Conlon, Sanders, & Zapart, 2004; Hood & Conlon, 2003; Laasonen, Service, & Virsu, 2002; Mody, Stuudert-Kennedy, & Brady, 1997; Studdert-Kennedy & Mody, 1995; Watson & Miller, 1993).

Despite these criticisms, research continues in this area. Current researchers are more interested in the processing of a variety of sounds by children with dyslexia including phonemes, pure tones of differing pitches, masked tones, speech sounds, and beats. Results are mixed. Researchers have established that children with dyslexia often display deficits in various verbal and auditory skills. In recent years a growing body of literature supports an underlying auditory temporal processing deficit in dyslexia, although the exact nature of this deficit remains unclear (Alonso-Bua, Diaz, & Ferraces, 2006; Ben Artzi, Fostick, & Babkoff, 2005; Booth et al. 2000; De Martino et al. 2001; Heiervang, Stevenson, & Hugdahl, 2002; King et al. 2003; Ray et al. 2002; Walker et al. 2002). Some authors have refuted this theory outright while others have adapted it to include other factors such as speech sound specificity (Bretherton & Holmes, 2002; McAnally et al. 2004; Mody, Studdert-Kennedy, & Brady, 1997; Nittrouer, 1999; Rosen &

Manganari, 2001) and multimodal temporal processing (Cacace et al. 2001; Conlon, Sanders, & Zapart, 2004; Hood & Conlon, 2003; Laasonen, Service, & Virsu, 2002; Van Ingelghem et al. 2000). However, interest in the temporal deficit hypothesis continues with a general acceptance of the likelihood that auditory processes influence language and literacy development. "Deficits in temporal processing have been shown to be associated with impairments in the phonological aspects of language and reading skills development, although the exact nature of the relationship is unknown" (Walker, Shinn, Cranford, Givens, & Holbert, 2002. p. 603).

In 1989, Reed attempted to replicate and extend Tallal's (1980) findings. Generally, her findings supported those of Tallal that found children with reading disabilities had more difficulty that non-reading disabled peers in processing briefly presented non-speech stimuli and in making order judgments with consonant-vowel syllables. Reed suggested that children with reading difficulties appeared to have less sharply defined phonological categories. She hypothesized that this could be due to either difficulty with phonemic discrimination or difficulty in analyzing briefly presented auditory cues. Together with Tallal's work, Reed's 1989 study opened the door for investigating the processing of the temporal aspects of speech by children with dyslexia. From Tallal's initial theory stemmed a new line of research into the possibility of a speech specific temporal auditory processing deficit as an underlying cause of dyslexia. This investigation into the observed deficits in temporal processing possibly being speech specific was the first of two primary branches of research stemming from Tallal's rapid temporal processing deficit theory.

**Speech-specific temporal processing hypothesis**

A number of subsequent studies investigated a speech specific temporal processing theory. Many found little support for pure tone temporal processing deficits (Bretherton & Holmes, 2002; McAnally et al. 2004; Mody, Studdert-Kennedy, & Brady, 1997; Nittrouer, 1999; Rosen &

Manganari, 2001). Researchers investigating this hypothesis pointed out that the non-speech tones used in earlier studies varied markedly from actual speech sounds, and therefore that the earlier claims that deficits in pure tone temporal processing could not logically be extended to the temporal processing of speech sounds (Mody, Studdert-Kennedy, & Brady, 1997; Rosen & Manganari, 2001). The suggestion that the auditory temporal processing deficits seen in dyslexia *caused* phonological deficits also was criticized, when at most they could be regarded as one possible causal factor (Rosen & Manganari, 2001) that perhaps had an effect on speech perception and discrimination, and in turn affected the development of phonological skills. In support of these criticisms, a study by Watson and Miller (1993) found no relationship between nonverbal auditory processing skills and phonological ability. Watson and Miller also did not find a relationship between reading skills and nonverbal auditory processing skills. However, they found speech perception explained a significant amount of the variance in phonological ability.

Other researchers also have proposed that temporal processing deficits seen in many children with dyslexia are not a true auditory temporal processing deficit but are a speech specific deficit in speech perception and/or speech discrimination skills. For example, Adlard and Hazen (2004) conducted a study of speech perception in children with dyslexia and found a subgroup of children with dyslexia performed poorly on speech discrimination tests, particularly with consonant contrasts, fricatives, nasals, and stop consonants. However, this subgroup did not perform significantly worse than controls on non-speech psychoacoustic tasks. In support of Watson and Miller (1993), Adlard and Hazen also suggested that speech processing difficulties rather than true auditory processing have implications for reading difficulties. Given the obvious

complexity of speech sounds when compared to pure tones, signal complexity cannot be overlooked as a possible confounding variable.

Several authors attempted to correct methodological concerns in earlier studies. For example, Mody, Studdert-Kennedy, and Brady (1997) used tones with sine wave patterns that matched those in the speech tasks in order to control for variations in tones between speech sounds and pure tones used in earlier studies. They found the performance of the weak readers was specific to speech sounds, and that a deficit was not seen when children responded to matched sine wave non-speech acoustic stimuli. However, this study has been criticized for using “garden variety” poor readers rather than children truly diagnosed with dyslexia, and for severe violations of statistical assumptions (Denenberg, 1999). Nittrouer (1999) attempted to control for variations in the nature of speech sounds when compared to pure tones. This study used a more complex pure tone task that better matched the ongoing nature of the speech stream than had been used in previous studies to test the performance of a group of low readers with deficient phonological skills. Although this study found no evidence that temporal auditory processing of pure tones caused phonological deficits, some subtle perceptual differences between control subjects and children with dyslexia were found. Other researchers also have concluded that speech specific deficits impact reading ability rather than lower level auditory processing problem (Godfrey et al. 1981; Mody, Studdart-Kennedy, & Brady, 1997).

Research continued along this line for some time, with several theoretical variations emerging. One such variation investigated different temporal aspects of the speech stream. Some evidence exists for a deficit in specifically rapid auditory processing of speech sounds in children with dyslexia (De Martino, Espesser, Rey, & Habib, 2001; Rey, De Martino, Espresser, & Habib, 2002) and for the judgment of order of phonemes in speech sounds (De Martino, Espesser, Rey,

& Habib, 2001). Studdert-Kennedy and Mody's (1995) review of the literature offered some clarity to the nature of the speech specific deficits seen in children with dyslexia and suggested that phonological deficit displayed by low readers and known to be linked to reading problems is a deficit in rapid perception, not temporal perception, and that this deficit is speech specific.

Proponents of the speech specific hypothesis pointed out that further support for the speech specific nature of the deficit comes from research showing verbal memory deficits in children with reading disabilities (Brady, Shankwieler, & Mann, 1983; Nelson & Warrington, 1980; Wilkinson, Elkins, & Bain, 1995) and research showing categorical perception difficulties in the same population (Godfrey et al, 1981). Although speech perception difficulties possibly underlie phonological awareness deficits, little behavioral evidence has been found to support a general deficit in the processing of sounds as an underlying cause of deficits in the perception of speech sounds. Recent brain research offers some promise.

The most convincing evidence for an auditory temporal processing deficit as an underlying biological cause in language based learning disabilities comes from brain research using functional magnetic imaging (fMRI), positron emission tomography (PET) scans, and mismatch negativity (MMN) response studies. Several researchers have found evidence for a link between pre-attentive auditory processing and phonological awareness or reading deficits (Alonso-Bua, Diaz & Ferraces, 2006; Kujala et al. 2000; Poldrack et al. 2001; Purdy, Kelly & Davies, 2002; Sharma et al. 2006; Taylor & Keenan, 1999; Temple et al. 2000). Mismatch negativity response has been particularly helpful in determining that people with reading disabilities have differences in their neurological perception of sounds, both syllabic and tonal, when compared to people without reading difficulties ( Baldeweg et al., 1999; Alonso-Bua, Diaz & Ferraces, 2006; Kraus, et al., 1996; Kujala, 2000).

Mismatch negativity is a brain response which is an electrophysiological index of the central auditory system's ability to discriminate auditory information pre-attentively. The brain's ability to discriminate auditory input is detectable as a negative wave which occurs between 150ms and 250 ms after a deviant stimulus is presented following repeated initial stimuli. The MMN response is not affected by the subject's attention or motivation. Kujala et al. (2000) and colleagues examined the ability of brains in adults with dyslexia to discriminate temporal information within complex tone patterns by recording mismatch negativity. Kujala et al. (2000) found that brains of people with dyslexia fail to discriminate the tone patterns due to problems in the early cortical mechanisms. Additionally, difficulty in discrimination was especially evident when the sounds were surrounded by other sounds, as may be true of phonemes in words.

Mismatch negativity response was used to investigate auditory neural traces further by Alonso-Bua, Diaz, and Ferraces (2006). Several interesting conclusions were made from this research implicating general pre-attentive auditory processing as a factor in reading disabilities. Group differences existed between the group of subjects with reading disabilities and the group of normally achieving children on MMN response latency for linguistic (syllabic) stimuli. Children with reading disabilities had significantly longer latencies. Additionally, Alonso-Bua, Diaz, and Ferraces (2006) investigated a second negativity within the ERP which is known to occur later in processing (400-500ms) known as the late discriminative negativity (LDN). Results from this deeper analysis of ERP suggested that children with reading disabilities differ from children without reading disabilities on LDN for both linguistic and temporal tonal sounds. The authors claim that "the results demonstrate that the auditory deficit of temporal processing becomes more serious in late stages of the automatic processing of information" (Alonso-Bua, Diaz, & Ferraces, 2006, p. 164). Thus, a combination of both speech-specific and tonal temporal

auditory processing deficits may be present in children with reading disabilities, with the speech specific deficit being more prominent. Further, Alonso-Bua, Diaz, and Ferraces (2006) suggest that deficits in temporal phonological processing and tonal auditory processing are not identical but rather, run parallel, with the phonological component being related to automatic detection by the brain and the deficit in non-linguistic temporal auditory processing being related to biological maturation.

A recent study (Sharma, et al., 2006) using both behavioral and electrophysiological measures of auditory processing found that all the children with dyslexia (n=23) displayed auditory processing difficulties either on behavioral measures, electrophysiological (mismatch negativity response) measures, or on both. Temporal processing tasks appeared to be most problematic for the reading disabled group. Both control group children and compensated dyslexics (i.e. children with a history of reading difficulties who have overcome their reading deficits) performed significantly better on behavioral auditory measures than children with dyslexia. None of the control children displayed difficulties with auditory processing. However, 33% of those with compensated dyslexia displayed continuing auditory processing difficulties despite average reading scores. Interestingly, some children who displayed no auditory processing difficulties on behavioral measures actually displayed electrophysiological signs of auditory processing difficulties, suggesting that some amount of compensation may have taken place. Additionally, six of the children with reading disabilities did not display problems detected by the electrophysiological measure yet displayed auditory deficits on behavioral measures. This may be due to the confounding impact of attention, memory, and motivation when auditory processing is assessed with behavioral tests. The authors suggest mismatch negativity response methods and behavioral methods used to assess auditory processing

disorders may examine auditory processing in different ways. Auditory processing skills were correlated with non-word and reading scores. This research indicates that APD and reading disabilities often are co-morbid and that patterns of difficulties vary within reading disabled populations (Sharma et al., 2006).

Further research is needed on potential deficits in processing different types of sounds (e.g. speech, tonal, clicks) and on the possibility that people display very specific and different deficits in processing certain sound frequencies, specific speech sounds, or sounds presented in particular orders, combinations, or at specific speeds.

**Multimodal temporal processing**

The second major divergence in research related to the rapid auditory temporal processing deficit theory proposed by Tallal was based on the hypothesis that the temporal processing deficits seen in children with dyslexia were not specific to the auditory modality. Reading is a multi-modal activity that requires temporal processing of both visual and language-based stimuli. Thus, several researchers advanced the theory that a general multi-modal temporal processing deficit is an underlying cause of reading failure rather than a specifically auditory temporal processing deficit (Cacace et al. 2001; Conlon, Sanders, & Zapart, 2004; Hood & Conlon, 2003; Laasonen, Service, & Virsu, 2002; Van Ingelghem et al., 2000). Evidence again is mixed, and research is criticized for many of the same reasons as research that investigated the purely auditory modality.

A study by Van Ingelhem, Van Wieringen, Wouters, Vandenbussche, Onghena, and Ghesquiere, (2001) provided evidence for a more general multi-modal temporal processing deficit in children with dyslexia. Readers with dyslexia were found to be weaker in auditory temporal processing skills than their age matched, normally achieving counterparts, and to have deficiencies in visual temporal processing. Temporal processing measures used in this study

were found to be significantly related to word and pseudo-word reading ability. The authors suggest that a general temporal processing deficit underlies reading difficulties, and not a specifically auditory deficit.

Several other studies have found similar patterns of general temporal processing deficits in people with dyslexia. Hood and Conlon (2003) found that both auditory and visual temporal processing skills predicted reading and spelling development in a large sample of young children. Likewise, Conlon, Sanders, and Zapart (2004) found that performance on two multimodal temporal processing tasks explained 70% of the variance seen in the reading abilities of adults with reading difficulties. Similarly, Laasonen, Service, and Virsu (2002) found that the temporal processing of young adults with dyslexia was weaker on each of several crossmodal temporal processing tasks than the controls. Further, Laasonen et al. suggest that, although a deficit in temporal processing is a general correlate of reading ability, it is not sufficient for the development of reading disabilities due to overlaps in performance between people with and without dyslexia.

Contrary to the results described above which support a general multi-modal temporal processing deficit in dyslexic children, Bretherton and Holmes (2003) did not find support for this hypothesis. They included a visual temporal processing task in their study of auditory temporal processing skills in reading disabled children. Overall, Bretherton and Holmes found that the children with dyslexia as a whole performed more poorly on the visual order task than did the normally achieving readers. However, a different subset of the group of children with dyslexia displayed these visual processing deficits than had displayed the auditory tone order processing deficits. Thus, Bretherton and Holmes concluded that the visual order processing deficits seen in some of the children with dyslexia were independent of the auditory tone order

processing deficits seen in a different subset of children with dyslexia. This independence of modalities in temporal processing was confirmed by Booth et al. (2000) who found that rapid auditory temporal processing explained variance in children's phonological processing and orthographic skills while rapid visual temporal processing tasks explained variance in children's orthographic skills.

A well designed longitudinal study examining relationships among preschoolers' auditory and visual temporal processing skills and reading skill development was conducted by Hood and Conlon (2004). Hood and Conlon reasoned that, if temporal processing difficulties are due to prenatal neurological abnormalities, then they should be detectable prior to reading skill development. Furthermore, if these temporal processing problems are related to reading development, then they should predict later reading abilities. Hood and Conlon found that preschool performance on both visual and verbal temporal order judgment tasks predict letter and word reading accuracy and reading rate in grade 1, even after controlling for age, environment, attention, memory, nonverbal ability, and speech/language problems. Results from Hood and Conlon (2004) also showed that visual temporal order judgment tasks and verbal temporal order judgment tasks were related to different components of early reading. Prior to Hood and Conlon's study, Benasich and Tallal (2002) had found that temporal processing deficits were present and detectable in infancy, well before reading and language development had occurred and that the deficits predicted later language learning outcomes. It appears that each individual may display different neurological processing abilities in different modalities due to different brain characteristics some of which are anomalies, and that various combinations of type and severity ultimately contributes to reading failure.

**Further research on Tallal's theory**

Two different lines of research stemming from Tallal's initial rapid temporal processing deficit theory have been discussed. Additional research has investigated the general auditory temporal processing hypothesis. More recent studies have attempted to address many of the methodological weaknesses in earlier studies. As a result, further evidence has been found for an underlying auditory temporal processing deficit in dyslexia. Much of this further evidence has arisen from studies that employed up to date procedures and measures and used newer methods of statistical analysis.

Heiervang, Stevenson, and Hugdahl (2002) investigated the temporal processing deficit hypothesis among Norwegian children with and without dyslexia. When compared to age matched controls without dyslexia, children in the dyslexic group were found to have impaired ability to process and identify rapidly presented complex tones of short duration. This study confirmed the earlier findings of Tallal (1980) and Reed (1989) and lends further support to the likelihood of a general auditory processing deficit in reading disabled children. Likewise, a review of the literature on the relationship between temporal processing and reading disability by Farmer and Klein (1993) found generally in favor of a temporal processing deficit in reading disabilities.

Similarly, Walker, Shinn, Cranford, Givens, and Holbert (2002) studied a small sample of young adults with reading disabilities and found relationships between reading ability and temporal processing abilities on a series of tests involving varying tone pitches and durations. These findings suggest a relationship between lower level auditory temporal processing skills and decoding efficiency. More specifically, children with reading disabilities exhibited a deficit in their ability to discriminate tonal patterns. This finding of auditory discrimination difficulties

in children with reading disabilities, whether speech specific or tonal, has been common in the literature and seems to be closely related to phonological awareness deficits.

Partial support for Tallal's original theory has come also from several recent studies. However, a number of these studies were unable to completely replicate Tallal's 1980 findings. Parts of Tallal's theory appear to hold true and other parts do not. For example, recent research found temporal processing deficits in children with reading disabilities yet failed to find that rapid temporal processing was necessarily a factor (Waber, Weiler, Wolff, Bellinger, Marcus, Ariel, Forbes, & Wypij, 2001). Similar results are reported by Heath, Hogben, and Clark (1999). Several studies have found group differences in the low level auditory temporal processing skills of reading disabled and normally achieving students but could not establish that these differences accounted for independent variance in reading ability (Heiervang et al. 2002; Richardson, et al. 2004 ).

**Methodological issues**

The body of research investigating the various aspects of temporal processing theory has been criticized heavily and has sparked much debate. One common criticism centers around a lack of consistency in the way children with reading disabilities and control children are identified and grouped (McArthur & Bishop, 2001). Few studies use consistent and strict inclusion criteria for identifying dyslexic readers, often including garden variety poor readers and children with additional learning difficulties such as language delays. Likewise, control subjects are loosely defined as 'normal readers' in most studies. These issues with defining good and poor reading ability may account for the large variations in performance and commonly observed overlaps in performance seen between groups. Rey et al. (2002) point out that selecting garden variety poor readers as subjects in the 'dyslexic' group maximizes possible environmental causes for poor reading skills and does not adequately represent the more severe reading disabled

children who are more likely to have neurological or biological causes rather than environmental causes underlying their reading deficits. This introduction of potential environmental confounds calls the interpretation of results into question.

An extension of this criticism relates to individual performances within groups. In many studies, only subgroups of the people with dyslexia seem to display auditory temporal deficits and that substantial overlap between groups is common (see Watson, 1992). In Tallal's 1980 study, only 8 of the 20 children with dyslexia were found to be deficient in auditory temporal processing skills (Rosen, 2003). Studies generally have failed to address the large amount of variance seen in performances within and between groups. Possible reasons for these discrepancies include issues of reliability and validity, methodological concerns with the grouping of subjects, the likelihood that there are different subtypes of dyslexia and that other qualities within individuals mediate the development of compensatory strategies.

Watson (1992) found that a group of college students with reading disabilities performed significantly less well on auditory temporal processing tasks than controls. However, some students who did not have reading disabilities also performed poorly on the temporal tasks, while some students with reading disabilities did as well as controls on the auditory temporal tasks. Consistent with Bretherton and Holmes (2002), Watson argues that auditory temporal processing difficulties are neither necessary nor sufficient for reading disabilities to occur. Issues concerning divergent validity, covariates, dyslexic subtypes and mediating factors are likely explanations.

Furthering this argument, Heath and Hogben (2004) point out that most studies use only between-group comparisons of different measures to make general statements and decisions about individuals within the groups. In actuality, considerable between group similarities often

exist. Group differences may be attributed to the more extreme performances of two or three individuals and that, when these individual scores are accounted for, group differences often are substantially reduced.

Heath, Hogben, and Clark (1999) present evidence refuting previous claims that auditory temporal processing problems underlie dyslexia and expand on the problematic grouping of individuals within groups. In their study, only the subgroup of dyslexics with oral language delays demonstrated poor auditory temporal processing skills while all subjects with reading disabilities exhibited poor phonological skills. They concluded that at least two subtypes of dyslexia exist and that, since auditory temporal processing deficits are not seen in dyslexics without language delays, ATP cannot be a causal factor in all reading disabilities. Heath and colleagues further argue that previous studies that claim that auditory temporal processing deficits underlie the phonological deficits seen in poor readers did not differentiate between poor readers with and without concomitant language delays. Similarly, Rosen and Manganari (2001) concluded that an auditory processing deficit is neither sufficient nor necessary to cause dyslexia, and that either an important language component or acoustic complexity influences performance on these tasks. Language skills of individuals within the dyslexic group are an important variable that often is overlooked.

**Reliability and validity**

The most salient criticisms relate to the reliability and validity of the auditory processing measures (Heath & Hogben, 2004; McArthur & Bishop, 2001). The reliability of measures used in studies rarely is reported, although sometimes is addressed by training of subjects prior to testing. Few studies concur on their definition of the term ‘auditory temporal processing’ and yet they purport to measure the same construct by measuring different specific skills with a variety of different tasks. Heath and Hogben (2004) further point out “there has been a marked absence

of standardized stimuli and procedure" across studies (Heath & Hogben, 2004. p.1276). In fact, the reliability of measurement that assesses auditory processing skills has been heavily debated in audiology, in part because these skills are though to depend heavily on several other cognitive abilities (e.g. memory, language and attention) which are commonly known to be deficient in children with reading disabilities. Studies using mismatch negativity address this concern (see Alonso-Bua, Diaz & Ferraces, 2006; Kujala et al. 2000; Poldrack et al. 2001; Purdy, Kelly & Davies, 2002; Sharma et al. 2006; Taylor & Keenan, 1999; Temple et al. 2000)

Validity has been called into question as the definition of 'temporal processing' has not been adequately defined in many studies. Varying definitions and methods of measurement across studies are difficult to consolidate, thus calling construct validity into question (Farmer & Klein, 1995; Heath & Hogben, 2004; Nittrour, 1999). The same general term of 'auditory temporal processing' has been used to describe a variety of auditory skills measured by a variety of tests. Heath and Hogben (2004) pose the question, "to what extent is ATP (auditory temporal processing) a valid construct, demonstrable across a range of different measures?" (Heath & Hogben, 2004. p.1276.). This is an important question to answer if further progress is to be made in the understanding of these relationships.

**Interpretational issues**

Criticisms have been aimed at the interpretation of results in studies examining this issue. Most prominently, assumed or implied causal connections, the overlooking of potential confounds, and questions of construct validity have been implicated as possible factors leading to erroneous interpretations.

Tallal's initial theory implied a possible causal link between rapid auditory temporal processing and reading disability. However, the causal nature was not shown. Later studies often report correlations between temporal processing skills and reading ability. Critics of Tallal's

theory point out that correlation between poor reading skills and temporal processing deficits do not imply causation. Nevertheless, many studies interpret results based on either refuting or accepting causal connections. In fact, a clear causal pathway between these variables has neither been shown nor dismissed. Qualities such as language, attention, IQ, and verbal memory may mediate and thus, have a place in a causal chain between auditory temporal processing and early reading skills. Such a chain, originating with atypical neuronal migration in fetal development, has been proposed by Galaburda (2005). Of course, auditory temporal processes may not have a place in such a casual chain. Likewise, this causal chain may be appropriate only for certain subtypes of dyslexia. A causal model must take all potential variables into account. With advancing knowledge of the brain, possible causal chains may become clearer.

In support of this belief, Marshall, Snowling, and Bailey (2001) found no evidence that deficits in phonological abilities are caused by deficits in processing of rapid auditory stimuli. They hypothesized that perhaps the ability to label (i.e. remember) sounds and letters in paired association tasks of this nature may mediate performance, and that further investigations into the cognitive and strategic demands of such tasks are warranted in order to clarify the nature of the relationship between variables.

Issues of construct validity mentioned earlier also call into question interpretation of results. Several reviews of the literature suggest that researchers often are measuring something other than auditory temporal processing. For example, Bretherton and Holmes (2002) refuted the claim that auditory temporal order processing underlies reading problems or phonological awareness and suggested that studies which show this deficit may have actually shown that the subjects had trouble differentiating the sounds themselves and do not have trouble with temporal aspects. Issues of construct validity and confounds with frequency discrimination ability and

other basic auditory skills in pure tone temporal processing tasks largely have been ignored in the literature (Heath & Hogben, 2004; Hetah et al. 1999; Studdert-Kennedy & Mody, 1995). Given some reports of frequency discrimination deficits in people with reading disabilities (Baldeweg et al. 1999; McAnnaly & Stein, 1996), this may be an important oversight in interpretation.

Similarly, temporal processing tasks that use speech sounds such as similar sounding syllables and ask the subject to distinguish the order of speech sounds are (for example, “sp” versus “ps”) probably are assessing phonological awareness skills (Mody, 2003). A subject must be able to discriminate between the target speech sounds before he or she can determine their order. As we already know that poor readers have poor phonological skills, we would expect them to do poorly on such tasks (Rey et al. 2002). This begs the question, “What has been measured?”

Concerns also have been raised as to the possible ways in which developmental level may affect results in such experiments. The potential problems associated with testing and comparing persons of differing ages and developmental levels on cognitive tasks (Heath & Hogben, 2004) are apparent. Cognitive, physiological, or neurobiological developmental does play an important role in the skills in question. Likewise, compensatory strategies may mediate performance with development. Many studies do not adequately control for developmental level thus making comparisons of results across studies and generalization difficult. However, these deficits have been demonstrated across several different age groups from mid childhood to adults with reported histories of childhood reading difficulties (McArthur & Bishop, 2001; Watson, 1992; Whitton et al. 1998; Watson & Willows, 1995). Still, further investigation into the

developmental nature of skills in question may help to explain conflicting findings in the literature (McArthur & Bishop, 2001; Watson & Willows, 1995).

**Future Directions**

McArthur and Bishop (2001) made several salient suggestions for future research on relationships between auditory processing skills and reading ability following their thorough review of research related to the rapid temporal processing theory. McArthur and Bishop suggest that the lack of reliability and validity of tasks used to measure rapid auditory processing skills may account for the inconsistency in results across studies. They recommend measuring and controlling for more variables that are known to be correlated with reading and language deficits (e.g. language skills, nonverbal IQ, memory, and attention). Further, McArthur and Bishop also recommend that individual results be reported more often by researchers rather than merely reporting group differences. Given more evidence of dyslexic subtypes, the reporting of individual differences or subgroup variances in test results becomes more important than reporting only group differences.

Several additional issues need to be addressed in future research if we are to gain a clearer insight into a possible causal connection of temporal auditory processing to reading skill. Firstly, the constructs of temporal processing, discrimination, speech sounds, and reading ability must be defined and delineated more clearly. Secondly, additional aspects of acoustic signals that may affect perception need to be addressed. Finally, future research that explores individual patterns of performance (or case studies) on a variety of auditory and literacy skills to gain insight into potential connections and causal pathways between very specific auditory skills and very specific deficits in early literacy skills.

In conclusion, the exact nature of relationships between auditory temporal processing skills and the development of early reading skills, particularly phonological skills, remain unclear. The

opinion that deficits in auditory processing skills, particularly those related to temporal aspects of acoustic signals, could interfere with or place limits on the accurate neurological representation and subsequent perception of speech and thus negatively impact the development of phonological skills is generally accepted. Results of research on this theory are mixed, although recent brain research tends to lend support to the general nature of the theory. Mild to moderate correlations between auditory processing skills and reading skills have been found, and a possible causal pathway has been hypothesized by Galaburda in 2005, who suggests that sensory memory may have a place in this causal pathway. Others have proposed similar pathways (Bretherton & Holmes, 2002). However, no clear causal connection has been established.

A recent review of the literature linking auditory temporal processing deficits and reading disabilities by Ramus (2003) concluded that the literature is inconsistent and that phonological processing deficits are the most salient feature of reading disabilities. Further, Ramus argues that this phonological deficit cannot be accounted for by a low level auditory processing deficit. Ramus's review found approximately 39% of people with dyslexia displayed an auditory deficit. While he argued that auditory deficits may act to aggravate dyslexia, he claimed that phonological deficits seen in dyslexics could arise independently of any auditory deficit. Thus, although auditory deficits cannot be established as an underlying cause of all early reading problems, evidence suggests that they can occur in association with reading disabilities.

Dyslexia is a heterogeneous condition that needs more precise definition. Lack of clear definition may explain discrepancy in research results. Brain studies seem to produce more consistent results in establishing the link between auditory processing skills and reading. Phonological dyslexia, represented by phonological deficits, fits better into this causal chain than other definitions of dyslexia. Persons with phonological dyslexia may be unable to make

accurate sensory representations in the brain to allow for accurate short-term memory and thus allow accurate phonological processing to take place. The nature of auditory short-term memory in individuals with dyslexia will be discussed in an attempt to elucidate another possible link in the chain between auditory processing and reading disabilities.

## Reading and Memory

Memory is a cognitive ability which has consistently been shown to be associated with reading deficits. Specifically verbal memory, including verbal working memory, is known to be weaker in people with reading disabilities. While visual memory deficits have not been consistently found among those with reading disabilities (see O'Shaughnessy & Swanson, 1998; Liberman, Mann, Shankweiler & Werfelman, 1982; Mann, Liberman, & Shankweiler, 1980; Nelson & Warrington, 1980), children with reading disabilities have been found to perform poorly in almost all aspects of verbal memory (Bauer, 1977; Cornwall, 1992; Howes et al. 2003; Howes, Bigler, Burlingame, & Lawson, 2003; Messbauer & de Jong, 2002; Nelson & Warrington, 1980; Penney & Godsell, 1999; Plaza et al., 2002; Torgesen, 1982; Torgesen, 1985; Torgesen & Goldman, 1977; Wilkins, Elkins, & Bain, 1995). Likewise, verbal working memory skills also have been shown to be weaker in children with reading disabilities when compared to their same aged, normally achieving peers (Cain, Bryant & Oakhill, 2004; de Jong, 1998; Kibby et al. 2004; MacDonnald et al. 1992; Nation et al 1999; Oakhill, Cain & Bryant, 2003). An understanding of how memory skills contribute to successful reading acquisition, or of how deficits in memory skills may underlie reading and learning disabilities, may help identify effective ways to intervene for children with reading deficits.

Memory is a basic cognitive function that cannot be clearly separated from general intellectual functioning or learning. Memory is vital to the acquisition of reading skills, to the execution of efficient reading, and to the understanding and retention of what we read. Young

children use memory skills to remember the letters of the alphabet, the sounds represented by letters and letter blends, sight words, decoding strategies, word meanings, and other early reading skills. More advanced readers must retain this basic knowledge and simultaneously attend to and process information being obtained from their reading. Thus, a competent reader uses several interrelated memory skills in order to comprehend text.

**Verbal Memory and Reading**

Children with reading disabilities display lower verbal memory skills than their non-reading disabled peers (Ackerman, Dykman., & Gardner, 1990; Cornwall, 1992; Howes et al. 2003; Howes, Bigler, Burlingame, & Lawson, 2003; Messbauer & de Jong, 2002; Nelson & Warrington, 1980; O'Shaughnessy & Swanson, 1998; Torgesen, 1982; Wilkins, Elkins, & Bain, 1995). Studies have attempted to elaborate on this general finding by examining some of the unusual memory skill patterns and deficits in youngsters with reading disabilities. Studies that investigate this issue commonly focus on such skills as rote verbal recall of word, nonword or number lists, recall of stories, sentence recall, working memory, and memory span tasks.

Many studies examining verbal recall have been conducted with reading disabled children. These studies generally have found that children with reading disabilities generally display lower verbal recall than children without reading difficulties. In one of the earlier studies addressing verbal recall in youngsters with reading disabilities, Torgesen and Goldman (1977) found that poor readers generally had lower recall than their same aged non-disabled peers. Poor readers also were less inclined to use verbal rehearsal strategies that could aid recall. This finding was supported further by Bauer (1977). Other studies have attempted to elaborate on this finding. In a study reported by Wilkinson, Elkins and Bain (1995), stories were read to third graders with reading disabilities and then the children were asked them to recall the stories under both free recall and probed conditions. A large subset of less skilled readers recalled less of the stories,

displayed less understanding of story structure, and displayed patterns of category recall that differed from normal readers.

Weak readers are known to perform lower on memory tasks involving the retention of lists of words or numbers. Brady, Shankwieler, and Mann, (1983) performed a series of experiments to investigate the ability of weak readers to recall word strings. Weak readers performed less well on recall of words strings and were not aided by rhyming words in the strings. Also poor readers were less competent in remembering word order. These findings may relate to similar findings connecting temporal order processing to reading ability (Ahisser et al. 2000; Heiervang et al, 2002; Reed, 1989; Rey et al. 2002; Tallal, 1980, 1984; Walker et al, 2002). Interestingly, Brady, Shankwieler, and Mann (1983) found that poor readers were less able to remember word lists when background noise was present and that they did not display this deficit when background noise was not present. Also, weak readers did not display difficulty remembering non-speech environmental sounds whether background noise was or was not present. The authors concluded that weak readers have a speech-specific perceptual deficit that interferes with auditory verbal memory.

Das and Mok (1994) found that word series recall was a linear function of phonemic segmentation ability, an important aspect of phonological awareness that is highly associated with early reading success. These observations lend support to theories that suggest children with reading disabilities have difficulty encoding the phonological aspects of speech/language based stimuli (Liberman, Mann, Shankweiler, & Werfelman, 1982; Tijms, 2004; Torgesen, 1985), and, by inference, may implicate auditory processing skills as important contributing deficits.

Differing recency and primacy effects between groups of normal and disabled readers have been observed when recalling lists of numbers or word strings (ex. Bauer, 1977; Penney &

Godsell, 1999). This finding supports theories which posit that reading disabled children retain less of a neurological 'trace' after a verbal stimulus and that their trace may be more susceptible to interference. According to this hypothesis, this echoic memory trace is either limited in capacity in children with reading disabilities or decays at a faster rate than in non reading disabled subjects (see Hurford & Shedelbower, 1993; Sipe & Engle, 1986). This finding may explain deficits in recall as it may impact a child's ability to effectively and correctly process incoming verbal information sufficiently for accurate recall.

Recognition memory, particularly rapid or automized recognition is another important skill for early reading acquisition and later reading fluency. Such a skill may be measured by rapid naming tasks in which the subject is asked to rapidly identify the names of common pictures or symbols. In addition to processing speed, this task also requires long term memory/knowledge. Many studies have found inferior rapid naming skills in subsets of the reading disabled population (Cornwall, 1992; Torgesen & Houk, 1980; Wolf & Bowers, 1999). Ackerman, Dykman, and Gardner (1990) found that readers with severe reading deficits have impaired immediate memory spans and that this is correlated with low performance on a rapid naming task. Similarly, Cornwall (1992) examined the relationships of rapid naming, phonological awareness, and verbal memory to reading ability in a group of severely disabled readers. She found that word list memory and rapid naming skills contributed significantly to the prediction of word recognition skills when controlling for general language ability. The rapid recognition and naming of letters and words is a skill which is vital to reading development.

**Encoding**

In 1985 Torgesen reviewed research on memory in children with reading disabilities and offered a framework for beginning to understand the complex memory difficulties displayed by children with reading disabilities. At that point, the modern conceptualization of memory deficits

in these children focused on difficulties in the encoding process, that is, the process of translating information into a form that can be stored and retrieved efficiently. Torgesen argued that children with reading disabilities have difficulty encoding the phonological features of sounds and language, whether it be vocal or sub-vocal in nature, and that this poor encoding leads to poor storage and thus retrieval. This line of thinking is supported by general information processing theories in which an auditory sensory trace (phonological in this argument) is poor or faulty thus impacting the accurate processing and storage of auditory information and subsequent recall of that information.

Some support has been found for this phonological encoding deficit hypothesis. For instance, poor readers do not appear to have impaired memory performance when asked to use non-verbal (or visual) codes to remember things. However, they almost always show deficits when compared to peers without reading disabilities on verbally or phonologically encoded material (Liberman, Mann, Shankweiler, & Werfelman, 1982). Similarly, Tijms (2004) indicated that impairments in verbal memory and phonological deficits in dyslexics seemingly stem from the same root problem, and that readers with dyslexia are unable to correctly encode the phonological characteristics of verbal messages. Likewise, Messbauer and de Jong (2002) suggested that the verbal learning and phonological deficits seen in dyslexic children in their study of verbal and nonverbal paired association learning may reflect the same underlying problem: phonological encoding. This phonological encoding deficit hypothesis also was supported by Gang and Siegal (2002) and by Penney and Godsell (1999) with general ideas that poor phonological encoding lead to poor processing of phonological information and thus poor memory.

In 1988, Torgesen reported on a series of studies with children with learning disabilities who also performed very poorly on memory span tasks. Torgesen claimed that this subgroup comprises about 15-20% of children with dyslexia. This series of studies provide considerable evidence that these children have difficulty encoding the phonological aspects of speech in verbal short-term memory tasks (Torgesen 1988). Additionally, the brains of individuals with dyslexia may have difficulty forming phonological representations accurately both during input and output processes (Alonso-Bua, Diaz, & Ferreces, 2006; Penney & Godsell, 1999). Investigations into why this may be true continue.

Prior to Torgesen's 1985 review, several researchers had proposed potential explanations for the apparent encoding and memory pattern difficulties observed in children with reading disabilities. One group of researchers proposed that the rate of access to verbal information in long term memory may account for processing and memory differences between normal readers and disabled readers (Ellis, 1981; Torgesen & Houck, 1980). While this may be consistent with data from rapid automized naming tasks, it offers little explanation for observed deficits in immediate short-term verbal memory.

Another possible explanation is that good readers may be better able to generate articulatory codes for verbal short term memory better than poor readers (Badderly, 1985) thus enhancing their ability to rehearse and recall verbally presented information. Ackerman, Dykman, and Gardiner (1990) support this hypothesis arguing that people with slower than normal articulation, whether vocal or sub vocal, are at a disadvantage on recall tasks as they would lack rehearsal time for encoding and that evidence suggests this to be true of reading disabled subjects. They further argue that "children with RD (reading disabilities) seem less able to appreciate that articulated sounds fall into logical groupings" (Ackerman, Dykman, &

Gardiner, 1990, p. 325), resulting in phonological difficulties and hence slower articulation and reading difficulties. Likewise, Badderly (1986) argues that verbal memory span is related to the rate at which the material can be articulated, a quality that is likely to be close to the root of phonological dyslexia through impaired functioning in the articulatory loop.

**Storage**

Memory storage abilities also influence a child's ability to remember information. Nelson and Warrington (1980) investigated long and short term memory storage in 51 Dutch dyslexic children in an attempt to determine if storage may be an underlying problem. Three main findings came of this study. First, children with dyslexia have impaired short term memory both in terms of capacity and in terms of temporal storage or time constraints. Second, children with dyslexia have impaired long term verbal memory storage. Third, children with dyslexia have impaired ability to acquire new information in the semantic system, and do not display difficulty accessing well established information in the semantic memory system. Nelson and Warrington state "In conclusion, it is our view that the reading difficulties of dyslexic children could best be accounted for by a combination of memory deficits, deficient short term storage having its principal effect on phonological reading and deficient semantic memory having its principal effect on 'direct' route reading" (p. 502). The authors describe this information in reference to a double deficit hypothesis in graphemic-phonemic and graphemic-semantic reading routes.

The influence of prior knowledge on a child's ability to store verbal information also has been examined. Knowledge about the world helps people integrate new information into their existing memory stores. This hypothesis is compatible with the parallel distributed processing model, where base knowledge stored in the brain offers more pathways by which connections can be made to new incoming information, thus aiding retention. Some indirect evidence for this hypothesis has been offered by a study conducted by Torgesen and Houck (1980). Familiarity

with material was found to aid recall. More importantly, the typical differences in recall seen between learning disabled children and normally learning peers were reduced when material which was unfamiliar to all groups was to be recalled.

**Level of development**

Developmental levels in memory skill constitute a related issue. Several researchers have put forward evidence for the hypothesis that the verbal memory deficits seen in children with reading disabilities may result from developmental lag. Memory performance of children with reading disabilities often has been likened to that of younger, non dyslexic children. For example, a study by Howes, Bigler, and Burlingame (2003) was conducted to determine how three different theoretical perspectives on dyslexia (i.e. phonological deficit, dual route and phonological core variable-difference model) might explain the variability of immediate memory performance of children with different reading abilities. A secondary purpose was to examine the specific memory processes of children who display different theoretical subtypes of dyslexia. The sample consisted of three groups: children with dyslexia, age matched peers, and younger children matched for reading level. Children with dyslexia performed similarly to younger reading level matched children on memory tasks. The phonological core variable-difference model accounted for the most variance in memory skill. The authors hypothesized that the memory delays seen in all dyslexic children are characteristic of developmental lags. Conversely, results of meta-analysis of the literature concerning documented memory deficits in reading disabled populations conducted by O'Shaughnessy and Swanson (1998) indicted that the memory difficulties displayed by persons with reading disabilities persisted across age, indicating that a memory deficit model, rather than a developmental lag, best describes the nature of these results. A memory deficit model is supported by the findings of Watson and Willows (1995) who found that many processing deficits, including verbal memory deficits were

persistent across age and that such processing problems become more generalized and more marked with age.

**Working Memory and Reading**

Working memory is not consistently and precisely defined in cognitive science literature. While this term is sometimes confused with short term memory, or used interchangeably with it in some older models of memory, more recent models attempt to differentiate the two based on their functions. Short term memory holds a limited amount of simple information for a very limited time and typically is described as operating independently of long term memory (Klapp, Marshburn, & Lester, 1983). The term working memory is used to denote all forms of memorized information, from any of the human memory stores, that is currently available for interpretation and manipulation (Anderson, 1995). Thus, a person's working memory ability refers to one's ability to use and work with information in conscious awareness. It is considered to be a dynamic and active system that simultaneously processes and stores information (Wong, 1995). Likewise, working memory also is seen as utilizing long term memory (Cantor & Engle, 1993) by integrating knowledge retained in long term memory with information from other sources. Short-term memory, on the other hand, does not process or integrate information.

The functional difference between short term memory and working memory is best illustrated with concrete examples. For example, in a short term memory task a child may be asked to remember a series of numbers (e.g. 2, 6, 4.). The child can hold this set of numbers in short-term memory for a brief moment and repeat back the series without much thought. As the list gets longer the task becomes more difficult due to the limited capacity of the system. This type of parroting task relies on short-term storage. However, if a child is given the same list of digits and then asked to repeat them in reverse order the nature of the task is different. The child's working memory is used when completing this more complex task which requires some

manipulation of the information in addition to the retention of the numbers in the sequence. Other working memory tasks include mental arithmetic problems and reading. When a child is reading or completing a math problem, the child must hold certain information in conscious awareness while manipulating it, taking in additional information and recalling information from long-term storage before putting all the information together in order to solve the math problem or understand the sentence being read. Thus, rather than simply being a short-term store, working memory uses information in short term storage by integrating it with additional information. Low short-term memory capacity, or difficulty with perception and encoding of immediate verbal input, impacts working memory (See Badderly & Hitch, 1974 for models of working memory).

Working memory plays an important, and sometimes overlooked, role in reading. A dual role of working memory during reading of text has been posited and supported by the work of several researchers. In such models applied to reading, working memory performs two main tasks. First, it holds recently read and processed text in order to make connections to the current input. Second, it maintains the overall meaning of what has been, or is being read for the construction of a situation model (Engle et al., 1992; Shah & Miyake, 1996).

Working memory helps readers decode unfamiliar words, guess at the meaning of words from context, and comprehend complicated text. The actual functions of working memory may differ depending on the level of the reader. For example, beginning readers with good working memory skills are better able to hold initial sounds in mind while finishing the decoding of an unfamiliar word. More advanced readers with good working memory skills can process ambiguous words and sentences more efficiently (Miyake et al., 1994) and are better at guessing the meanings of unfamiliar words based on context (Daneman & Green, 1986). Working memory generally has been found to correlate highly with reading comprehension (Engle et al.,

1992). If a reader has a high capacity for language based or verbal working memory, then comprehension processes (e.g. word encoding, lexical access, syntactic analysis and semantic analysis) are less of a strain on the limited capacity system. (Miyake, Carpenter, & Just, 1994). In other words, readers with superior working memory have more resources available for concurrent integration and comprehension.

The processes of integrating information and forming inferences while reading are important for the construction of a situation model. A coherent situation model, or a clear mental representation of the text's message is optimal in reading comprehension. The construction of a coherent situation model requires that relevant information from text, long term memory, from inferences made while reading, and from other sources be available for integration and processing. (Calvo, 2005) This makes the comprehension of text dependent on working memory. "Working memory is a resource that affects an individual's ability to carry out many of the processes associated with the construction of the text representation" (Cain, Oakhill, & Bryant, 2004, p. 32).

Results of a study conducted by De Jong (1998) indicated that children with reading disabilities display lower working memory skills than controls and that this deficit could not be explained by other processing problems or verbal short term memory capacity. De Jong concluded that "reading disabled children seem to have a general lack of capacity for the concurrent processing and storage of verbal information". (De Jong, 1998, p. 75). This is interesting given that verbal working memory, both for words and for numbers is related to reading comprehension (Oakhill, Cain, & Bryant, 2003). In a similar study conducted by Cain, Bryant, and Oakhill (2004), working memory was found to explain unique variance in reading comprehension when controlling for other skills (e.g. word reading ability, verbal skills and

vocabulary skills). Palladino et al. (2001) also found working memory skills associated with selecting relevant data and avoiding intrusion errors to be associated with reading comprehension. Along these lines, Engel, Cantor, and Carullo (1992) also support a general capacity explanation for the relationship between working memory and reading comprehension.

**Links to Processing**

Many researchers have hypothesized that an underlying cognitive processing problem is at the heart of the memory deficits seen in reading disabled youngsters. Although the exact nature of such a processing problem is debated, it seems likely that such a problem occurs at the time of, or immediately following the sensory registrar. Different hypotheses have explored language processing, auditory processing and phonological processing as possible processing deficits underlying these verbal memory deficits in children with reading disabilities. Likewise, the observation that as a general group, reading delayed children seem to do less well adjusting to the strategic processing requirements of verbal memory tasks than normally achieving children, (Torgesen 1977; Torgesen & Goldman, 1977) has been a debated aspect of dyslexia. Perhaps further investigation into the role of different processing skills and their possible hierarchical nature in verbal memory and reading ability will shed some light on these hypotheses.

**Depth of processing**

One such hypothesis is that information must be processed at a deep enough level in order to be remembered. According to Craik and Lockhart (1972), information can be processed either at a shallow level or at a deep level. The deeper the level at which information is processed, the better it can be remembered. A study conducted by Torgesen, Murphy, and Ivey (1979) sought to explore the hypothesis that the differences typically observed between good and poor readers on memory tasks could be eliminated if both groups were made to process the information to be

remembered in the same way and at a suitable depth. In other words, the better verbal mediation of the better readers would not be as evident if all subjects were made to process the information in a nonverbal and sufficiently ‘deep’ way. Initially, in a free recall condition the reading disabled subjects remembered significantly fewer items than the better readers. In the next step of the study, all subjects were made to process the information the same way by sorting pictures on cards into categories. This task required a deeper processing of the information. As expected, the memory performances improved on the second (processing experimental) condition. The dyslexic group improved more and the difference in performance between the two groups became non significant. This lends support for the idea posed by Craik and Lockhart (1972) that the trace of information in memory is improved by deeper processing of the information. It also ties in with evidence that visual and verbal processing of information occurs along different pathways requiring different skills, and carries implications for teaching reading disabled youngsters.

Plaza, Cohen, and Chevrie-Muller (2001) also explored the idea that children with dyslexia display a general processing limitation. In this study a group of French children with dyslexia were found to perform more poorly than controls on auditory memory skills, word and sentence processing skills and word retrieval skills. The findings were consistent with a processing limitation hypothesis that suggests children with dyslexia display a core deficit in processing auditory information and forming plans from auditory input.

**Language processing**

Language processing deficits also have been hypothesized as a cause of the verbal memory deficits seen in children with reading disabilities. A study by Cermack et al. (1980) found that children with reading disabilities performed similarly to others on a short term retention task and that children with higher verbal IQ scores as measured by a Wechsler Intelligence Scale for

Children – Third Edition (WISC – III) generally performed better on this verbal retention task which did not allow rehearsal. Likewise Torgesen and Houck (1980) reported that children with reading disabilities performed similarly to non-reading disabled peers on tasks that required them to remember strings of nonsense syllables. However, when required to remember strings of words, children with reading disabilities performed significantly lower than controls. The control children appear to be using language based strategies that are not being used by the group of children with reading disabilities when memorizing words, and which were not available to them when remembering nonsense syllables. These studies indicate that a language processing component may be important in verbal recall. They also call into question the nature of the phonological encoding issues discussed earlier.

Martin (2000) believes an important relationship exists between word processing and short term verbal memory and that this relationship has not been fully explored. Martin argues that sounds, specifically words, must be processed with sufficient efficiency and adequacy and held in short term memory long enough in order to be integrated into longer term memory. In other words, sounds have to be detected, discriminated, processed for phonology and meaning, placed together to form words, and held in consciousness while processing more incoming sounds and words before some meaning can be derived from the message and the message can be stored and/or manipulated by the recipient. If initial sounds are not discriminated well, or processed efficiently and assigned meaning, as may be the case with children with auditory processing or language processing deficits, then the remaining chain is negatively affected, thus impacting memory. This hypothesis fits well with the levels of processing model proposed by Craik and Lockhart (1972) and with a hierarchical paradigm of interrelated processes of differing complexity. Martin believes an understanding of this process must be improved if we are to

accurately comprehend theories of verbal learning, language acquisition and language related deficiencies such as dyslexia.

**Auditory / phonological processing**

A type of auditory processing or, more specifically, phonological processing deficit may be the underlying cause of observed verbal memory deficits in poor readers. According to human information processing models, information must be coded in the sensory register accurately prior to further processing. The initial sensory memory trace is then processed further and results in a conscious short term memory store. It is hypothesized by several authors that this auditory sensory trace may not be adequate to allow further processing for phonological aspects of the auditory signal. It may follow that more complex sound, such as speech may make accurate processing of sound less likely.

A study conducted by Merlo (1986) sought to explore relationships between verbal short term recall and phonetic processing efficiency. Children were given a variety of verbal and non-verbal memory and phonetic tasks. A strong relationship between short term recall and phonetic processing efficiency was found. This finding supports the author's hypothesis that memory capacity increases when phonetic processing requirements are reduced. Merlo also found that developmental improvements in verbal short term memory occur when children are able to process phonetic tasks more efficiently.

DiDonato (2002) compared the verbal memory performance of children diagnosed with (central) auditory processing disorders ((C)APD) with that of children diagnosed with ADHD. She found that the (C)APD group performed significantly worse than the ADHD group on verbal memory tasks from the Wide Range Assessment of Memory and Learning (WRAML). Further, and more importantly, the children with (C)APD also performed significantly worse on memory tests than the norming sample for the WRAML. Given our knowledge that verbal memory

encoding and phonological processing take place in the temporal lobe of the brain, where pivotal aspects of auditory processing take place, a connection between some verbal memory patterns and central auditory processing abilities seems logical.

In conclusion, evidence exists that children with reading disabilities display consistent deficits in a variety of verbal memory skills, especially verbal short term memory and verbal working memory. Many hypotheses have been put forward as to why these deficits occur in this population. Common areas of inquiry include the possibility of an underlying information processing deficit, specific to the auditory domain, leading to problems with encoding verbal or phonological information, the ineffective use of strategies, and a slow rate of access to long term memory stores. Despite the copious amount of research on learning disabilities, answers as to why some children have difficulty learning to read and why they display various unusual cognitive patterns and deficits come slowly.

Several methodological and conceptual issues arise as being potentially problematic in this review of the literature related to memory and reading skill. First, the issue of defining the term 'reading disabled' is of concern. Children with reading disabilities do not fall into a neat homogeneous category, a fact often overlooked in research pertaining to the variety of skill deficits known to be associated with difficulties in reading. Persons with reading disabilities display differing patterns of processing deficits which may warrant the need to establish subtypes of reading disabilities (see Watson & Willows, 1995). In addition, children with reading difficulties often display any of a number of co-morbid conditions, thus complicating research and increasing error variance in results obtained from this population.

While many studies attempt to address at least part of this problem by making sure that their study subjects with reading disabilities meet basic well defined diagnostic criteria for

reading disabilities, other studies have attempted to subcategorize reading disabilities according to particular features observed from a profile of scores following psychoeducational testing conducted prior to subject selection (Cermak et al., 1980; Liddell & Rasmussen, 2005; Watson & Willows, 1995) and have found different memory patterns between high and low verbal ability subjects with reading disabilities. Higher verbal ability, despite dichotomous reading disability status, aids verbal memory performance. High verbal ability is likely to depend at least partially on good phonological awareness. In as far as this is true, it may add some weight to the argument that poor readers have difficulty processing and encoding the phonological aspects of verbal messages. However, Watson and Willows (1995) studied memory modalities in children with reading difficulties and without oral language deficits. This eliminated the possibility of poor verbal memory performance being due to undeveloped or delayed language skills. The results of this study indicated that children with reading difficulties and good oral language skills still displayed lower levels of verbal memory skills than their non-reading disabled counterparts thus pointing to a deficit stemming from something other than verbal skills.

Another problem lies in the complex nature of cognitive processes and difficulty separating several interrelated cognitive skills in studies of this nature. Although patterns and trends can be observed, the ability to set up experimental conditions that may allow the manipulation of a sole cognitive skill or process is nearly impossible. Additionally, people with learning disabilities tend to draw on strengths to compensate for weaknesses in other areas. The degree to which this may be occurring in test subjects is difficult to judge. It is likely that subjects with higher general cognitive abilities are better able to compensate for areas of skill deficit.

Along these lines, some variability in research results may be attributable to the complex nature of memory tasks and the slightly different cognitive requirements of seemingly similar verbal memory tasks. Some memory tasks can be affected by other cognitive skills that are peculiar to the individual, such as language skills, knowledge stores, attention or previously learned strategies. However, as a general rule, difficulties with verbal memory tasks are common in people with reading disabilities. Thus, a significant amount of research points to auditory processing deficits, especially temporal processing deficits in dyslexia. Research results also call attention to the difficulty of dyslexic brains to discriminate sounds even prior to cognitive awareness. Perhaps part of the cause of these observed dyslexic traits can be explained by primary auditory processing in the brain.

## Auditory Processing Skills and Verbal Memory

Given the discussion above, an underlying deficit in auditory information processing may be partially responsible for the phonological and memory difficulties observed in many children with dyslexia. Little research using behavioral techniques examines relationships between various auditory processing skills and verbal memory. However, recent studies are beginning to provide information on this issue (Ceponiene et al., 1999; DiDonato, 2002), including a growing number of studies that use electrophysiological methods. Several behavioral studies have found some support for a connection between auditory processing and phonological and memory deficits in children with dyslexia. For example, Di Donato (2002) found that the memory ability of children with central auditory processing deficits (CAPD) was lower than the norming sample on a well known standardized memory test.

Behavioral tests that assess auditory processing skills require verbal short-term or phonological memory. Thus, children who obtain low scores on these behavioral APD tests may have deficient verbal memory skills. This potential methodological issue has made the design of

studies that use behavioral measures of auditory processing and verbal memory more difficult due to possible overlap of these two skills. Riccio et al., (2005) addressed these issues and found that behavioral APD tests were measuring qualities other than memory and attention. Studies using more direct methods of assessing auditory processing skills, such as brain imaging methods, may be more promising by overcoming various potential confounds associated with the use of behavioral assessments.

Most evidence linking auditory processing and verbal memory skills comes from neuroimaging studies of the brain. This line of research and our growing knowledge of the brain will continue to shed light on underlying neural and biological causes of dyslexia and other developmental disorders. Common methods used include PET scans, fMRI techniques and event-related potentials (ERP) techniques, especially using mismatch negativity (MMN) responses. The technique of mismatch negativity response relies on a pre-attentive brain response to an auditory stimulus which indexes the accuracy of auditory discrimination at the neural level. The brain is believed to develop a memory trace of a given repeated stimulus such that, when a deviant stimulus is presented, the brain detects the deviation as differing from the memory trace. The brain's detection of the different stimulus is measured as a negative voltage deflection on an EEG. Studies using mismatch negativity response generally have found that people with reading disabilities differ in latency and/or magnitude on the voltage deflection on the EEG when a deviant stimulus is presented (Alonso-Bua, Diaz, & Ferraces, 2006; Kujala et al. 2000; Poldrack et al. 2001; Purdy, Kelly, & Davies, 2002; Sharma et al. 2006; Taylor & Keenan, 1999; Temple et al., 2000) thus indicating that people with reading disabilities have problems with accurate neurological representation and discrimination of auditory information.

A general information processing model can be used as a means by which to understand the significance of this finding. In such a model, the faulty auditory sensory representation indicated by a lack of MMN response is analogous to a faulty or poor sensory registry trace. Attention is given to the sensory trace, and further processing is performed in order to transform the information into some useful or meaningful format in short-term memory stores. From here the partially processed information may be used for further integration with knowledge from long-term stores or simply lost. Obviously, an inaccurate initial sensory trace will result in poor memory outcome further down the information processing path. Likewise, the processing of incorrect traces of complex auditory stimuli such as speech will result behaviorally in poor phonological awareness skills and delayed reading acquisition.

Ceponiene et al., (1999) used the mismatch negativity (MMN) response and behavioral measures to examine relationships between auditory sensory trace and phonological short term memory in normally developing children. Differences in pre-attentive auditory sensory memory traces were found to parallel differences in phonological short-term memory. Ceponiene and colleagues concluded that the brain's ability to automatically discriminate minute acoustic differences influences its ability to process phonological aspects of speech. Although no children with dyslexia were used in this study, subtle differences in the initial short-term phonologic memories of children in the sample were able to produce these results. Likewise, Alonso-Bua, Diaz, and Ferraces (2006) concluded that phonological deficits are present at a pre-attentional and automatic level in children with poor reading performance.

The findings from an earlier study (Kraus et al., 1996) concur with those from Ceponiene et al. (1999) and Alonso-Bua, Diaz, and Ferraces (2006). These studies found that some children with learning disabilities and speech discrimination deficits have neurological problems

originating in the auditory pathway even before a sound is perceived. As we have already established, speech discrimination deficits negatively impact verbal encoding. (Booth, 2000; Brady, Shankwieler, & Mann, 1983; Hurford & Shedelbower, 1993; Tijms, 2004; Studdard-Kennedy & Mody, 1995). Acoustic similarity affects verbal recall of items (Hulme, 1987), thus providing further evidence of the importance of discrimination of the initial sounds at the early neurological level for memory. Deficits in auditory abilities (e.g. discrimination of phonemes) may pervasively negatively impact word processing abilities (Booth, 2000). Deficits in word processing likewise negatively impact verbal memory (Lespinet et al. 2004; Martin, 2000; Plaza et al., 2001).

More expansive brain research involving PET scans and fMRI studies indicate areas of the left temporal-parietal cortex are active during verbal memory encoding (Casasanto et al. 2002; Lespinet et al. 2004), auditory signal perception and processing (Bellis, 1997; Burton, et al. 2001), phonological processing (Gupta & MacWhinney, 1997; MacCandliss, 2003; Poldrack et al. 2001), and language processing (Burton, et al. 2001). Additionally, the left posterior temporal region is underactivated during reading tasks in the brains of people with dyslexia (Alonso-Bua, Diaz, & Ferraces, 2006; McCandliss, 2003; Salmelin, 2004). The brains of persons with dyslexia often have cellular differences, perhaps resulting from abnormal neuronal migration during the prenatal period, in the subcortical and cortical regions of the auditory system (Galaburda, 2004). Thus, auditory processing, phonological processing, verbal memory, language processing and reading abilities may be related in a complex neuro-biological, information processing based system that warrants further investigation.

The progression of research in these related areas suggests the presence of one or more underlying neurological or sensory information processing deficits in children with reading

disabilities. In some children, an underlying shortfall in the central auditory pathway or in the temporal-parietal cortex may lead to a deficit in the neurological representation and subsequent processing of auditory stimuli, which in turn may lead to inaccurate progression through the information processing steps, poor phonological awareness skills, verbal memory deficits, language and vocabulary deficits, and reading disabilities.

Due to individual variations in anatomy and cognitive skills, some brains overcome potential problems while others do not. While one processing deficit may negatively impact reading ability, the presence of a second or third processing deficit will make it far more difficult for a person to compensate and develop adequate reading skills. Cortical malformations resulting from neuronal migration may lead to changes in underlying brain structures which may lead to auditory processing difficulties in some people (Galaburda, 2004). In turn, these auditory processing difficulties affect phonological representations in the brain, on which further information processing takes place which fundamentally causes observed phonological deficits that are known to lead to reading difficulties. Galaburda further proposes that the original neuronal migration in this causal chain may be genetic in origin.

## Summary

In all likelihood, different subtypes of reading disabilities exist, and they are compounded by several other variables. Thus, the causal path outlined by Galaburda (2004) may not be the only one. While links between many variables have been explored, the possible link between verbal memory and auditory processing deficits in children with reading disabilities has not been addressed despite the seemingly probable connection. Thus, the purpose of this study is to examine the hypothesized link between auditory processing, reading, and verbal memory. Accordingly, this study seeks to investigate more specific aspects verbal memory skill deficits already documented in the literature (Ackerman, Dykman, & Gardner, 1990; Cornwall, 1992;

Howes, Bigler, Burlingame, & Lawson, 2003; Messbauer & de Jong, 2002; Nelson & Warrington, 1980; Torgesen, 1982; Torgesen & Goldman, 1977; Wilkins, Elkins, & Bain, 1995) and to investigate how qualities displayed by persons with a co-morbid diagnosis of APD and reading disability might impact this observation.

This study seeks to answer the following questions:

1. Compared to children without reading disabilities, do children with reading disabilities have significantly lower verbal memory skills? Several hypotheses related to this question emerge:
    a. The verbal memory of children with reading disabilities is expected to be lower than for children without reading difficulties.
    b. Children with reading disabilities are expected to display higher visual memory than verbal memory skills.
    c. The visual memory of children with and without reading disabilities is not expected to differ.
2. Within a sample of children with reading disabilities, do children with auditory processing disorders have significantly lower verbal memory skills than children with reading disabilities alone? Once again, several hypotheses extend from this question:
    a. The verbal memory of children who display both reading disabilities and auditory processing disorders is expected to be lower than for children with reading disabilities alone.
    b. The visual memory of children who display both reading disabilities and auditory processing disorders is not expected to differ from that of children with reading disabilities alone.

# CHAPTER 2
# METHOD

## Participants

Sixty children from a variety of elementary schools in northern Florida participated in this study. The children were divided into two groups based on a history of reading disabilities. One group consisted of children with moderate to severe reading disabilities. The other group consisted of children with no history of reading difficulty and who were reading at or slightly above grade level at the time of the study. The groups will hereafter be referred to as the reading disabled group (RD group) and the normally achieving or control group.

### The Reading Disabled Group

The reading disabled (RD) group consisted of forty children between the ages of 7 years, 0 months and 12 years, 6 months who displayed moderate to severe reading disabilities. All RD group participants were selected from the clinical client population of the University of Florida's Multidisciplinary Diagnostic and Training Program (MDTP). The children were referred to MDTP due to their moderate to severe learning disabilities. These children had been diagnosed previously by school district personnel and had not responded to school and/or community interventions. Prior to each child's acceptance into the MDTP program, a consultant from the program went out to each child's school to observe and evaluate the integrity and appropriateness of interventions that had implemented. If interventions were determined to be inadequate, the consultant worked with teachers in order to improve the quality of the interventions and monitored the child's progress. If it was determined that appropriate interventions had been attempted and yet the child had still not shown sufficient progress, then the child was accepted into the program for full evaluation and follow-up services. Thus, the

children who eventually came to MDTP and were participants in this study had received and had not responded to school based interventions.

All participants in the RD group received the full multidisciplinary assessment battery offered by the MDTP team of professionals. This comprehensive multidisciplinary battery consisted of educational, psychological, speech and language, occupational therapy, and audiological evaluations. Potential RD group participants were selected from a data base maintained by MDTP. Criteria for inclusion in the study included an IQ above 75 as measured by one of several reputable standardized and norm-referenced intelligence tests, a formal assessment of auditory processing skills, normal hearing sensitivity, absence of chronic health conditions, and a history of significant reading difficulties determined by standard scores on standardized, norm referenced reading achievement tests being at least one standard deviation below expected performance based on grade level or based on IQ. The RD group had an average reading standard score of 83.7 (SD = 10.1).

The RD group was divided further into two sub groups, one consisting of twenty children with RD diagnosed with an auditory processing disorder (APD) by the Speech and Hearing Center at the University of Florida (RD-APD group; n=20), and a second group of children with RD and without auditory processing difficulties (RD-NAPD group; n=20). The mean age of the RD-NAPD group was 116.55 months (SD=16.57) while the mean age for the RD-APD group was 116.15 months (SD=17.55). Both groups were of mixed race and gender with approximately 65% of participants in each group being boys.

**The Normally Achieving Group**

The normally achieving control (NA) group was comprised of twenty children with no history of learning difficulties and reading achievement levels at or above grade level expectations. Participants in this group ranged from 7 years 4 months to 12 years 4 months.

Participants in the NA group were selected from the student population at the University of Florida's Developmental Laboratory School, P. K. Yonge. After initial teacher referral for the study, reading achievement levels were verified by accessing student scores on norm referenced assessments such as the Gates-McGinitie Reading Test or, where applicable, scores on the reading portion of the Florida Comprehensive Assessment Test (FCAT). Selection criteria included reading level between the 45$^{th}$ and the 85$^{th}$ percentile in reading, no chronic medical conditions and a measured IQ above 75. The average percentile in reading for this group was the 64$^{th}$ percentile (SD = 12.9). This group was matched as closely as possible to the RD group for gender and age range ($\pm$ 8 months). Informed consent was obtained from parents of students in the NA group prior to testing.

## Procedure

Testing was completed by specialists certified for practice in their profession or by advanced doctoral students and interns in either school psychology or audiology who were completing their training at MDTP or at The University of Florida and were supervised by university faculty.

### Audiological Evaluations

Auditory processing disorders are evaluated and diagnosed by an audiologist. Assessment begins with patient screening and a thorough case history, usually obtained through means of an interview or patient questionnaire. Based on this initial information, a test battery is selected that considers the patient's age, behavioral symptoms, cognitive development, ability to sustain attention and other pertinent individual characteristics. Testing typically is conducted in a sound booth using calibrated instrumentation with the subject wearing headphones.

The audiological evaluations of the participants with reading disabilities took approximately one hour. As these evaluations were conducted for clinical purposes, they more

extensive than the evaluations conducted on normally achieving subjects. Evaluations of children in the normally achieving group took about 15 minutes and primarily consisted of screening instruments in order to rule out auditory processing difficulties.

**Audiological assessment instruments**

Each of the auditory assessment techniques used in this study is described below.

**SCAN-C** The SCAN-C Revised (Keith, 2000) is a screening test battery for auditory processing disorders in children ages 5 through 12. It consists of four subtests, each of which screens for a specific type of auditory processing deficit and provides a composite score. This testing is administered in a sound booth with the signals delivered to the child through headphones. Instructions are given verbally, and the child is required to respond verbally. Administration of the SCAN-C is standardized and results are norm referenced based on a sample of 650 children who reflect the 1997 United States census data. All children spoke English without articulation errors. Reliability estimates include test-retest reliability and internal consistency. Overall, the composite score produces acceptable levels of reliability (> 0.8). However, individual subtest reliabilities vary and are less reliable, especially in reference to internal consistency. Criterion validity for the SCAN – C was estimated by comparing results to those obtained on the original SCAN. Results were less than optimal, with correlations between 0.19 and 0.79. Construct and convergent validity also are problematic. Construct validity was evaluated using a discriminate analysis study with positive results.

The following subtests of the SCAN-C were administered: Filtered Words, Auditory Figure-Ground, and Competing Words. The Filtered Words subtest requires a child to repeat back words filtered at 1000 Hz he or she hears. Filtering the words in this manner makes the speech distorted. In the auditory figure ground subtest, words are presented to the child along with background noise similar to what might be heard in a school cafeteria. The child is required

to repeat the words he or she hears. This subtest measures the child's ability to distinguish speech sounds within background noise. During the Competing Words subtest, the child hears two different words at the same time, one in each ear. He then is required to repeat back the words he heard. This dichotic listening subtest measures the child's ability to integrate sounds coming simultaneously from different directions.

**Dichotic Digits Test** Dichotic digits tests assess a child's ability to integrate sounds coming through both ears simultaneously, otherwise known as binaural integration. During this test, the child hears two different numbers presented simultaneously in each ear, followed by two additional different numbers presented likewise. The child is required to repeat the numbers he or she heard in each ear (a total of 4 numbers). Normative data are available for the dichotic digits test.

**Pitch Pattern Sequence Test** The Pitch Pattern Sequence Test, a test of temporal order processing, assesses the child's ability to sequence sounds. This ability is related to language and reading skills. When taking this test the child is presented with a sequence of three pure tones that differ in pitch. The tones may be high or low in pitch and may be presented in any combination of three sounds. During the first part of this test the child is required to verbally label each sound as high or low in the order they were presented. During the second stage of this test the child is required to hum the sequence he or she heard. The manual provides means, standard deviations and score ranges for three different age groups.

**Staggered Spondaic Word Test** The Staggered Spondaic Word (SSW) test (Katz, 1963). This is a norm referenced test that assesses a child's ability to integrate compound words heard from both ears into a meaningful word. During this test, portions of words are presented to each ear, with portions of each word overlapping with the information being presented to the other

ear. The child then is required to repeat the two words he or she heard in order to make a compound word. The test is old and several items are out of date. In addition to this concern, newer recordings of the items on this test are not of modern quality and have background noise which may influence results and diminish validity. This test often is used as a back-up or confirmatory test following possible deficits detected on the SCAN-C.

**Phonemic Synthesis Test** This is a test of phonemic skills. The child is required to identify words that are presented as a sequence of disjointed phonemes.

**Auditory processing disorder diagnosis**

The results of auditory tests are interpreted using norms. Intra-test and inter-test analysis within and between various subtests of the test battery can provide additional diagnostic information. The audiologist attempts to identify patterns and trends among subtests to help confirm a diagnosis. Relevant information from other disciplines such as speech/language or psychology, including an understanding of potential co-morbid influences, generally are considered before arriving at a diagnosis of central auditory processing disorder (ASHA, 2005a; ASHA, 2005b; Jerger & Musiek, 2000). After considering relevant information from additional sources, a diagnosis of APD generally is made if a child displays skill deficits that are at least two standard deviations below average for his or her age, on one or both ears on at least two tests in the test battery (ASHA, 2005b). These guidelines were followed for purposes of this study.

**Cognitive Assessment Instruments**

**Memory assessment**

Children who participated in this study had both their verbal and visual memory assessed under immediate and delayed conditions. This took approximately one hour to complete using the Children's Memory Scale (Cohen, 1997).

**Children's Memory Scale (CMS)** The Children's Memory Scale (Cohen, 1997) is a comprehensive, standardized, norm referenced instrument designed to assess learning and memory in children from 5 to 16 years of age. It assesses visual and verbal memory, both in context and in isolation. It also assesses short term and delayed memory in both visual and verbal modalities thus allowing within subject comparisons of several aspects of memory. Standard scores are available for general memory, immediate verbal memory, delayed verbal memory, immediate visual memory, delayed visual memory, attention/working memory, learning, and for prompted verbal recognition recall. The standard battery, consisting of two subtests in each of the index categories was administered to each of the study participants.

The standardization sample for the Children's Memory Scale consisted of 1000 children representative of the population of children in the United States according to 1995 census data. Children with a history of academic difficulties, children who had previously received any special education services, and children with a history of neurological deficits or injuries were excluded from the general norming sample. However, a clinical sample of children with neurological and neurodevelopmental issues was included. Average reliability coefficients for the index scores follow: Visual Immediate Memory 0.76, Visual Delayed Memory 0.76, Verbal Immediate Memory 0.86, Verbal Delayed Memory 0.84, General Memory 0.91, and Attention/Concentration 0.87. Estimates of inter-rater reliability range from 0.91 to 1.0 depending on the subtest and age of the respondent. The manual also reports studies which address construct validity, convergent validity, concurrent validity and content validity. Overall the instrument is reported to be a valid measure of memory skills.

**Intelligence tests**

Participants in this study were each administered one of five different standardized intelligence tests. For the RD group, the IQ test to be used with each client was carefully selected

and administered by interns or advanced graduate students in school psychology. Tests used included the Wechsler Intelligence Scale for Children – Fourth Edition (WISC IV), the Differential Ability Scales (DAS), the Woodcock-Johnson III - Tests of Cognitive Abilities (WJ III – cog), or the Universal Nonverbal Intelligence Test (UNIT). Children in the NA group were each administered the Kaufman Brief Intelligence Test – Second Edition (KBIT-2). All five assessment instruments are well known, norm referenced, standardized measures of general intelligence.

**Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV)** The WISC – IV (Wechsler, 2003) is an individually administered intelligence test for use with children between the ages of 6 years, 0 months and 17 years, 11 months. A total of 15 WISC-IV subtests are designed to measure a wide array of cognitive abilities and processes. The WISC-IV yields scores in each of four Indices: Verbal Comprehension, Perceptual Reasoning, Working Memory and Processing Speed, in addition to a Full Scale IQ. The standardization sample for the WISC-IV included 2,200 children representative of the general population of the United States according to 2000 census data based on race, geographic location, gender and parent education level.

The psychometric properties of the WISC-IV are strong. Internal consistency reliability coefficients are reported to be between 0.79 and 0.90 for the core battery of subtests, between 0.88 and 0.94 for the four index scores, and 0.97 for the Full Scale IQ. Interscorer reliability coefficients are reported to be between 0.95 and 0.99 for the WISC-IV subtests. Test-retest stability coefficients are reported to be between 0.76 and 0.92 for the subtests, between 0.86 and 0.93 for the four index scores and 0.93 for the Full Scale IQ (Wecshsler, 2003).

The WISC-IV manual supplies extensive evidence of validity. Evidence is provided based on test content, response processes, internal structure, and correlations with other published cognitive measurement instruments. Content validity, concurrent validity, and convergent validity are reported to be high.

**The Differential Ability Scales (DAS)** The DAS (Elliot, 1990) is an individually administration to children from 2.5 through 17 years of age. It contains multiple subtests and gives an overall General Conceptual Ability (GCA) score which is analogous to IQ. It was standardized on 3,475 U.S. children stratified according to 1988 U. S. Census data. The normative sample included children from several special education categories. Mean internal consistency reliabilities range from 0.7 to 0.92 for subtests and 0.88 to 0.92 for composite scores. Test-retest reliabilities reportedly ranged from 0.53 to 0.97. Validity was evaluated using confirmatory factor analysis, with subtests not loading sufficiently on the general factors retained for diagnostic purposes only. Concurrent validity studies with several commonly used measures of intellectual ability were strong. The DAS is considered to be a well constructed and valid measure of intellectual ability.

**The Woodcock-Johnson III - Tests of Cognitive Abilities (WJ III – cog.)** The WJIII-cog. (Woodcock, McGrew, & Mather, 2001) is an individually administered test of cognitive processing abilities. It is suitable for use with people aged between 24 months and 90 years. The test gives an overall general intellectual ability score in addition to a variety of composite scores indicating skill level in commensurate cognitive processing domains. The standardization sample of the WJIII-cog consisted of 8,818 subjects believed to be representative of the United States population. The WJIII manual (McGrew & Woodcock, 2001) reports median inter-rater reliability coefficients between 0.88 and 0.98 for those subtests requiring subjective scoring by

the administrator. Test-retest reliabilities are reported to be between 0.81 and 0.98 for the cluster scores and 0.97 for the General Intellectual Ability score. Additionally, the manual provides extensive evidence of validity through examinations of internal structure, tests content and concurrent validity with other measures of cognitive functioning.

**The Universal Nonverbal Intelligence Test (UNIT)** The UNIT (Bracken & McCallum, 1998) is an individually administered test of cognitive ability that does not require the use of any verbal instructions during administration. It is standardized and normed on children aged 5 through 17 years. It is considered especially useful for persons with limited English language skills. The UNIT is comprised of six subtests and provides an overall composite score. The test was normed on a sample of 2100 children. The norming sample included children from a variety of special education categories. Estimates of internal consistency range from 0.89 to 0.95 for the standard battery. The test-retest reliability coefficient for the Full Scale IQ is 0.91. The UNIT is reported to correlate well with other measures of intelligence and is reported to demonstrate sound construct validity.

**The Kaufman Brief Intelligence Test- Second Edition (KBIT – 2)** The KBIT-2 (Kaufman & Kaufman, 2004) is an abbreviated, individually administered, standardized and norm referenced intelligence test for use with people between the ages of 4 and 90. It is typically used as a screener of general intelligence. It was normed on a sample of 2120 people across the United States. This sample was reflective of US census data. Internal consistency reliability is strong with coefficients for the IQ Composite ranging 0.89 to 0.96 depending on age. Test-retest reliability is also strong with adjusted coefficients for the IQ Composite score ranging from 0.88 to 0.92 depending on age. The KBIT-2 is reported to correlate well with other measures of intelligence.

The KBIT-2 was determined to be  sufficiently valid and reliable to be used for screening control group participants. The screening of control group participants was done for two reasons. An estimate of intelligence was required in order to control for intelligence during the analysis phase of the study and to make sure participants possessed the intellectual ability necessary to accurately complete the audiological components of the testing process. The KBIT-2 was thought to be suitable for both purposes ( Kaufman & Kaufman, 2003)

**Reading Assessment**

Children with reading disabilities received individually administered, standardized, and norm referenced assessments of reading ability. A reading disability was confirmed if the child displayed general reading skills at least one standard deviation below grade level, or if children achieved a reading standard score at least one standard deviation below their measured IQ. For children in the normally achieving control group, performances on the Gates – McGinitie Reading Assessment Test and/or performances on the reading portion of the Florida Comprehensive Assessment Test (FCAT) and the Norm Referenced Test (NRT) were used to verify grade level reading skills. All reading scores were subsequently converted to percentile ranks for easy comparisons across different measures.

**The Woodcock-Johnson III - Tests of Achievement (WJ III – ach.)** The WJIII-ach. (Woodcock, McGrew, & Mather, 2001) is a standardizd and norm referenced, individually administered assessment of academic achievement. The test assesses a variety of academic skills in the areas of reading, mathematics, writing, oral language skills, and general knowledge. The test gives a standard score in Total Achievement along with standard scores in several academic clusters including Broad Reading, Broad Mathematics and Broad Writing. It is suitable for use with people aged between 24 months and 90 years and is normed for both age and grade level. The standardization sample of the WJIII-ach. consisted of 8,818 subjects believed to be

representative of the United States population. The WJIII manual (McGrew & Woodcock, 2001) reports test-retest reliabilities between 0.87 and 0.96 for the cluster scores and 0.98 for the Total Achievement score. Additionally, the manual gives extensive evidence of validity through examinations of internal structure, tests content and concurrent validity with other measures of achievement.

**The Wechsler Individual Achievement Test – Second Edition (WIAT-II)** The WIAT-II is an individually administered, standardized and norm referenced test of academic achievement suitable for assessing people between the ages of 4 and 85 years. The test assesses a variety of academic skill areas including reading, mathematics, writing, and oral language. The WIAT – II is normed for both age and grade level. The standardization sample for the grade based norms consisted of 3600 children representative of the U.S. population in grades pre-K through 12. The WIAT – II manual reports test-retest reliabilities between 0.85 and 0.98. Evidence of content related validity, construct related validity and criterion related validity are also given in the WIAT – II manual.

**The Gray Oral Reading Tests – Forth Edition (GORT - 4)** The GORT – 4 is a standardized and norm referenced, individually administered test of oral reading ability. It is suitable for use with people aged between 6 and 19 years. The GORT - 4 provides scores in reading rate, fluency, accuracy and comprehension. An overall Reading Ability score combines a student's fluency and comprehension. The standardization sample for the GORT – 4 consisted of 1,677 students from 28 states across the United States. The sample was believed to be representative of the U. S. population. The GORT – 4 manual (Wiederholt & Bryant, 2001) gives evidence of reliability related to content sampling, test-retest and interscorer differences. Test-

retest reliability coefficients range from 0.78 to 0.95. The manual also gives ample evidence of content validity, criterion-prediction validity and construct-identification validity.

**The Gates-McGinitie Reading Assessment Test** The Gates-McGinitie is a standardized group administered, nationally norm referenced reading assessment. Scores are given for Vocabulary , Comprehension and Total Reading.

## Data Analysis

The primary goal of this study was to determine if children with auditory processing disorders display a pattern of memory skills that differs from children without auditory processing difficulties. Specifically it was hypothesized that children with auditory processing disorders would have lower verbal memory skills than expected when compared to norms, and when compared to peers without auditory processing disorders, and that their verbal memory skills will be lower than their visual memory skills. Children with reading difficulties often display verbal memory deficits (Ackerman, Dykman., & Gardner, 1990; Cornwall, 1992; Howes et al. 2003; Howes, Bigler, Burlingame, & Lawson, 2003; Messbauer & de Jong, 2002; Nelson & Warrington, 1980; Torgesen, 1982; Torgesen & Goldman, 1977; Wilkins, Elkins, & Bain, 1995). Thus, the possible contribution of auditory processing disorders to memory problems in reading disabled children was examined. It was further hypothesized that the presence of an APD in children with reading disabilities would have additional adverse affects on verbal memory skills. Because memory skills are also known to be correlated with IQ (Wechsler, 2003), ability to attend, and age (Cohen, 1997), where necessary, these additional variables were controlled in this study.

In order to clarify how the groups differed on important variables such as reading level, IQ and auditory processing skills, descriptive statistics on all variables were provided. Additional analyses were conducted in several steps.

**Question 1**

The first set of analyses were used to determine if memory patterns across visual and verbal domains in participants with reading disabilities differ significantly from those found in normally achieving control subjects. A group (RD vs NA) by memory (visual and verbal) analysis of covariance (ANCOVA) was conducted with IQ as the covariate. Multivariate analysis of covariance (MANCOVA) procedures were then used to examine whether the groups differed significantly on immediate and delayed memory skills. Again, IQ was used as the covariate. Paired samples t-tests were used in order to make within group comparisons across performances in visual and verbal memory domains.

**Question 2**

A second set of analyses were used to determine if the presence of an APD in addition to a diagnosed reading disability had an additional adverse affect on verbal memory. Group (RD-APD vs RD-NAPD) by memory (visual and verbal) ANCOVAs were conducted. The Multivariate analysis of covariance (MANCOVA) procedure was then used to establish whether these groups differed on immediate or delayed memory skills across both visual and verbal domains. IQ was the covariate in each analysis.

# CHAPTER 3
# RESULTS

Results from this study are presented in three parts. The first section presents the descriptive statistics for all variables investigated in this study. The second section addresses each of the hypotheses related to Question 1. The final part of this results chapter addresses each of the hypotheses related to Question 2. The implications and limitations of these findings are discussed in Chapter 4.

## Descriptive Statistics

Table 3-1 displays the descriptive statistics for the memory variables. Scores for General Memory, Visual Immediate Memory, Visual Delayed Memory, Verbal Immediate Memory, Verbal Delayed Memory, and IQ represent raw scores that have been converted into standard scores (M=100, SD=15). Scores for Total Visual Memory and Total Verbal Memory represent the sum of two standard scores within the memory category described. Reading scores in Table 3-1 are national percentile ranks.

As can be seen from Table 3-1, the overall performance of the entire sample was stronger on visual memory skills than on verbal memory skills. The average IQ for the whole sample (M=99) was close to the expected population mean of 100 with a slight skew towards the upper end of the range.

On average, children in the normally achieving (NA) group performed slightly higher than the population average on all memory measures. IQs for the NA group tended to be higher than the expected average of 100. Of the three groups, the normally achieving group performed best on all memory variables. The group consisting of children with reading disabilities and without auditory processing disorders (RD-NAPD group) performed at a level lower than that of the

normally achieving children, but higher than that of the group consisting of children with reading disabilities and auditory processing disorders (RD-APD group) on all variables.

Table 3-2 displays results of a correlation analysis between IQ and memory variables across the three groups. As can be seen from Table 3-2, IQ correlated significantly with memory variables for the entire sample but not for variables within groups. However, when data from the two RD groups (RD-NAPD and RD-APD) were combined, IQ correlated significantly with Total Verbal Memory, General Memory and Attention/Concentration. Within the combined RD groups, a significant inverse correlation was found between IQ and APD status ($r$ = -.396; $p$ = .011) – that is, APD diagnosis is associated with significantly lower IQ. To address possible covariance between IQ and APD status, IQ was controlled in further analyses. Gender and age did not correlate significantly with any memory variables within or across any of the three groups.

**Research Question 1**

The purpose of the first question was to determine whether children with reading disabilities have significantly lower verbal memory scores than children without reading disabilities. In addition, Question 1 sought to look more broadly at memory skills across both visual and verbal domains and compare performances on several additional memory variables, such as immediate and delayed memory skills between RD and normally achieving children. Hypotheses related to Question 1 were tested using ANCOVAs and MANCOVAs were used to compare the performances of the RD-NAPD group and the NA group on all memory measures and using IQ as a covariate. Results are displayed in Tables 3-3 to 3-6.

Hypothesis 1a was that the verbal memory of children with reading disabilities would be lower than the verbal memory of children without reading difficulties. A one-way analysis of covariance was conducted with total verbal memory as the dependent variable in order to test

this hypothesis. A preliminary analysis evaluating the homogeneity of slopes assumption indicated no significant interaction effect between the covariate (IQ) and RD status on the dependant variable (total verbal memory). This confirms that differences in total verbal memory among groups do not vary as a function of IQ. As can be seen from Table 3-3, Hypothesis 1a. was supported. A significant main effect was found for RD status, specifically children in the RD-NAPD group had significantly lower total verbal memory scores than children in the NA group when controlling for IQ ($F(1,37) = 5.92$, $p=0.02$). RD status was found to explain approximately 14% of the observed variance in total verbal memory scores.

Results of a one sample t-test indicated that the RD-NAPD group had total verbal memory skills which also were significantly below the expected population average ($t = -3.138$, $p = .005$). The total verbal memory scores of the NA group did not differ significantly from the population average ($t = 1.24$, $p = .232$).

In order to assess whether the two component skills of total verbal memory, verbal immediate memory and verbal delayed memory differed across the groups, a one way MANCOVA using verbal immediate memory and verbal delayed memory as the dependent variables and IQ as a covariate was conducted. Results of this analysis are presented in Table 3-4 and indicated that both dependent variables were significantly different across the RD-NAPD group and the normally achieving group. Verbal immediate memory ($F(1,37) = 4.94$, $p = .032$) and verbal delayed memory ($F(1,37) = 5.85$, $p=.021$) were both significantly stronger in the NA group than in the RD-NAPD group.

Hypothesis 1b was that children with reading disabilities were expected to display higher visual memory than verbal memory. This hypothesis was tested with paired samples t-tests. Results indicated that total visual memory was significantly stronger than total verbal memory

within the RD group (t = 2.56, p=.019). This pattern was not significant in the NA group (t = 1.19, p = .25).

Hypothesis 1c was that the visual memory of children with reading disabilities would not differ significantly from that of normally achieving children. A one-way analysis of covariance was used to test this hypothesis using total visual memory as the dependent variable and IQ as a covariate. A preliminary analysis evaluating the homogeneity of slopes assumption indicated that there was no significant interaction effect between the covariate (IQ) and RD status on the dependant variable (total visual memory). Thus, differences in total visual memory among groups do not vary as a function of IQ. Results reported in Table 3-5 indicate that this hypothesis was supported (F(1,37) = 3.169; p =.08) and that no significant difference in total visual memory across the NA and the RD-NAPD groups was evident. Results of a one sample t-test indicated that the total visual memory of the RD-NAPD group did not significantly differ from the expected population mean given in the test manual (t = -.462, p = .649).

In order to establish whether the component skills of total visual memory, visual immediate memory and visual delayed memory differed significantly between the RD and normally achieving groups a one way MANCOVA using IQ as the covariate was conducted. Results presented in Table 3-6 indicated that the groups did not differ significantly on visual immediate memory (F(1,37) = .84, p = .37). However, the groups did differ significantly on visual delayed memory (F(1,37) = 6.04, p = .02) with the NA group displaying significantly better delayed visual memory than the RD-NAPD group.

**Research Question 2**

The purpose of the second research question was to determine if children with comorbid diagnoses of APD and RD demonstrated significantly weaker verbal memory skills than children with RD alone. Hypotheses related to this question further sought to examine memory patterns

across both verbal and visual domains in these two groups of children. Once again, in order to test the hypotheses related to this research question a series of ANOVAs and MANCOVAs were conducted. Results are displayed in Tables 3-7 to 3-10.

Hypothesis 2a was that the verbal memory of children with both reading disabilities and auditory processing disorders (RD-APD) would be weaker than for children with only reading disabilities (RD-NAPD). A preliminary analysis evaluating the homogeneity of slopes assumption indicated that there was no significant interaction effect between the covariate (IQ) and group on the dependant variable (Total Verbal Memory). ANCOVA indicated that this hypothesis was unsupported ($F(1,37) = 0.40$; $p = .53$) demonstrating that a diagnosis of APD does not significantly affect the overall verbal memory performance within a group of children with reading disabilities. Results can be seen in Table 3-7.

In order to examine Hypothesis 2a further, a MANCOVA was conducted using the two components of Total Verbal Memory, Verbal Immediate Memory and Verbal Delayed Memory with IQ as the covariate. Results presented in Table 3-8 indicated that the RD-APD group and the RD-NAPD group did not differ significantly on either dependent variable (verbal immediate $F(1,37) = .06$, $p = .81$; verbal delayed $F(1,37) = .91$, $p = .35$).

Hypothesis 2b was that the visual memory of children with both reading disabilities and auditory processing disorders (RD-APD) would not differ from that of children with only reading disabilities (RD-NAPD). A preliminary analysis evaluating the homogeneity of slopes assumption indicated that there was no significant interaction effect between the covariate (IQ) and group on the dependant variable (Total Visual Memory). ANCOVA indicated that this hypothesis was supported by the data ($F(1,37) = 2.9$; $p = .097$) demonstrating that these two groups did not differ on Total Visual Memory. Results can be seen in Table 3-9. Further analysis

with MANCOVA indicated that the two groups did not differ on Visual Immediate ($F(1,37) = 1.2$, $p = .28$) or Visual Delayed Memory ($F(1,37) = 3.97$, $p = .054$).

**Post Hoc Analyses**

Post hoc analyses conducted within the sample of children with reading disabilities uncovered additional significant differences between the RD-NAPD and the RD-APD groups (See tables 3-11 to 3-12). Results of a one way ANOVA confirmed that the RD-NAPD group had a significantly higher average IQ than the RD-APD group ($F(1,37) = 7.680$, $p = .009$). A one way ANCOVA was then conducted with IQ as a covariate and reading level as the dependant variable. Results of this analysis indicated that the RD-NAPD group displayed significantly higher average reading levels than the RD-APD group when IQ was controlled ($F(1,37) = 7.054$, $p = .011$). Levene's test of equality of error variances was significant.

Further post hoc analyses were conducted across all three groups (NA, RD-NAPD, RD-APD). A one way ANOVA confirmed that the three groups differed significantly from each other on IQ ($F(2, 57) = 16.552$, $p < .01$, adjusted $R^2 = .345$). The NA group had the highest mean IQ which was significantly higher than the RD-NAPD ($p = .009$). In turn, the RD-NAPD group had a significantly higher mean IQ than the RD-APD ($p = .033$) group. A post hoc multiple regression analysis was conducted to examine how well IQ, verbal memory and APD status predicted reading percentile ranking. The linear combination of IQ, verbal memory and APD status significantly predicted reading level ($F(3, 56) = 24.88$, $p < .01$, adjusted $R^2 = .548$) Indicating that 55 % of the variance in reading performance was accounted for by the linear combination of the predictor variables. Table 3-12 displays the indices to indicate the relative strength of the individual predictor variables.

Table 3-1. Descriptive statistics for all memory variables, IQ and reading levels across groups

| | Total visual memory[b] Mean (SD) | Total verbal memory[b] Mean (SD) | General memory[a] Mean (SD) | IQ[a] Mean (SD) | Reading percentile Mean (SD) |
|---|---|---|---|---|---|
| NA group (n=20) | 212.95 (17.52) | 206.35 (22.98) | 108.05 (11.97) | 109.95 (11.94) | 64.00 (12.89) |
| Boys (n=12) | 212.92 (18.72) | 204.33 (27.38) | 107.17 (14.06) | 109.17 (11.13) | 60.25 (11.88) |
| Girls (n=8) | 213.00 (16.83) | 209.38 (15.42) | 109.38 (8.63) | 111.13 (13.78) | 69.69 (12.99) |
| RD-NAPD (n=20) | 197.80 (21.30) | 174.90 (35.78) | 90.85 (16.08) | 98.40 (14.50) | 26.30 (20.01) |
| Boys (n=13) | 199.00 (21.40) | 173.00 (38.32) | 90.62 (17.39) | 99.23 (15.17) | 30.38 (23.12) |
| Girls (n=7) | 195.57 (22.63) | 178.43 (33.07) | 91.29 (14.61) | 96.86 (14.17) | 18.71 (9.55) |
| RD-APD (n=20) | 180.05 (26.04) | 160.30 (27.85) | 79.10 (17.03) | 88.65 (7.71) | 10.50 (7.05) |
| Boys (n=13) | 183.85 (26.32) | 161.85 (20.93) | 80.77 (13.95) | 89.38 (7.02) | 10.31 (8.14) |
| Girls (n=7) | 173.00 (25.91) | 157.43 (39.56) | 76.00 (22.63) | 87.29 (9.29) | 10.86 (4.98) |
| 3 groups combined | 196.93 (25.44) | 180.52 (34.75) | 92.67 (19.14) | 99.00 (14.48) | 33.60 (26.66) |
| Boys (n=38) | 198.21 (24.91) | 179.08 (34.14) | 92.47 (18.42) | 99.00 (13.91) | 32.95 (25.72) |
| Girls (n=22) | 194.73 (26.78) | 183.00 (36.45) | 93.00 (20.78) | 99.00 (15.77) | 34.73 (28.79) |

Table 3-1. Continued

| | Visual immediate memory[a] Mean (SD) | Visual delayed memory[a] Mean (SD) | Verbal immediate memory[a] Mean (SD) | Verbal delayed memory[a] Mean (SD) |
|---|---|---|---|---|
| NA group (n=20) | 105.35 (10.01) | 107.60 (9.47) | 103.75 (11.93) | 102.60 (12.87) |
| Boys (n=12) | 105.08 (10.48) | 107.83 (10.47) | 102.00 (13.76) | 102.33 (15.28) |
| Girls (n=8) | 105.75 (9.95) | 107.25 (8.41) | 106.38 (8.70) | 103.00 (9.07) |
| RD-NAPD (n=20) | 99.45 (12.69) | 98.35 (10.09) | 86.45 (19.70) | 88.45 (17.91) |
| Boys (n=13) | 99.92 (11.77) | 99.08 (10.49) | 86.77 (21.50) | 86.23 (19.18) |
| Girls (n=7) | 98.57 (15.21) | 97.00 (9.95) | 85.86 (17.44) | 92.57 (15.79) |
| RD-APD (n=20) | 91.05 (18.61) | 89.00 (12.72) | 79.05 (14.82) | 81.25 (14.81) |
| Boys (n=13) | 92.00 (21.17) | 91.85 (9.34) | 79.62 (12.14) | 82.23 (11.17) |
| Girls (n=7) | 89.29 (13.95) | 83.71 (16.96) | 78.00 (19.98) | 79.43 (20.96) |
| 3 groups combined | 98.62 (15.19) | 98.32 (13.13) | 89.75 (18.72) | 90.77 (17.53) |
| Boys (n=38) | 98.84 (15.89) | 99.37 (11.82) | 89.13 (18.48) | 89.95 (17.45) |
| Girls (n=22) | 98.23 (14.25) | 96.50 (15.25) | 90.82 (19.53) | 92.18 (17.97) |

Note: [a] Standard scores, M=100, SD = 15; [b] Two standard scored combined, M=200, SD=30

Table 3-2. Correlations between IQ and memory variables.

| | Total visual memory | | Total verbal memory | | General memory | | Attention/ concentration | |
|---|---|---|---|---|---|---|---|---|
| | *r* | *p* | *r* | *p* | *r* | *p* | *r* | *p* |
| NA group (n=20) | .307 | .188 | .222 | .347 | .331 | .154 | -.199 | .400 |
| RD-NAPD (n=20) | .107 | .655 | .271 | .247 | .276 | .240 | .374 | .104 |
| RD-APD (n=20) | .370 | .108 | .353 | .127 | .405 | .076 | .172 | .468 |
| All groups combined | .471** | <.001 | .511** | <.001 | .570** | <.001 | .489** | <.001 |
| Both RD groups (n=40) (RD-NAPD + RD-APD) | .308 | .053 | .350* | .027 | .399* | .011 | .413** | .008 |

Note: ** $p<.01$; * $p<.05$

Table 3-3. Analysis of covariance for total verbal memory across reading ability groups

| Source | df | F | $\varepsilon^2$ | *p* |
|---|---|---|---|---|
| IQ (covariate) | 1 | 2.518 | .064 | .121 |
| RD Status | 1 | 5.924 | .138 | .020 |
| Error | 37 | (869.33) | | |

Note: Value enclosed in parentheses represents mean square error

Table 3-4. Multivariate analysis of covariance for verbal immediate and verbal delayed memory across reading ability groups

| Source | df | F | $\varepsilon^2$ | *p* |
|---|---|---|---|---|
| IQ (covariate) | | | | |
| Verbal immediate | 1 | 6.997 | .159 | .012 |
| Verbal delayed | 1 | .183 | .005 | .671 |
| RD Status | | | | |
| Verbal immediate | 1 | 4.940 | .118 | .032 |
| Verbal delayed | 1 | 5.849 | .137 | .021 |
| Error | | | | |
| Verbal immediate | 37 | (229.168) | | |
| Verbal delayed | 37 | (248.386) | | |

Note: Value enclosed in parentheses represents mean square error

Table 3-5. Analysis of covariance for Total visual memory across reading ability groups

| Source | df | F | $\varepsilon^2$ | *p* |
|---|---|---|---|---|
| IQ (covariate) | 1 | 1.348 | .035 | .253 |
| RD status | 1 | 3.169 | .079 | .083 |
| Error | 37 | (377.025) | | |

Note: Value enclosed in parentheses represents mean square error

Table 3-6. Multivariate analysis of covariance for visual immediate and visual delayed memory across reading ability groups

| Source | df | F | $\varepsilon^2$ | *p* |
|---|---|---|---|---|
| IQ (covariate) | | | | |
| Visual immediate | 1 | 2.144 | .055 | .152 |

| | | | | |
|---|---|---|---|---|
| Visual delayed | 1 | .377 | .010 | .543 |
| RD Status | | | | |
| Visual immediate | 1 | .840 | .022 | .365 |
| Visual delayed | 1 | 6.041 | .140 | .019 |
| Error | | | | |
| Visual immediate | 37 | (126.802) | | |
| Visual delayed | 37 | (97.315) | | |

Note: Values enclosed in parentheses represents mean square error

Table 3-7. Analysis of covariance for total verbal memory across reading disabled sub-groups

| Source | df | F | $\varepsilon^2$ | *p* |
|---|---|---|---|---|
| IQ (covariate) | 1 | 3.418 | .085 | .072 |
| APD status | 1 | 0.400 | .011 | .531 |
| Error | 37 | (966.297) | | |

Note: Value enclosed in parentheses represents mean square error.

Table 3-8. Multivariate analysis of covariance for verbal immediate memory and verbal delayed memory across reading disabled sub-groups

| Source | df | F | $\varepsilon^2$ | *p* |
|---|---|---|---|---|
| IQ (covariate) | | | | |
| Verbal immediate | 1 | 7.609 | .171 | .009 |
| Verbal delayed | 1 | .628 | .017 | .433 |
| RD status | | | | |
| Verbal immediate | 1 | .060 | .002 | .809 |
| Verbal delayed | 1 | .908 | .024 | .347 |
| Error | | | | |
| Verbal immediate | 37 | (258.956) | | |
| Verbal delayed | 37 | (272.637) | | |

Note: Values enclosed in parentheses represents mean square error

Table 3-9. Analysis of covariance for total visual memory across reading disabled sub- groups

| Source | df | F | $\varepsilon^2$ | *p* |
|---|---|---|---|---|
| IQ (covariate) | 1 | 1.447 | .038 | .237 |
| APD status | 1 | 2.903 | .073 | .097 |
| Error | 37 | (559.264) | | |

Note: Value enclosed in parentheses represents mean square error.

Table 3-10. Multivariate analysis of covariance for visual immediate memory and visual delayed memory across reading disabled sub-groups

| Source | df | F | $\varepsilon^2$ | *p* |
|---|---|---|---|---|
| IQ (covariate) | | | | |
| Visual immediate | 1 | 1.253 | .033 | .270 |
| Visual delayed | 1 | .862 | .023 | .359 |
| RD status | | | | |
| Visual immediate | 1 | 1.197 | .031 | .281 |
| Visual delayed | 1 | 3.974 | .097 | .054 |
| Error | | | | |
| Visual immediate | 37 | (251.949) | | |
| Visual delayed | 37 | (132.284) | | |

Note: Values enclosed in parentheses represents mean square error

Table 3-11. Analysis of covariance for total reading ability across reading disabled sub-groups.

| Source | df | F | $\varepsilon^2$ | *p* |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| IQ (covariate) | 1 | .447 | .012 | .508 |
| APD status | 1 | 7.680 | .172 | .009 |
| Error | 37 | (228.462) | | |

Note: Value enclosed in parentheses represents mean square error

Table 3-12. The bivariate and partial correlations of the predictors of reading percentile rank from post hoc multiple regression analysis.

| Predictors | Correlation between each predictor and reading percentile | Correlation between each predictor and reading percentile controlling for other predictors |
|---|---|---|
| IQ | .593** | .275* |
| Total verbal memory | .614** | .40** |
| APD status | - 0.618** | - 0.414** |

Note: * p < .05, ** p < .0

# CHAPTER 4
# DISCUSSION

The purpose of this study was to investigate memory patterns across visual and verbal domains in children with reading disabilities and in those children with reading disabilities and concomitant auditory processing disorders, thus examining a hypothesized link between auditory processing, verbal memory, and reading. Consistent with prior studies, (Ackerman, Dykman., & Gardner, 1990; Cornwall, 1992; Howes et al. 2003; Howes, Bigler, Burlingame, & Lawson, 2003; Messbauer & de Jong, 2002; Nelson & Warrington, 1980; Snyder & Downey, 1991; Torgesen, 1982;  Torgesen & Goldman, 1977; Wilkins, Elkins, & Bain, 1995), this study found that children with reading disabilities displayed lower verbal memory skills when compared to their non reading disabled peers and when compared to the greater population. However, although children with both reading disabilities and auditory processing deficits were expected to display further deficits in verbal memory due to the theoretical idea that it is more difficult for them to process, and thus remember auditory input, this investigation found little to no support for auditory processing deficits contributing to further verbal memory deficits within a reading disabled sample.

## Question 1 Results

When the memory skills of the participants in the normally achieving group (NA group) were compared to those of the participants in the reading disabled group (RD-NAPD group), it was found that the children with reading disabilities performed significantly lower on all verbal memory variables but similarly to normally achieving children on total visual memory and immediate visual memory. This finding was consistent with prior literature on the subject. It was not expected that these two groups would differ on visual delayed memory. At first glance, this unexpected finding might seem to indicate that the visual memory of children with reading

disabilities decays faster than that of children without reading disabilities. While this is partly true, the significant difference between the groups in the visual delayed condition was due mostly to improved standard scores seen in the NA group in the visual delayed condition over the visual immediate condition. The NA group seemed to be able to move visual information into longer term storage and retrieve it more efficiently. When combined with slight visual memory decay observed in the RD-NAPD group, a significant difference between groups in the delayed visual memory condition was observed (see Figure 4-1). It is important to note here that Levene's test for equality of error variances was significant for analyses with total verbal memory and verbal immediate memory as dependent variables indicating that the groups had unequal variances on the dependent variable.

Little support for deficits in delayed visual recall among children with reading disabilities can be found (see Kirk, 1998). O'Shaughnessy and Swanson's (1998) meta-analysis of studies on memory deficits in children with reading disabilities found that low verbal memory tasks did not produce significant group differences. However, where children were able to aid visual or nonverbal memory by the use of language-based strategies, such as naming or describing visual objects verbally, differences on visual memory tasks have been found between RD and non RD groups (see Torgesen, Murphy & Ivey, 1979), with the non RD children performing at higher levels due to their ability to use language based strategies to aid recall. It has been suggested that children with reading disabilities do not use language-based mediating strategies to aid recall as well as their non reading disabled peers (Torgesen & Houck, 1980). The current finding of significantly lower visual delayed memory skills in children with RD may have occurred for this reason and that children with better verbal skills (i.e. the higher readers) used verbally based mediation strategies, whether audible or sub-vocal, in order to aid longer term visual memory.

This method was observed in one normally achieving child who audibly verbalized her strategy for remembering faces by describing each face she was asked to remember.

Visual memory is most crucial during the early stages of reading acquisition. Children who first are learning to read use phonological skills and pair sounds with letter shapes. As reading progresses, verbal memory and language based skills become more significant, and visual memory skills, while still active, take a backseat. The obvious implication of this difference between children with RD and normally achieving children in visual delayed memory is that remembering letters or sight words over time early in the reading acquisition process may be stronger in children with higher verbal skills due to the influence of the verbal mediation strategies they seem to employ to aid both visual and verbal recall. This difference also may be apparent later in reading acquisition when children have to recognize words that have been seen only once or twice before. Children with stronger verbal skills will likely draw on these skills and use them in order to aid longer term recall. Verbal skills, including verbal memory remain the most substantial and constant difference between RD and non RD groups.

In addition, the visual memory skills of the NA group were found to be significantly above the population mean of 100 in one sample t-tests. This was the case for total visual memory ($t = 3.305$, $p = .004$) and in both the visual immediate ($t = 2.39$, $p = .027$), and visual delayed ($t = 3.59$, $p = .002$) conditions. On average, their verbal skills did not differ significantly from the population mean (see Figure 4-1). Their average IQ was also higher than the population mean in a one sample t-test ($t = 3.727$, $p = .001$) thus making their visual memory ability but not their verbal memory ability commensurate with their IQ. Once again these children who have higher verbal abilities and higher IQ seem to be employing additional verbally-based strategies to aid visual recall. They do not appear to be employing this strategy in the opposite direction. While it

seems easy enough for these children to aid visual recall with verbal strategies (their theoretical strength), it may be more difficult for such children to employ helpful visual strategies to aid verbal recall, thus resulting in only average verbal memory skills. Employing strategies that cross over modalities (i.e. using verbal strategies to aid visual recall and using visual strategies to aid verbal recall) may enhance memory and learning in both modalities. This is supported by the levels of processing theory proposed by Craik and Lockhart (1972) and is a strategy which is often taught to children in special education settings. Perhaps the ability to draw from other modalities in order to aid processing and recall is mediated by intelligence.

Are these deficits in verbal memory present before children begin to read? Several studies have indicated that preschool children who display deficits in their ability to recall verbally presented sequences or stories often later display difficulty learning to read (Catts, 1993; Kirk, 1998; Muter & Snowling, 1998; Snowling, 1991; Snyder & Downey, 1991). It has been hypothesized that these observed deficits in a child's ability to recall stories, sequences and other verbal information may be the result of language processing deficits (Cermack, 1980; Martin, 2000). Others have hypothesized that the observed poor performance on memory for verbal information that must be phonologically coded is a reflection of inadequate or inaccurate underlying phonological representations at the neural level (Kirk, 1998; Katz, Shankweiler, & Liberman, 1981; Benasich & Tallal, 2002; Maurer et al., 2003) and that low-level deficits in auditory processing precede and predict later language learning difficulties. The latter hypothesis was the basis for the current study that extended previous research on verbal memory deficits seen in children with reading disabilities to include a sample of reading disabled children with auditory processing disorders.

## Question 2 Results

The latter part of this study sought to examine a less explored area, namely relationships between auditory processing, reading ability, and verbal memory. Within the group comprised of all the children with reading disabilities, the children with concomitant auditory processing disorders displayed lower levels of skill on all memory variables. However, this lower skill level was not found to be significant for any of the memory variables studied across both visual and verbal domains. The assumption of equal covariance was violated in the MANCOVA for the visual immediate and visual delayed memory variables. Such violations were not observed for analyses conducted within the verbal memory domain.

The objective here was to explore the possibility that auditory processing deficits may further negatively impact the already low verbal memory skills of children with reading disabilities. Confirmation of this link would offer some evidence for a possible causal pathway between auditory processing abilities and reading ability via verbal memory that has been hypothesized by several authors (Galaburda, 2004; Alonso-Bua, Diaz, & Ferraces, 2006). As discussed earlier in this paper, there is electrophysiological evidence to suggest that there is a relationship between auditory processing skills and neurological memory traces from verbal input in people with reading difficulties (Alonso-Bua, Diaz, & Ferraces, 2006; Kujala et al., 2000; Poldrack et al., 2001; Purdy, Kelly, & Davies, 2002; Sharma et al., 2006; Taylor & Keenan, 1999; Temple et al., 2000). The general hypothesis states that, in some children, an underlying shortfall in the central auditory pathway or in the temporal-parietal cortex may lead to a deficit in the neurological representation and subsequent diminished processing of auditory stimuli. The ability of the brain to automatically discriminate minute differences in acoustic stimuli will influence its ability to process phonological aspects of speech (Ceponiene, et al., 1999). This in turn may lead to inaccurate progression through the information processing steps,

poor phonological awareness skills, verbal memory deficits, language deficits, and reading disabilities. Support for this hypothesis, is found in evidence that shows through the use of electrophysiological measures that phonological deficits are evident pre-attentively in the brains of children with impaired reading performance (Alonso-Bua, Diaz, & Ferraces, 2006). If this hypothesis is correct then we would expect to see behaviorally measured verbal memory deficits in subjects with ADP. While the current study did observe lower verbal memory skills in the RD-APD group than in the RD-NAPD group, the difference was not significant.

Several possible reasons could be used to explain why the current study may have failed to find the hypothesized result that children with RD and APD would have significantly weaker verbal memory skills than children with RD alone. Issues related to methodology, particularly associated with diagnosis of auditory processing deficits, sample size, and sample selection may explain some divergence from the hypothesized result. Further reasons relate to cognitive processes and individual characteristics of the children in the study.

This study used only behavioral means of assessing auditory processing. Data from studies using behavioral methods of assessing APD have been inconsistent and inconclusive about differences between RD and non RD groups (see Stoodley et al., 2006). Compensatory cognitive strategies are likely to be employed by some children in the behavioral setting. This may have compromised the accurate division of children with reading difficulties into the RD subgroups (RD-APD or RD-NAPD). Compensatory strategies employed by some children may have acted as confounds in the identification of children with APD and thus may have impacted results on memory test comparisons across groups. Compensatory strategies may include reasoning, memory strategies, top-down processing, visual cues in the room etc. Such strategies are unavailable when electrophysiological methods are used to assess auditory processing skills.

Thus, electrophysiological methods may lead to more definitive division of children into APD or non APD subgroups and perhaps clearer results on verbal memory tasks (Stoodley et al., 2006).

Some support for the idea that compensatory strategies employed during behavioral measures of auditory processing skills may compromise accurate diagnosis of APD was offered by Sharma et al., (2006) who found that all children in her study who had been diagnosed with reading disabilities displayed auditory processing deficits on at least one of either electrophysiological measures or behavioral measures used to assess auditory processing disorders. Further, a subset of children with reading disabilities displayed auditory processing deficits on electrophysiological measures but not on behavioral measures. She reasoned that other cognitive strategies must be employed by individuals to compensate for mild neurological deficits in the auditory pathway. Sharma et al. (2006) also found that some children with reading disabilities did not display auditory processing problems on the electrophysiological measures but did display behaviorally measured auditory processing deficits. This observation was explained by confounding variables such as attention and motivation. These variables, which do not remain constant across time or settings, are likely to impact results in all studies involving children in ways which are difficult to measure.

In the current study, children in the RD sample without APD also were found to have significantly higher average IQs than those with RD and APD. Higher IQs may allow for a wider variety of compensation strategies as children with high IQs have more cognitive strengths on which to draw in order to overcome areas of skill weakness. This may be true both for auditory processing (Stoodley et al., 2006) tests and for memory tests. Behavioral methods of assessing auditory processing skills have been criticized heavily for problems with reliability and validity. However, behavioral measures do give us the best indication of a child's actual functioning in

real life situations as some children appear to be able to overcome neurological auditory deficits such that they display normal auditory processing skills in behavioral settings.

The proposed causal pathway suggested by Galaburda (2004) may not apply to all subtypes of reading disabilities. The pathway has been most strongly linked to phonologically based reading difficulties and may not be relevant for reading difficulties based in other reading skills such as reading fluency or comprehension. Similarly, the observed verbal memory deficits seen in children with different patterns of reading skills may stem from different sources. Verbal memory deficits seen in the RD-NAPD group may stem from one source, while the verbal memory deficits seen in the RD-APD group stem from a different source. They may also be reflective of more general cognitive deficits. The sample size in the current study did not allow for further examination of these possibilities. Expected deficits in verbal memory may have shown up using behavioral methods of APD diagnosis with a larger sample size or with further delineation of participants into groups based on reading skill profiles. The sample in this study was too varied and too small to see significant effects. Furture studies using electrophysical means of diagnosing APD, larger sample sizes, and subtyping of reading disabilities may be useful in exploring these possibilities.

Post-hoc analyses uncovered additional significant findings. The two reading disabled groups (RD-APD group and the RD-NAPD group) were found to differ significantly on IQ ($F(1,37) = 7.054$, $p = .011$) in a one way ANOVA. These two groups also differed significantly on reading scores when IQ was controlled ($F(1,37) = 7.680$, $p = .009$) in a one way ANCOVA. In both cases, the RD-NAPD group scored significantly higher than the RD-APD group. However, the assumption of equal error variance was violated in both of these analyses.

The RD-NAPD group displayed more variance in scores than the RD-APD group. This may be due in part to the influence of a couple of data points in the RD-NAPD group. The non APD subgroup had three children in it who were reasonable readers with IQs measured in the above average range (over 120). While they still met a strict definition of reading disabled based on IQ-reading level discrepancy, their broad reading scores, which were comprised of several different reading skills, suggested that they were reading at or close to grade level. Scores from these three children may have had an undue influence on results in such a small sample size. The difference in error variance also may be due in part to the fact that there was a lower IQ limit set at 75 in order to be eligible for the study thus limiting variance by design. A larger sample size would obviously be beneficial. However, appropriate and eligible subjects from clinical settings can be difficult to obtain due largely to the wide array of confounding issues clinical clients present with such as complicated medical diagnoses, psychological diagnoses, neurological problems, language delays, developmental issues and cognitive deficits. Another possibility for addressing this issue in future studies of this type may be to limit the IQ of participants to the average range (standard scores between 85 and 115). This may also lessen the likelihood of a child drawing on other intellectual skills in order to develop compensatory strategies to aid in reading and/or memory performance as measured by the standardized tests given.

The failure to find support for the hypotheses that there would be differences between the RD-NAPD group and the RD-APD group on verbal memory skills may be an important finding to audiologists. While verbal memory may be deficient in children with reading disabilities, verbal memory was not found to be significantly further deficient in children with reading disabilities who have also been diagnosed with APD. The importance of this is understood with

the knowledge of the substantial immediate verbal memory requirements inherent in the behaviorally based audiological tests conducted as part of the APD diagnostic process. In other words, the children who were diagnosed with APD through the use of data from behavioral methods of assessment were not diagnosed due solely to verbal memory deficits. This idea is supported by a study conducted by Riccio et al., (2005) who found that behavioral APD tests were measuring qualities other than memory and attention.

## Post Hoc Results

The post hoc finding that the RD-APD group was significantly lower than the RD-NAPD group on reading ability was unintended. The RD sample was divided into two groups based on APD status. Although they all were diagnosed with reading disabilities, actual reading level was not considered when subdividing the children with RD. It could be argued that the presence of an auditory processing disorder increases the severity of reading disabilities. This belief would partially support the hypothesized causal chain. However, overall cognitive ability or IQ cannot be overlooked as a likely confound. It could also be argued that both severe RD and APD are manifestations of larger and more general cognitive deficits. This later idea is supported by the fact that the RD-APD subgroup also had significantly lower mean IQ scores than their RD-non APD counterparts. Whatever the explanation, children in the RD-APD group are likely to be very resistant to academic interventions.

Post hoc analysis of IQs across all three groups with a one-way ANOVA found that all three groups differed significantly from each other on IQ scores. The NA group had the highest mean IQ which was significantly higher than the RD-NAPD ($p = .009$). In turn, the RD-NAPD group had a significantly higher mean IQ score than the RD-APD ($p = .033$) group. IQ is a significant variable that appears to influence so many of the skills we assess in education and cognitive psychology. While a succinct definition of IQ is difficult to ascertain, it is comprised of

a variety of factors representing an array of cognitive skills and the ability to coordinate and combine their use. A child with a high IQ is likely to have many cognitive strengths on which to rely and integrate when completing a given task. Where deficits exist in other skills, one's intelligence can be used to compensate for the weakness. Children who score lower on IQ tests are likely to have fewer strengths to compensate for areas of weakness.

A post hoc multiple regression analysis was conducted to examine how well IQ, verbal memory and APD status predicted reading percentile ranking. The linear combination of IQ, verbal memory and APD status significantly predicted reading level ($F(3, 56) = 24.88$, $p < .01$, adjusted $R^2 = .548$). This indicates that 55 % of the variance in reading performance was accounted for by the linear combination of the predictor variables. As expected the presence of APD negatively correlates with reading level, such that a child with APD will be likely to have a lower reading percentile rank. IQ and verbal memory predicted reading level directly. Judgments about the relative importance of the three predictors are difficult because they are all correlated.

## Implications of Findings

This research adds to the current body of knowledge on reading disabilities, verbal memory deficits and the role of auditory processing disorders by highlighting the pervasive nature of verbal memory deficits in children with reading disabilities. Findings also suggest that these same children display weaker visual delayed memory. While this study did not find significant evidence that auditory processing disorders further negatively impact verbal memory skills within a reading disabled population, findings do emphasize the array of intercorrelated and interdependent cognitive processes and skills which impact results producing high levels of variance in performances and the importance of considering these variables as potential confounds in practice and in future research.

What are the implications of these findings in the classroom? Education is verbally based in our culture and verbally based skills become more important for educational success with increasing grade level. Many educators are unaware of the extent to which verbal memory skills are deficient in children with reading deficits. With strong current trends in education towards serving children with special needs in the general education classroom and towards the use of classroom based response to intervention models, teacher training programs need to offer teachers skills in teaching RD populations. The usual “chalk and squawk” methods of teaching are likely to be less effective than desirable with children with reading disabilities. A commonly recommended teaching strategy for teachers of children with reading disabilities is the use of visual cues. As children with RD are also less inclined to use verbal strategies to aid visual recall, this strategy alone may not be enough for some children with Reading disabilities. Perhaps the teaching of metacognitive strategies to such children is an area for future investigation. A logical extension of this study would be to investigate whether memory strategies and metacognitive strategies can be taught to children with RD of different ages and if the use of such strategies assists them academically.

Results obtained in this study also may have implications for teaching children with APD. Despite the continued controversy over APD and its diagnostic criteria (see Cacace & McFarland, 1998; McFarland & Cacace, 1995; Bellis, 1997; Cacace & McFarland, 1998; Jerger & Musiek, 2000; Sharma, Purdy, Newell, Wheldall, Beaman, & Dillon, 2006), children are being diagnosed with this disorder. The controversies around APD assessment and diagnosis do not negate the fact that these behaviors are observable and measurable and that children are receiving this diagnosis. Teachers need training in how such a diagnosis may affect learning in these children. Children who have reading disabilities and auditory processing disorders are even more

in need of specialized instruction catered to their patterns of strengths and weaknesses. This group of children with this double diagnosis may well represent Torgesen's "treatment resisters" (Torgesen, 2000). The double diagnosis may echo broader cognitive deficits which should be assessed and discussed with teaching personnel. In today's education climate where inclusion is desirable and often practiced, children with more severe learning deficits are often left behind by teachers who are not well informed nor adequately trained in strategies suitable for teaching children with special needs. As these children with the double diagnosis of APD and RD are the ones who are likely to be resistant to interventions, early identification and appropriate educational intervention is paramount in securing their future educational attainment.

## Limitations

Although the current study found several significant and interesting results, a few important limitations need to be considered. One of the most salient limitations of this study is its small sample size. The sample size was not large enough to allow for thorough investigation of possible confounds. Ideally, it would have been desirable to investigate different subtypes or skills related to of reading difficulties and to investigate different types of auditory processing disorders within this sample. However, the overall sample size obtained did not allow for this extent of division of subjects. With a large sample size a cluster analysis may provide much cleaner and interpretable results. Power was typically acceptable with this sample size for the analyses conducted; however, violations of assumptions did occur some of which might have been ameliorated with a larger sample size. It is also likely that a larger sample size or differentiation of different sub types of reading disabilities might have produced the expected differences between the two RD groups on verbal memory skills as proposed in the review of the literature as the proposed causal path speaks specifically to phonological skills.

In several of the analyses conducted in this study violations of assumptions occurred. The most common violation was of the equal error variance. The equality of covariance assumption was also violated in a couple of analyses. These violations of assumptions may make some results uncertain. Past research also has run into problems with variance when studying this population. It seems that populations with learning disabilities display a complicated array of skills and deficits which lead to a large amount of variance in their performances across many domains and on many psychoeducational measures. In turn this observation of large levels of variance makes it difficult to divide poor readers into subtypes as so many skills and deficits overlap producing problems with covariance.

While the current study only used clinically reading disabled children, defined by strict and generally accepted criteria, as opposed to garden variety poor readers, it did not distinguish between reading deficits based on phonological deficits, fluency or comprehension difficulties. The lack of inclusion of a measure of phonological awareness skills was a distinct limitation in this study, especially given the likelihood that the hypothesized causal pathway involving auditory processing skills includes phonological awareness deficits. Deficits in other reading skills may not have a place in the proposed pathway.

Further, different reading skills have been shown to be more important at different stages in the reading acquisition process. This means that a younger child with reading deficits is likely to have deficits related to phonological skills and visually based recognition fluency while an older child with reading difficulty is more likely to have deficits in fluency, comprehension or other language based skills. This study did not find any correlation between age and memory. We would expect this given that the Children's Memory Scale is norm referenced on age. However, it may be an interesting future direction to analyze age or stage in the reading

acquisition process and its relationship to memory skills. Additionally, it would be interesting to conduct this same study with a sample of phonologically deficient readers as this is the basic reading skill most likely to be aligned with auditory processing skills and least reliant on processing speed or complex language based skills.

The potential impact of reading disability subtypes in a study of this nature is dramatic. Several studies which have made attempts to subtype subjects with reading disabilities have found that they differ in auditory and memory skill profiles (Heath, Hogben & Clark, 1999; Lachmann et al., 2005; Watson, 1992; Bretherton & Holmes, 2002). At this time no generally accepted, clear delineation of reading disability subtypes exists.

This issue may be exemplified by discussing a study by Liddell and Rasmussen (2005) that used the Children's Memory Scale to investigate the memory patterns in a group of children diagnosed with nonverbal learning disabilities (NVLD). NVLD result from a deficit in the right hemispheric functioning of the brain and lead to a variety of learning, processing and social problems, one of which is reading comprehension difficulties emerging in the middle elementary years. Children with NVLD do not typically have any difficulty with phonological awareness or early reading skills such as rote learning of letters and sight words. The CMS was used by Liddell and Rasmussen in a very similar way to the current study, investigating visual and verbal memory across the immediate and delayed conditions. The study found that children with NVLD had significantly stronger verbal memory than visual memory. As might be expected, this is the opposite of the findings in the current study. Several subjects in the current study displayed patterns of strengths and weaknesses across the various test results that would fit the diagnostic criteria for NVLD. One can assume, based on the way reading skills tend to develop in children with NVLD, that these children had reading deficits related to comprehension. It was

hypothesized that it is the phonological aspects of reading acquisition which are most likely impacted by APD. In such a small sample, these subjects may influence results heavily. This demonstrates the importance of sub-typing reading disabilities as much as possible in future studies.

When conducting research on reading disabilities, it is also important to consider where a child is in the reading acquisition process and what reading skills are most salient at different points in reading acquisition. Children identified early with reading disabilities most likely display different skills deficits to those identified in later grades when different skills become more important for proficient reading. Likewise, a child who was identified early on may learn to compensate and may develop measurably normal reading skills in later elementary schooling. The importance of this and its potential impact on research of this type was exemplified by a child who participated in the current study. At the outset of this study it was not certain whether there would be a group of normally achieving children who would meet the diagnostic criteria for an auditory processing disorder. The existence of such a group was doubtful but unknown due to the fact that it is only children who are struggling in school who typically be referred for an auditory processing evaluation. Only one child in this study who was deemed an average second grade reader failed the APD screening conducted in the school setting. This child was eliminated from the current study and was then taken to the University of Florida's Department of Communicative Disorders and was administered a full battery of audiological tests. His test scores were indicative of an auditory processing disorder. Interestingly, this child's IQ was measured to be quite low for a child reportedly reading on grade level and his verbal memory skills were significantly lower than his visual memory skills. This pattern of results might be expected in a child with RD and yet this child displayed grade level reading skills. This brings up

the issue of where a child is in the reading acquisition process and how that may impact his or her identification and receipt of appropriate services.

Reading skills are learned in a hierarchy beginning with phonological awareness and culminating in the ability to fluently read and derive meaning from text. Different combinations of a variety of skills are vital at different stages in the process of becoming a competent reader. The child described above who failed the APD screenings despite grade level reading skills was one of the youngest in the study. In second grade he was still in the early stages of reading skill development, learning sight words and building fluency with largely decodable, connected text in simple and concrete sentences. It is possible that his reading skills will not progress with his grade level and that he may present as a struggling reader in years to come as the demands on language, vocabulary and reading comprehension increase. More students like the child described above may be found if a larger sample of children was tested. Perhaps this pattern of test results would occur in older children who had shown adequate progress in early reading but had failed to maintain grade level reading skills with progressing years of schooling. A future study might address stage of reading development as a variable.

Similarly, several different kinds of auditory processing disorders exist and each is likely to have a different impact on schooling and academic performance. Temporal processing is the auditory processing skill which has been most associated with reading skills. Deficits in auditory processing skills related to temporal aspects of acoustic signals, could interfere with or place limits on the accurate neurological representation and subsequent perception of speech sounds and thus negatively impact the development of phonological skills (see Alonso-Bua, Diaz, & Ferraces, 2006; Farmer & Klein,1993; Heath, Hogben, & Clark, 1999; Heiervang, Stevenson, & Hugdahl, (2002); Kujala et al., 2000; Poldrack et al., 2001; Purdy, Kelly & Davies, 2002; Reed,

1989; Sharma et al., 2006; Taylor & Keenan, 1999; Tallal, 1980; Temple et al., 2000; Waber, Weiler, Wolff, Bellinger, Marcus, Ariel, Forbes, & Wypij, 2001; Walker, Shinn, Cranford, Givens, & Holbert (2002); and Watson, 1992). Links to reading ability is generally not seen for other types of auditory processing deficits, although some research has been conducted on dichotic deficits and reading (Dermody, Mackie, & Katsch, 1983; Moncrief & Musiek, 2002). The fact that this study did not distinguish between different types of APD may have weakened results as some forms of APD are not theorized to be connected with verbal memory or reading.

In the technical report issued by the American Speech-Language-Hearing Association's working task force on auditory processing disorders in 2005 (ASHA, 2005b), the heterogeneity of auditory processing disorders is discussed at length. Each individual's unique confluence of 'bottom-up' and 'top-down' cognitive abilities, combined with other cognitive and neurological strengths and deficits, and a variety of social and environmental factors is likely to result in different functional manifestations of the same type of auditory processing disorder. This offers some explanation as to why studies are mixed in their results as to causal links between lower level auditory processing skills and higher order abilities such as language and reading skills. Thus "it is to be expected that a simple one-to-one correspondence between deficits in fundamental, discrete auditory processes and language, learning, and related sequelae may be difficult, if not impossible, to demonstrate" (ASHA, 2005b. p.3.)

As with many studies investigating cognitive processes, difficulty arises in separating out different cognitive skills. Each of the skills measured in this study is likely to rely on other cognitive skills for its execution. For example, tests conducted during the typical auditory processing evaluation have come under criticism due to a failure to isolate auditory skills from other cognitive skills such as verbal working memory, attention, general intelligence, processing

speed, and other kinds of processing (Cacace & McFarland, 1998; McFarland & Cacace, 1995). Additional psychological factors such as fatigue, motivation and mental age are also often overlooked. Validity and reliability are thus called into question (Bellis, 1997; Cacace & McFarland, 1998; Jerger & Musiek, 2000; Sharma, Purdy, Newell, Wheldall, Beaman, & Dillon, 2006). This study and the following discussion have highlighted several of the potentially confounding variables which should not be overlooked in administration of behavioral auditory processing assessments. Not the least of which is perhaps IQ. Without considering these variables it cannot be ascertained that behavioral measures of APD are measuring a clean construct. However, behavioral measures do offer us real information about how a child may actually function in real world settings.

A further limitation in this study related to the auditory processing screening which was conducted in an educational setting. These were less than ideal circumstances due to interruptions, distractions and ambient noise. Some comfort can be gained in the knowledge that if a child can pass the screener under those conditions, they are certainly likely to do better under ideal conditions in a sound booth. However, the nature and setting of the screening measures used in this study may not have been the most appropriate.

## Summary and Future Directions

In summary, this study found evidence in favor of the widely accepted observation that children with reading disabilities have deficits in verbal memory skills when compared to their normally achieving peers. This is true across both immediate and delayed conditions. These findings are consistent with previous research. This study also found evidence that children with reading disabilities perform similarly to controls on immediate visual memory and display a higher rate of visual memory decay, performing significantly more poorly than controls in the visual delayed memory condition.

This study, however did not find evidence suggesting that children with reading disabilities and concomitant auditory processing deficits were significantly lower in memory performance when compared to a group of similarly reading disabled peers without APD. While these two groups differed significantly on reading scores and IQ, they did not differ significantly on any memory skills in either modality when IQ was controlled. Nor did they differ across immediate and delayed conditions when IQ was controlled.

Post hoc analyses revealed some additional significant differences between the groups and trends across groups. When differences between the groups were examined more fully it was found that the two subgroups of the sample with reading disabilities (RD-APD and RD-NAPD) differed significantly on both IQ and on measured reading ability. This brings into question whether more general cognitive ability may be an important factor in APD assessment and diagnosis or whether the presence of auditory processing deficits may lead to more severe manifestation of reading difficulties.

The finding that the children diagnosed with APD had a significantly lower mean IQ may be problematic for audiologists. This finding needs to be investigated further. There may be a direct relationship between IQ and auditory processing ability. According to one of the most popular theories of human intelligence, the Cattel-Horn-Carrol (CHC) Theory, auditory processing is a factor believed to be a constituent of overall intellectual ability (g). If this is the case, then we would expect that lower performance on auditory processing tasks to be indicative of lower IQ. Similarly, children with lower IQ would be more likely to be diagnosed with auditory processing disorders. Further investigation of this relationship could be useful in our understanding of human intellectual abilities.

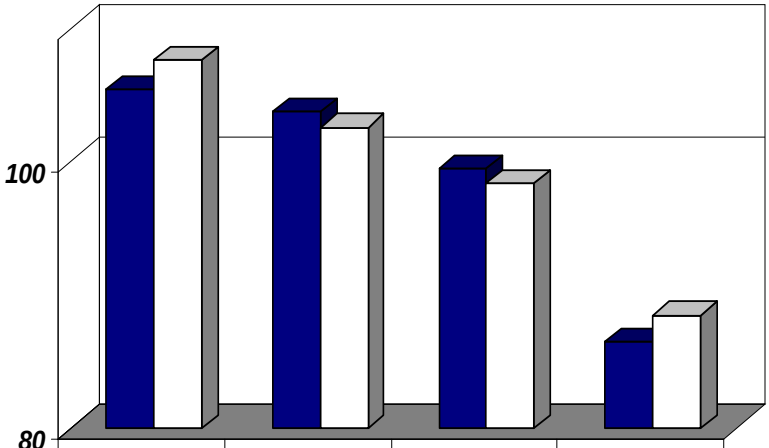
Research on the role of auditory processing skills in verbal memory and reading skill development is relatively new and complicated often producing less than clean results. The very nature of cognitive processes and their possible confounding effects on each other presents many obstacles in research of this type. Future research on memory and it's potential connection to auditory processing and/or reading should strive to address the interplay of cognitive processes and aim to isolate skills, including different reading skills where possible. Future research that explores individual patterns of performance (or case studies) on a variety of auditory and literacy skills, in order to gain insight into potential connections and causal pathways between very specific auditory skills and very specific deficits in early literacy skills is needed.

As discussed above, behavioral measures of APD can be unreliable (Cacace & McFarland, 1998; Jerger & Musiek, 2000; Sharma et al., 2006) as results can be impacted by psychological factors such as attention, fatigue and motivation. The methods used to assess and diagnose APD have been heavily criticized and several authors have called for more valid and reliable means of assessing and diagnosing auditory processing disorders. Perhaps future research studies could address these psychological confounds by utilizing electrophysiological means for assessing APD. However, behavioral measures remain important because they most accurately reflect real life functioning and give us an indication of a child's practical ability to compensate for any neurological deficits. This does not belittle the importance of controlling for potential confounds such as attention, language, and motivation in studies using behavioral measures. The American Speech-Language-Hearing Association's working task force on auditory processing disorders (ASHA, 2005b) call for the development of additional behavioral screening and diagnostic tests which possess more stringent psychometric properties and have been validated on known auditory system dysfunctions. They also call for clearer criteria for differential diagnosis and for

systematic examination of relationships between higher order language and learning sequalae and performances on different central auditory diagnostic tests. They further suggest that such studies must take into account the heterogeneity of auditory processing disorders and learning disabilities and that large subject groups and advanced statistical procedures be used to examine the multiple possible relationships between variables (ASHA, 2005b).

Many studies have made attempts to subtype reading disabilities with varying results and little concordance across studies. It is generally accepted that there are different types and causes of reading disabilities. However, as reading is such a complex task requiring a multitude of skills and processes which are not only interdependent but also vary during reading acquisition and across stages of development, it is difficult to develop descriptions of clear subtypes or causal pathways. While some basic typing can be based on observed differences in specific composite skills, the wide array of skills and processes which are required for proficient reading lead to a large amount of variance in results obtained from samples of reading disabled people, even if they are typed by specific skills.

The causal pathway proposed and examined in this study was one beginning with poor auditory processing leading to poor sensory memory traces and thus to poor phonological processing and delayed reading skill development. While the current study did not find clear support for this suggested causal pathway, it is still possible that this pathway is responsible for the weak development of certain skills reading. Phonologically based reading deficits seem the most likely candidate for such a causal pathway. Future studies that make further attempts to differentiate subtypes of reading disabilities and form groups of reading disabled children based on similar skill profiles need to be conducted before this causal pathway can be disregarded.




| | NA group visual | NA group verbal | RD group visual | RD group verbal |
|---|---|---|---|---|
| ■ Immediate | 105.4 | 103.8 | 99.5 | 86.5 |
| □ Delayed | 107.6 | 102.6 | 98.4 | 88.5 |

Figure 4-1. Graph of comparisons of immediate and delayed memory conditions across modalities in normally achieving and RD-NAPD groups.

LIST OF REFERENCES


Ackerman, P. T., Dykman, R. A., & Gardner, M. Y. (1990). Counting rate, naming rate, phonological sensitivity and memory span: Major factors in dyslexia. *Journal of Learning Disabilities, 23,* 325-327.

Adlard, A. & Hazen, V. (2004). Speech perception in children with specific reading difficulties ( Dyslexia). *The Quarterly Journal of Experimental Psychology, 51,* 153-177.

Ahisser, M & Protopapas, A., Reid, M., & Merzenich, M. (2000). Auditory processing parallels reading ability in adults. *Proceedings of the National Academy of Sciences of the United States of America, 97,* 6832.

Alonso-Bua, B., Diaz, F., & Ferraces, M. J. (2006). The contribution of AERPs (MMN and LDN) to studying temporal vs. linguistic processing deficits in children with reading difficulties. *International Journal of Psychophysiology, 59.* 159-167.

American Speech Language and Hearing Association. (1996). Central Auditory Processing: Current status of research and implications for clinical practice. *American Journal of Audiology, 5.* 41-54.

American Speech Language and Hearing Association. (2005a). (Central) Auditory Processing Disorders – The role of the audiologist. Position statement available at http://www.asha.org

American Speech Language and Hearing Association. (2005b). Technical Report: (Central) Auditory Processing Disorders. Available at http://www.asha.org/members/deskref-journals/deskref/default

Anderson, J. R. (1995). *Learning and Memory; An integrated approach.* John Wiley & Sons Inc. New York.

Badderly, A. (1996). *Working Memory.* Oxford: England. Clarendon Press.

Baddeley, A. (2003a). Working memory: Looking back and looking forward. *Neuroscience, 4,* 829-839.

Baddeley, A. (2003b). Working memory and Language: An overview. *Journal of Communication Disorders, 36,* 189-208.

Baddeley, A., Gathercole, S. & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105,* 158-173.

Baddeley, A. & Hitch, G. (1974). Working Memory. In G. Bower (Ed), *Recent Advances in Learning and Memory, 8,* 47-90. New York, Academic Press.

Ben-Artzi, E., Fostick, L., & Babkoff, H. (2005). Deficits in temporal order judgments in dyslexia: Evidence from dichotic stimuli differing spectrally and from dichotic stimuli differing only by perceived location. *Neuropsychologia, 43.* 714-723.

Benasich, A. & Tallal, P. (2002). Infant discrimination of rapid auditory cues predicts later language impairment. *Behavioural Brain Research, 136.* 31-49.

Berryman, M. J. (2000). An investigation of the performance characteristics of children with reading disabilities on the WRAML. Unpublished doctoral dissertation, Loyola University of Chicago, Illinois.

Bishop, D. V. M. (2007). Using mismatch negativity to study central auditory processing in developmental language and literacy impairments: Where are we, and where should we be going? *Psychological Bulletin, 133.* 651-672.

Bishop, D.V.M., Carlyn, R.P., Deeks, J.M. & Bishop, S.J. (1999). Auditory temporal processing impairment: Neither necessary or sufficient for causing language impairment in children. *Journal of Speech, Language and Hearing Research, 42,* 1295-1311.

Boets, B., Wouters, J., Van Wieringen, A., & Ghesquiere, P. (2006). Auditory temporal information processing in preschool children at risk for dyslexia: Relations with phonological abilities and developing literacy skills. *Brain and Language, 97.* 64-97.

Booth, J. R. & Burman, D. (2001). Development and disorders of neurocognitive systems for oral language and reading. *Learning Disability Quarterly, 24.* 205-212.

Booth, J.R., Perfetti, C.A., Mac Whinney, B. & Hunt, S.B. (2000). The association of rapid temporal perception with orthographic and phonological processing in children and adults with reading impairment. *Scientific Studies of Reading, 4,* 101-132.

Brady, S., Shankwieler, D., & Mann, V. (1983). Speech perception and memory coding in relation to reading ability. *Journal of Experimental Child Psychology, 35,* 345-367.

Bretherton, L. & Holmes, V.M. (2002). The relationship between auditory temporal processing, phonemic awareness, and reading disability. *Journal of Experimental Child Psychology, 84,* 218-243.

Breznitz, Z. (1997). Effects of accelerated reading rate on memory for text among dyslexic readers. *Journal of Educational Psychology, 89,* 289-297.

Burton, M.W., Noll, D.C.& Small, S.L. (2001). The anatomy of auditory word processing: Individual variability. *Brain and Language, 77,* 119-131.

Cacace, A.T. & McFarland, D.J. (1998). Central auditory processing disorder in school aged children: A critical review. *Journal of Speech, Language and Hearing Research,41,* 355-373.

Cacace, A. T., McFarland, D. J., Ouimet, J. R., Schrieber, E., & Marro, P. (2000). Temporal processing deficits in remediation resistant reading impaired children. *Audiology and Neuro-Otology, 5.* 83-97.

Cain, K., Bryant, P. & Oakhill, J. (2004). Children's reading comprehension ability: Concurrent prediction by working memory, verbal ability and component skills. *Journal of Educational Psychology, 96,* 31-42.

Calvo, M. (2005). Relative contribution of vocabulary knowledge and working memory span to elaborative inferences in reading. *Learning & Individual differences, 15,* 53-66.

Casasanto, D.J., Killgore, W.D.S., Maldjian, J.A., Glosser, G., Alsop, D.C., Cooke, A.M. et al. (2002). Neural correlates of successful and unsuccessful verbal memory encoding. *Brain and Language, 80,* 287-295.

Ceponiene, R., Service, E., Kurjenluoma, S., Cheour, M., & Naatanen, R. (1999). Children's performance on pseudoword repetition depends on auditory trace quality: Evidence from event-related potentials. *Developmental Psychology, 35.* 709-720.

Cermack, L. S., Goldberg, J., Cermack, S., & Drake, C. (1980). The short term memory ability of children with learning disabilities. *Journal of Learning Disabilities, 13,* 25-29.

Cohen, M. (1997). *Children's Memory Scale.* San Antonio, TX : Harcourt Brace.

Conlon, E., Sanders, M. & Zapart, S. (2004). Temporal processing in poor adult readers. *Neuropsychologia, 42,* 142.

Cornwall, A. (1992). The relationship of phonological awareness, rapid naming, and verbal memory to severe reading and spelling disability. *Journal of Learning Disabilities, 25,* 532-538.

Daneman, M. & Green, I. (1986). Individual differences in comprehending and producing words in context. *Journal of Memory and Language, 25,* 1-18.

Das, J. P. & Mok, M. (1994). The Role of speech processes and memory in reading disability. *Journal of General Psychology, 121,* 131-143.

De Jong, P.F. (1998). Working memory deficits of reading disabled children. *Journal of Experimental Child Psychology, 70,* 75-96.

DeMartino,S., Espesser,R., Rey, V., & Habib, M. (2001). The "Temporal Processing Deficit" hypothesis in dyslexia: New experimental evidence.

Dermody, P., Mackie, K., & Katsch, R. (1983). Dichotic listening in good and poor readers. *Journal of Speech and Hearing Research, 26,* 341-348.

DiDonato, M. (2002). Verbal memory and auditory-visual, temporal-spatial integration skills for central auditory processing disorder and attention deficit hyperactivity disorder in children aged seven to eleven years. *Dissertation Abstracts International, 63* (01), 81. (UMI No. 3041157)

Elliot, C. D. (1990). *Differential Ability Scales.* San Antonio, TX. Psychological Corporation.

Engle, R., Cantor, J,. Carullo, J. (1992) Individual differences in working memory and comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, memory and Cognition, 18.* 972-992.

Farmer,M.E. & Klein, R. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review. *Psychonomic Bulletin Review, 2,* 460-493.

Florida Department of education Technical Assistance Paper. (2001). *Auditory Processing Disorders.* FY 2001-9.

Galaburda, A. M. (2005). Dyslexia – A molecular disorder of neuronal migration. *Annals of Dyslexia, 55.* 151-165.

Gang, M. & Siegel, L. S. (2002). Sound-symbol learning in children with dyslexia. *Journal of Learning Disabilities, 35,* 137-157.

Gillet, P. (1993). *Auditory Processes.* Novato, Ca. Academic Therapy Publications.

Godfrey, J.J., Syrdal-Lasky, A.K., Millay, K.K., & Knox, C.M. (1981). Performance of dyslexic children on speech perception tests. *Journal of Experimental Child Psychology, 32,* 401-424.

Goswami, U., Thompson, J., Richardson, U., Stainthorpe, R., Hughes, M., Rosen, S., & Scott, S. (2002). Amplitude envelope onsets and developmental dyslexia: A new Hypothesis. *Proceedings of the National Academy of Science U.S.A. 2002, 99.* 10911-10916.

Granetz, S. B. (1984). The effects of sequential order on the short-term memory of dyslexic readers. Unpublished dissertation, Rutgers The State University of New Jersey – New Brunswick, New Jersey.

Gupta, P., & Mac Whinney, B. (1997). Vocabulary acquisition and verbal short-term memory: Computational and neural bases. *Brain and Language, 59.* 267-333.

Hall, J. (1999). CAPD in Y2K: An introduction to audiologic assessment and management. *The Hearing Journal, 52,* 35-42.

Heath, S. M. & Hogben, J. H. (2004). Cost effective prediction of reading difficulties. *Journal of Speech, Language and Hearing Research, 47.* 751-765.

Heath, S.M., Hogben, J.H., & Clark, C.D. (1999). Auditory temporal processing in disabled readers with and without oral language delay. *Journal of Child Psychology and Psychiatry, 40,* 637-647.

Heiervang, E., Stevenson, J., & Hugdahl, K. (2002). Auditory processing in children with dyslexia. *Journal of child psychology and psychiatry, 43,* p931-938.

Heim, S., Freeman, R.B., Eulitz, C., & Elbert, T. (2000). Auditory temporal processing deficit in dyslexia is associated with enhanced sensitivity in the visual modality. *Neuroreport, 12,* 507-510.

Hood, M. & Conlon, E. (2003). The role of temporal processing in early reading and spelling development. *Australian Journal of Psychology, 55,* 81-86.

Hood, M. & Conlon, E. (2004). Visual and auditory temporal processing and early reading development. *Dyslexia, 10.* 234-252.

Howard, R. W. (1995). *Learning and Memory; Major Ideas, Principals, Issues and Applications.* Praeger Publishing. Connecticut, USA.

Howes, N., Bigler, E. D., Burlingame, G. M., & Lawson, J. S. (2003). Memory performance of children with dyslexia: A comparative analysis of theoretical perspectives. *Journal of Learning Disabilities, 36,* 230-246.

Hugdahl, K., Heiervang, E., Nordby, H., Smievoll, A.I., Steinmetz, H., Stevenson, J., & Lund, A. (1998). Central auditory processing, MRI morphometry and brain laterality: Applications to dyslexia. *Scandinavian Audiology, 27,* 26-34.

Hulme, C. (1987). The effects of acoustic similarity on memory in children: A comparison between visual and auditory presentation. *Applied Cognitive Psychology, 1,* 45-51.

Hurford, D.P. & Shedelbower, A. (1993). The relationship between discrimination and memory ability in children with reading disabilities. *Contemporary Educational Psychology, 18,* 101-113.

Huslander, J., Talcott, J., Witton, C., DeFries, J., Pennington, B., Wadsworth, S., Willcutt, E., & Olson, R. (2004). Sensory processing, reading, IQ and attention. *Journal of Experimental Child Psychology, 88.* 274-295.

Jeffries, S. & Everatt, J. (2004). Working memory: It's role in dyslexia and other specific learning difficulties, *Dyslexia, 10,* 196-214.

Jerger, J. & Musiek, F. (2000). Report of the consensus conference on the diagnosis of auditory processing disorders in school aged children. *Journal of the American Academy of Audiology, 11*. 467-474.

Just, M. & Carpenter, P. (1992) A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99.* 122-149.

Katz, J., Basil, R. A., & Smith, J.M. (1963). A staggered spondaic word test for detecting central auditory lesions. *Annuals of Otological Rhinological Laryngology, 72.* 908-917.

Katz, R. B., Shankweiler, D., & Liberman, I. Y. (1981). Memory for item order and phonetic recoding in the beginning reader. *Journal of Experimental Child Psychology, 3,*. 474-484.

Kausler, D. H. (1974). *Psychology of verbal Learning and memory.* Academic Press. NY.

Keith, R. (2000). SCAN – C: Test for auditory processing disorders in children – Revised. The Psychological Corporation. San Antonio, TX.

Kibby, M. Y., Marks, W., Morgan, S. & Long, C. (2004). Specific impairment in Developmental reading disabilities: A working memory approach. *Journal of Learning Disabilities, 37,* 349-363.

King, W. M., Lombardino, L., Crandell, C., & Leonard, C. (2003). Comorbid auditory processing disorder in developmental dyslexia. *Ear and Hearing, 24.* 448-457.

Kintsch, W. & Buschke, H. (1969). Homophones and Synonyms in short term memory. *Journal of Experimental Psychology, 80,* 403-407.

Kirk, J. R. (1998). Selected Short-term Memory Tests as Predictors of Reading Readiness. *Psychology in The Schools, 35,* 137-144.

Klapp, S., Marshburn, E. & Lester, P. (1983). Short term memory does not involve the "working memory" of intellectual processing: The demise of a common assumption. *Journal of Experimental Psychology: General, 112,* 240-264.

Kraus, N., McGee, T.J., Carrell, T.D., Zecker, S.G., Nicol, T.G., & Koch, D,B, . (1996). Auditory neuropsychologic responses and discrimination deficits in children with learning problems. *Science, 273,* 971-973.

Kujala, T., Belitz, S., Tervaniemi, M., & Naatanen, R. (2003). Short Communication: Auditory sensory memory disorder in dyslexic adults as indexed by the mismatch negativity. *European Journal of Neuroscience, 17.* 1323-1327.

Kujala, T., Myllyviita, K., Tervaniemi, M., Alho, K., Kallio, J., & Naatanen, R. (2000). Baisc auditory dysfunction in dyslexia as demonstrated by brain activity measures. *Psychophysiology, 37.* 262-266.

Laasonen, M., Service, E., & Virsu, V. (2002). Crossmodal temporal order and processing acuity in developmentally dyslexic young adults. *Brain & Language, 80,* p340-355.

Lachmann, T., Berti, S., Kujala, T., Schroger, E. (2005). Diagnostic subgroups of developmental dyslexia have different deficits in neural processing of tones and phonemes. *International Journal of Psychophysiology, 56.* 105-120.

Leather, C.V. & Henry, L.A. (1994). Working memory span and phonological awareness tasks as predictors of early reading ability. *Journal of Experimental Child Psychology, 58,* 88-111.

Leonard, C. (2001). Imaging brain structure in children: Differentiating language disability and reading disability. *Learning Disability Quarterly, 24.* 158-175.

Lespinet-Najib, V., N'Kaoua, B., Sauzeon, H., Bresson, C., Rougier, A., & Claverie, B. (2004). Levels of processing with free and cued recall and unilateral temporal lobe epilepsy. *Brain & Language, 89,* 83-91.

Liberman, I., Mann, V., Shankweiler, D., & Werfelman, M. (1982). Children's memory for recurring linguistic and nonlinguistic material in relation to reading ability. *Cortex, 18.* 367-375.

Liddell, G. A. & Rasmussen, C. (2005). Memory profile of children with nonverbal learning disability. *Learning Disabilities Research & Practice, 20,* 137-141.

Lyytinen, H., Guttorm, T., Huttunen, T., Hamalainen, J., Leppanen, H. & Vesterinen, M. (2005). Psychophysiology of developmental dyslexia: A review of findings including studies of children at risk for dyslexia. *Journal of Nurolinguistics, 18.* 167-195.

Mac Donnald, M.C., Just, M. & Carpenter, C.M. (1992). Working memory constraints on the processing of syntactic ambiguity. *Cognitive Psychology, 24,* 56-98.

Mann,V.A., Liberman, I.Y., & Shankweiler, D. (1980). Children's memory for sentences and word strings in relationship to reading ability. *Memory and Cognition, 8,* 329-335.

Marshall, C.M., Snowling, M.J., & Bailey, P.J. (2001). Rapid auditory processing and phonological ability in normal readers and readers with dyslexia. *Journal of Speech, Language and Hearing Research, 44,* 925-940.

Martin, N. (2000). Word processing and verbal short term memory: How are they connected and why do we want to know? *Brain and Language, 71,* 149-153.

Matlin, M. W. (1998). *Cognition – Fourth edtn.* Fort Worth, TX. Harcourt Brace & Company.

Maurer, U., Bucher, K., Brem, S., & Brandeis, D. (2003). Altered responses to tone and phoneme mismatch in kindergarteners at familial dyslexia risk. *Neuroreport, 14.* 2245-2250.

McAnally, K., Castles, A., & Bannister, S. (2004). *Journal of Speech, Language and Hearing Research, 47.* 1237-1243.

McArthur, G.M., & Bishop, D.V.M. (2001). Auditory perceptual processing in people with reading and oral language impairments: Current issues and recommendations. *Dyslexia, 7,* 150-170.

McCandliss, B., & Noble, K. (2003). The development of reading impairment: A cognitive neuroscience model. *Mental Retardation and Developmental Disabilities Research Reviews, 9.* 196-205.

McFarland, D.J. & Cacace, A.T. (1995). Modality specificity as a criterion for diagnosing central auditory processing disorders. *American Journal of Audiology, 4,* 36-48.

McGrew, N. & Woodcock, R. W. (2001). Technical Manual. *Woodcock-Johnson III.* Itasca, IL: Riverside Publishing.

McGuinness, C. (2000). The elusive connection between blending and memory. *Parent – Teacher Magazine, 4.*

Merlo, M. J. (1986). Reading ability and short-term memory: The role of phonetic processing skills. Unpublished doctoral dissertation, University of Rhode Island, Rhode Island.

Messbauer, V. C. S. & de Jong, P. F. (2002). Word, non-word and visual paired associate learning in Dutch dyslexic children. *Journal of Experimental Child Psychology, 84,* 77-96.

Miyake, A., Just, M. & Carpenter, P.A. (1994). Working memory constraints on the resolution of lexical ambiguity: Maintaining multiple interpretations in neutral contexts. *Journal of Memory and Language, 33,* 175-202.

Mody, M. (2003). Rapid auditory processing deficits I dyslexia: a commentary on two differing views. *Journal of Phonetics, 31.* 529-539.

Mody, M., Studdart-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding? *Journal of Experimental Child Psychology, 64.* 199-231.

Moncrief, D. & Musiek, F. (2002). Interaural asymmetries revealed by dichotic listening tests in normal and dyslexic children. *Journal of the American Academy of Audiology, 13.* 428-437.

Muter, V. & Snowling, M. (1998). Concurrent and longitudinal predictors of reading: The role of metalinguistic and short-term memory skills. *Reading Research Quarterly, 33,* 320-337.

Naatanen, R. (2001). The perception of speech sounds by the human brain as reflected by the mismatch negativity (MMN) and its magnetic equivalent (MMNm). *Psychopysiology, 38.* 1-21.

Nation, K., Adams, J., Bowyer-Crane, C. A., & Snowling, M. (1999). Working memory deficits in poor comprehenders reflect underlying language impairments. *Journal of experimental child psychology, 73,*139-158.

Nelson, H. E. & Warrington, E. K. (1980). An investigation of memory functions in dyslexic children. *British Journal of Psychology, 71,* 487-503.

Nelson, P.B., & Soli, S. (2000). Acoustical barriers to learning: Children at risk in every classroom. *Language, Speech and Hearing Services in Schools, 31,* 356-361.

Nittrouer, S. (1999). Do temporal processing deficits cause phonological processing problems? *Journal of Speech, Language and Hearing Research, 42.* 925-942.

Oakhill, J., Cain, K., & Bryant, P. (2003). The dissociation of single word reading and text comprehension: Evidence from component skills. *Language and Cognitive Processes, 18.* 443-468.

O'Shaughnessy, T.E., & Swanson, H.L. (1998). Do immediate memory deficits in students with learning disabilities in reading reflect a developmental lag or a deficit? A selective meta-analysis of the literature. *Learning Disability Quarterly, 21,* 123-148.

Overy, K., Nicholson, R., Fawcett, A., & Clarke, E. (2003). Dyslexia and music: Measuring musical timing skills. *Dyslexia, 9.* 18-36.

Palladino, P., Cornoldi, C., De Beni, R., Pazzaglia, F. (2001). Working memory and updating processes in reading comprehension. *Memory & Cognition, 29.* 344-354.

Penney, C. & Godsell, A. (1999). Unusual modality effects in less-skilled readers. *Journal of experimental Psychology: Learning, Memory and Cognition. 25.* 284-289.

Phillips, D.P. (1995). Central auditory processing: A view from cognitive neuroscience. *The American Journal of Otology, 16(3),* 338-352.

Plaza, M., Cohen, H., & Chevrie-Muller, C. (2001). Oral language deficits in dyslexic children; Weaknesses in working memory and verbal planning. *Brain and Cognition, 48.* 505-512.

Poldrack, R., Temple, E., Gabrieli, J. D., Protopapas, A., Nagarajan, S., Merzenich, M., & Tallal, P. (2001). Relations between the neural bases of dynamic auditory processing and phonological processing: Evidence from fMRI. *Journal of Cognitive Neuroscience, 13.* 687-698.

Purdy, S., Kelly, A., & Davies, M. (2002). Auditory brainstem response, middle latency response and late cortical evoked potentials in children with learning disabilities. *Journals of the American Academy of Audiology, 13.* 367-383.

Ramus, F. (2003). Developmental dyslexia: Specific phonological deficit or general sensorimotor dysfunction. *Current Opinion in Neurobiology, 13.* 212-218.

Ray, V., De Martino, S., Espesser, R., & Habib, M. (2002). Temporal processing and phonological impairment in dyslexia: Effect of phoneme lengthening on order judgment of two consonants. *Brain and Language, 80.* 576-591.

Reed, M.A. (1989). Speech perception and the discrimination of brief auditory cues in reading disabled children. *Journal of Experimental child Psychology, 48,* 270-292.

Riccio, C., Cohen, M., Garrison, T., & Smith, B. (2005). Auditory processing measures: Correlation with neuropsychological measures of attention, memory and behavior. *Child Neuropsychology, 11.* 363-372.

Richard, G.J. (2001) *The Source for Processing Disorders.* East Moline, IL. Linguisystems inc.

Richardson, U., Thompson, J., Scott, S., & Goswami, U. (2004). Auditory processing skills and phonological representation in dyslexic children. *Dyslexia, 10.* 215-233.

Rosen, S. (2003). Auditory processing in dyslexia and specific language impairment: Is there a deficit? What is it's nature? Does it explain anything? *Journal of Phonetics, 31*. 509-527.

Rosen, S., & Manganari, E. (2001). Is there a relationship between speech and nonspeech auditory processing in children with dyslexia. *Journal of Speech, Language and Hearing Research, 44,* 720-736.

Salmelin, R. & Helenius, P. (2004). Functional Neuroanatomy of impaired reading in dyslexia. *Scientific studies of Reading, 8.* 257-272.

Sandak, R., Mencel,. W. E., Frost, S., & Pugh, K. (2004). The neurobiological basis of skilled and impaired reading: Recent findings and new directions. *Scientific Studies of Reading, 8.* 273-292.

Schulte-Korne, G., Deimel, W., Bartling, J., & Remschmidt, H. (1998). Role of auditory temporal processing for reading and spelling disability. *Perceptual Motor Skills, 86.* 1043-1047.

Shah, P. & Miyake, A. (1996) The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General, 125,* 4-27.

Sharma, M., Purdy, S., Newall, P., Wheldall, K., Beaman, R., & Dillon, H. (2006). Electrophysiological and behavioral evidence of auditory processing deficits in children with reading disorders. *Clinical Neurophysiology, 117.* 1130-1144.

Siegel, L & Ryan, E. (1989). The development of working memory in normally achieving and subtypes of learning disabled children. *Child Development, 60,* 973-980.

Sipe, S. & Engle, R. W. (1986). Echoic memory processes in good and poor readers. *Journal of Experimental Psychology – Learning, Memory and Cognition. 12.* 402-412.

Snyder, L. E. & Downey, D. M. (1991). The language-reading relationship in normal and reading disabled children. *Journal of Speech, Language and Hearing Research, 34.* 129-140.

Sprenger, M. (1999). *Learning and Memory; The brain in action.* Association for Supervision and Curriculum Development. Virginia, USA.

Stoodley, C.J., Hill, P.R., Stein, J. F., & Bishop, D. V. M. (2006). Auditory event related potentials differ in dyslexics even when auditory psychophysical performance is normal. *Brain Research, 1121.* 190-199.

Studdert-Kennedy, M., & Mody, M. (1995). Auditory temporal deficits in the reading impaired: A critical review of the evidence. *Psychonomic Bulletin and Review, 2,* 508-514.

Tallal, P. (1980). Auditory temporal perception, phonics and reading disabilities in children. *Brain and language, 9,* 182-198.

Taylor, M., & Keenan, N. (1999). ERP's to orthographic, phonological, and semantic tasks in dyslexic children with auditory processing impairment. *Developmental Neuropsychology, 15.* 307-327.

Tharpe, A.M. (1999). Auditory integration training: The magical mystery cure. *Language, Speech and Hearing Services in Schools, 30,* 378-382.

Thompson, J., Richardson, U., & Goswami, U. (2005). Phonological similarity neighborhoods and children's short-term memory: Typical development and dyslexia. *Memory and Cognition, 33.* 1210-1220.

Tijms, J. (2004). Verbal memory and phonological processing in dyslexia. *Journal of research in reading, 27,* 300-310.

Torgesen, J.K. (1985). Memory processes in reading disabled children. *Journal of Learning Disabilities, 18,* 350-357.

Torgesen, J.K. (2000). Individual differences in response to early interventions in reading: The lingering problem of treatment resisters. *Learning Disabilities Research and Practice, 15,* 55-64.

Torgesen, J. & Goldman, T. (1977). Verbal rehearsal and short-term memory in reading-disabled children. *Child Development, 48,* 56-60.

Torgesen, J. K. (1988). Studies of children with learning disabilities who perform poorly on memory span tasks. *Journal of Learning Disabilities, 21,* 605-612.

Torgesen , J. & Houck, D. G. (1980). Processing deficiencies of learning disabled children who perform poorly on the digit span subtest. *Journal of Educational Psychology, 72,* 141-160.

Torgesen, J. K., Murphy, H. A. & Ivey, C. (1979). The influence of an orienting task on the memory performance of children with reading problems. *Journal of Learning Disabilities, 12,* 396-401.

Van Ingelhem, M., Van Wieringen, A., Wouters, J., Vandenbussche, E., Onghena, P., & Ghesquiere, P. (2001). Psychophysical evidence for a general temporal processing deficit in children with dyslexia. *Neuroreport, 12.* 3603-3607.

Waber, D., Weiler, M., Wolff, P., Bellinger, D., Marcus, D., Ariel, R., Forbes, P., & Wypij, D. (2001). Processing of rapid auditory stimuli in school-aged children referred for evaluation of learning disorders. *Child Development, 72.* 37-49.

Walker, M.M., Shinn, J.B., Cranford, J.L., Givens, G.D., & Holbert, D. (2002). Auditory temporal processing performance of young adults with reading disorders. *Journal of Speech, Language and Hearing Research, 45,* 598-605.

Waters, G., Caplan, D. (1996). The measurement of verbal working memory capacity and it's relation to reading comprehension. *The Quarterly Journal of Experimental Psychology, 49A,* 51-79.

Watson, B.U. (1992). Auditory temporal acuity in normally achieving and learning disabled college students. *Journal of Speech and Hearing Research, 35,* 148-156.

Watson, B.U. & Miller, T.K. (1993). Auditory perception, phonological processing and reading ability/disability. *Journal of Speech and Hearing Research, 36,* 850-863.

Wechsler, D. (2001). *Wechsler Individual Achievement Test - Second Edition.* San Antonio, TX. The Psychological Corporation.

Wechsler, D. (2003). *Wechsler Intelligence Scale for Children – Fourth Edition.* San Antonio, TX.: The Psychological Corporation.

Wiederholt, J. L. and Bryant, B. R. (2001). *Gray Oral Reading Tests Examiners Manual.* Austin, TX. Pro-ed.

Wilkinson, I.A., Elkins, J. & Bain, J.D. (1995). Individual differences in story comprehension and recall of poor readers. *British Journal of Educational Psychology, 65,* 393.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson III Tests of Achievement.* Itasca, IL. Riverside Publishing.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson III Tests of Cognitive Abilities.* Itasca, IL. Riverside Publishing.

# BIOGRAPHICAL SKETCH

Julie Ann Ellis was born in Melbourne, Australia. The oldest of four, she grew up and attended college in Australia. She earned her B.Ed. in secondary education in 1989 from Deakin University. After several years of teaching and giving birth to two sons, Brandon and Christopher, Julie entered graduate school at the University of Florida where she earned a Masters of Education (M.Ed.) in educational psychology in 2000. She then was admitted into the school psychology program at the University of Florida where she earned a second M.Ed. in school psychology in 2006. Upon completion of her Ph.D. program, Julie intends to work in a setting which enables her to combine research with practice. She would like to investigate the development of language and literacy skills in preschool and early elementary age children.