The Role of Temporal and Phonological Processing In Early Reading Development: A Longitudinal Study

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Abstract

This study investigated the ability of auditory and visual temporal processing measured before school entry (mean age 5.36 years) to predict early reading development in an unselected sample of children. There were 142 children at the first phase (Preschool), 125 at the second phase 6 – 8 months later (early Grade 1; mean age 5.94 years), and 105 at the third phase 12 months later (Grade 2; mean age 6.94 years). There were similar numbers of males and females. Visual and auditory temporal order judgement (TOJ) and Temporal Dot accuracy (rapid visual sequencing task) measured at Preschool explained a significant percentage of the variance in letter identification (an important pre-reading skill) measured concurrently. These measures also predicted a significant percentage of the variance in letter and word identification (word reading accuracy) and reading rate (fluency) measured in early Grade 1, even after controlling for the effects of age, environment, memory, attentional vigilance, non-verbal ability, and speech and language problems. They also significantly discriminated between groups of children at Grade 1 who could and could not use phonological decoding to read non-words. By Grade 2, these Preschool measures accounted for significant variance in word reading accuracy and fluency and in non-word decoding. Only Preschool auditory temporal processing accounted for significant unique variance in the reading measures at Preschool or Grade 1, but by Grade 2, visual temporal processing (Temporal Dot) also accounted for significant unique variance. Temporal Dot accuracy also explained unique variance in the rate of growth in these reading measures across this period.

These changes in predictive ability by the auditory and visual temporal processing measures were interpreted as reflecting developmental changes in their
roles in reading as reading develops. Auditory temporal processing was important in early pre-reading and reading and remained important throughout. Visual temporal processing only became important in the later phase, possibly because of increasing need to analyse letter sequences. Preschool temporal and phonological processing measures accounted for approximately equal percentages of variance in the reading measures at Preschool and Grade 1, but by Grade 2, the Preschool phonological processing measures accounted for significantly more variance in all reading measures, except Pseudohomophone Choice (orthographic processing). Very little of the variance that was explained in the reading measures was common to temporal and phonological processing. The variance that each uniquely explained in reading was more important than the variance they explained in common. Therefore, utilising both temporal and phonological processing predictors optimised prediction of early reading skills.

The study also showed there was significant linear development occurring in temporal processing from Preschool to Grade 2. The correlations of scores on the temporal measures from Preschool to Grade 1 were moderate. The relative position of children within the distribution on these skills showed moderate stability over the short-term, but less stability over the long-term. The majority of children who fell in the bottom quartile on the temporal and phonological processing measures at Preschool remained in the bottom half of the distribution on those measures by Grade 2. These children may represent those who are at most risk for reading difficulties. Letter Word Identification showed high stability from Preschool to Grade 2.

There was little difference in the percentage of variance explained in subsequent reading between temporal processing measures obtained at Preschool or Grade 1. However, performance on the Visual temporal order judgement task was more likely
to account for significant unique variance in reading when measured after school entry than before. This was consistent with the expected developmental changes in reading. When measured after school-entry, phonological processing measures accounted for greater percentages of variance in the reading measures than when measured before. There were also developmental changes in which phonological processing measures were important predictors of reading skills. When measured at Grade 1, rhyme and alliteration detection and phonemic segmentation were the most important predictors. However, when measured at Grade 2, performance on the Rhyme and Alliteration task had reached ceiling, so would no longer be a useful predictor of later reading. These results were consistent with developmental models of reading and of phonological processing.

The results provided support for a causal role of temporal processing in reading development. They also showed that measures of visual and auditory temporal processing obtained close to school-entry would be a useful addition to predicting risk of early reading difficulties. However, additional work is needed to determine the most suitable temporal processing measures for this younger age group.
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LIST OF PUBLICATIONS DRAWN FROM THIS RESEARCH

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Other Conference Presentations
STATEMENT OF ORIGINALITY

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge, this dissertation contains no material previously published or written by another person, except where due reference is made in the dissertation.

Signed: ______________________________
CHAPTER 1: OVERVIEW

Using a prospective longitudinal design, the primary focus of this study was the ability of measures of visual and auditory temporal processing taken in pre-readers to predict individual differences in subsequent early reading development. To date, only one longitudinal study each has examined the relationship between early reading development and pre-existing visual processing (Lovegrove, Slaghuis, Bowling, Nelson, & Geeves, 1986) or pre-existing auditory temporal processing (Share, Jorm, MacLean, & Matthews, 2002). No longitudinal studies have examined the relationships between both pre-existing visual and auditory temporal processing measures and subsequent reading in the same sample. This is despite many calls in the literature for such research, which is critical to establishing a potentially causal role for these factors in reading development and in developmental dyslexia (Farmer & Klein, 1995; Ramus, 2004; Stein, 2001a).

Since the late 1970's, a great deal of evidence has accumulated from cross-sectional studies with older children, adolescents, and adults showing significantly poorer auditory and visual temporal processing in groups with dyslexia than in groups of control readers. Although less common, normative studies also showed significant relationships between temporal processing ability and ability on a range of reading, orthographic processing, and phonological processing measures. Overall, there is strong convergent evidence of a relationship between temporal processing and reading ability from psychophysical (e.g., Lovegrove, Bowling, Badcock, & Blackwood, 1980; Talcott et al., 2000, 2002; Tallal, 1980), anatomical (Galaburda, Menard, & Rosen, 1994; Livingstone, Rosen, Drislane, & Galaburda, 1991), electrophysiological (Lehmkhule, Garzia, Turner, Hash, & Baro, 1993), and neuroimaging studies (Demb, Boynton, & Heeger, 1998; Larsen, Høien, Lundberg, & Ødegaard, 1990).
However, cross-sectional research establishes only that temporal processing ability and reading ability co-vary. For causality, temporal precedence of the causal factor must also be established, which requires prospective longitudinal studies like the current one. Based on existing cross-sectional findings, temporal processing ability in pre-readers was expected to predict significant variance in subsequent single word reading, non-word decoding, word reading fluency, and orthographic skill. This study also examined whether visual and auditory temporal processing abilities predict independent variance in each reading measure versus the extent to which they account for overlapping variance.

By contrast to the research on temporal processing and reading, several longitudinal studies have shown pre-existing phonological processing ability significantly predicts subsequent reading ability and significantly discriminates between groups with dyslexia and control groups (e.g., Bowey, 1994; Bradley & Bryant, 1983; Lundberg, Olofsson, & Wall, 1980; Muter & Snowling, 1998). Nearly all of the individuals with dyslexia showed phonological processing deficits. Based on this, several researchers argued that phonological processing abilities are necessary for successful early reading development and are causally related to developmental dyslexia, whereas other factors, such as temporal processing ability (especially visual temporal processing ability) are secondary (Cestnick & Coltheart, 1999; Rack, Snowling, & Olson, 1992; Vellutino & Scanlon, 1991) or even coincidental (Ramus, 2003). Certainly phonological processing is a more proximal potential cause, and temporal processing is more distal. However, given the lack of longitudinal evidence in the temporal processing literature, it seems a little premature to dismiss or diminish the role of temporal processing in reading development.
Therefore, a second aim of the study was to compare the amount of variance in early reading accounted for by Pre-school measures of temporal processing versus phonological processing, to determine the importance of temporal processing in early reading development. The aim was also to determine if the variance in reading ability accounted for by temporal and phonological processing abilities was independent. In conjunction with this, the study examined whether a combination of pre-school phonological and temporal processing predictors would explain a greater amount of variance in early reading ability than using only one or the other type of predictor.

At the heart of the issue regarding the importance of temporal processing in reading and dyslexia is the type of causal model espoused (Laasonen, Service, & Virsu, 2001). Centralist theories postulate a single central linguistic causal deficit in reading disability, specifically impaired phonological processing. All other possible impairments (such as temporal processing deficits) are independent of, or coincidental to, that central causal deficit. The phonological processing deficit hypothesis of dyslexia (Stanovich, 1988; Vellutino, 1979, Wagner & Torgeson, 1987) is a centralist theory. Perceptual causal hypotheses postulate that perceptual deficits underlie and cause those characteristic phonological and orthographic processing deficits. The temporal processing deficit hypothesis is a perceptual causal hypothesis. Multifactor hypotheses propose these perceptual deficits are markers of dysfunctional neural systems related to other mechanisms, like attention (e.g., Hari, Renvall, & Tanskanen, 2001), which has direct effects on orthographic and phonological processing, and subsequently on reading. The temporal processing deficit hypothesis has also been interpreted in terms of the multifactor hypothesis. The current study was set within the framework of the perceptual deficit and multifactor hypotheses, but incorporated the linguistic centralist approach for comparison.
However, this study took an even broader multiple-levels approach (Fletcher et al., 2002; Fletcher, Taylor, Levin, & Satz, 1995; Frith, 1985, 1997; Lundberg, 1999). Snowling, Gallagher, and Frith (2003) argued that factors at the cognitive level (such as language skills and attention) and environmental factors (such as print exposure and method for teaching reading) interact with risk at the genetic or biological level to either exacerbate or compensate for that risk. Therefore, this study incorporated a range of cognitive (phonological processing, non-verbal ability, speech problems, memory), perceptual (temporal processing, attentional vigilance), environmental (early home literacy practices, school effects), and behavioural (reading) measures.

Within this multiple-level framework, Snowling (2000) recommended research take a developmental approach to describe the way the pattern of reading difficulty changes, both with age and through interaction with the environment. Thus, the final purpose of the study was to examine the developmental changes and stability of temporal processing over the period during which reading emerges (Preschool to Grade 2). Existing research demonstrated development in temporal processing ability until around 11 years of age (Crewther, Crewther, Barnard, & Klistorner, 1996; Raymond & Sorenson, 1998; Waber et al., 2001; Wightman, Allen, Dolan, Kistler, & Jamieson, 1989). However, these studies were cross-sectional, so knowledge is lacking about the stability of changes, particularly during the period in which reading begins. Despite rapid development over childhood, reading ability shows remarkable stability. For example, Juel (1988) estimated the probability that a poor reader in Grade 1 would still be a poor reader in Grade 4 as .88. Causal factors in reading development would need to show similar stability in order to explain this stability in reading. This study compared the development and stability in temporal processing to that in phonological processing and reading.
However, there is also the possibility of developmental changes in the predictive relationship between these temporal and phonological processing measures and reading as the nature of reading changes with development. For example, Ehri (1987) argued that phonological skills are important from the earliest stages of reading development, but as reading becomes automatic in the later stages, there is less reliance on phonological decoding and more reliance on automatic access of the mental lexicon, allowing word recognition by sight. If, as Tallal (1980) argued, auditory temporal processing underlies phonological processing, it should be related to reading (via phonological processing) from the earliest point in development. There is also evidence that visual temporal processing is more strongly related to orthographic skill (e.g., Booth et al., 2000; Cornelissen et al., 1998; Talcott et al., 2000), the ability to recognise the written sequences that specify words as whole units. As this ability emerges later in reading development, visual temporal processing might be more strongly predictive of later reading than of very early reading. However, the earliest stage of reading is characterised as being reliant on contextual visual cues (such as salient letter shapes) before phonological skills are well enough developed to allow complete analysis of the spelling. Thus, there might be a relationship between visual temporal processing and reading ability from the earliest point, even at a pre-reading point of single letter identification, but the nature of that relationship might change as the nature of reading changes. In order to examine these issues, the study examined both prospective longitudinal and concurrent relationships between temporal and phonological processing measures and reading at Preschool, Grade 1, and Grade 2, times that covered a range of stages in early reading development.
CHAPTER 2: MODELS OF DYSLEXIA AND NORMAL READING

Learning to read is a seemingly simple process for most children. However, in the 1996 National Survey, 10 to 15% of Australian children in Grades 3 and 5 showed serious literacy problems (Mapping Literacy Achievement, 1997). More generally, across English-speaking countries, 5 to 17% of children have developmental reading disability or dyslexia (S. E. Shaywitz, B. A. Shaywitz, Fletcher, & Escobar, 1990). There is evidence that dyslexia forms part of the normal spectrum of reading abilities. Using data from the Connecticut Longitudinal Study ($N = 414$), S. E. Shaywitz, Escobar, B. A. Shaywitz, Fletcher, and Makuch (1992) found a normal distribution model fitted the data very well. Dyslexia represented the lower tail that "blends imperceptibly with normal reading ability" (p. 148). It is not an all-or-nothing entity but, like normal reading ability, comes in varying degrees of (dis-) ability. Gilger and Kaplan (2001) argued that it might be a manifestation of normal variability in the brain, evident simply because of the relatively recent cultural demands for literacy. Therefore, knowledge of the factors that underlie normal reading development and the factors that characterise skilled adult reading potentially inform about what may be impaired or lacking in dyslexia. Similarly, knowledge of the deficits associated with dyslexia potentially inform about what is important for normal reading development.

Although the prevalence rates of dyslexia vary across languages, the characteristic difficulties associated with dyslexia do not differ, regardless of differences in orthographies (Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003). Thus, the underlying causes are universal, rather than language-specific. Despite thousands of studies, there is still no consensus on what causes dyslexia.
From the earliest report of developmental dyslexia, both language and visual processing deficits have been implicated in its cause. Morgan (1896) reported the first case of what he called *congenital word blindness* in a 14-year-old boy. Fildes (1922) found children with this condition showed deficiencies in the discrimination of identical figures of differing orientations, and in aspects of visual memory, although her sample consisted mainly of what would now be called *garden-variety* poor readers (children with poor reading and below average IQ). Orton (1937) also considered a visual perceptual deficit (specifically a disturbed sense of visual orientation) as the core deficit. He called the condition “strephosymbolia”, meaning “twisted symbols”, because of the prevalence of reversal errors these children made in their reading. He postulated the neurological basis was a failure to achieve unilateral hemispheric dominance, which resulted in a failure to see visuo-verbal symbols in their correct directional orientation. Between the 1930s and 1970s, most of the research into developmental dyslexia focussed on identifying deficits in visual abilities, with visual memory deficits being the focus (see Benton, 1991).

In a series of seminal studies, Vellutino and colleagues (Vellutino, 1979; Vellutino, Pruzek, Steger, & Meshoulam, 1973; Vellutino, Steger, Kaman, & De Setto, 1975) dismissed the hypothesis that poor and normal readers differed on visual memory by demonstrating that when the stimuli were from an unfamiliar orthography, such as Hebrew letters, no group differences occurred. They concluded that the previously reported differences in visual-spatial function were a result of confounding by linguistic factors. This led to a change in the focus of dyslexia research from visual processing deficits to linguistic deficits, specifically, phonological processing deficits. The phonological processing deficit hypothesis proposes that dyslexia is due to a deficit in the ability to use the sounds of one's language (the phonology) in
processing both the written (orthographic) and oral forms (Stanovich, 1988; Vellutino, 1979; Wagner & Torgeson, 1987). In keeping with the idea that dyslexia represents the lower extreme of normally distributed reading abilities, phonological processing skills have also been emphasised in models of both normal reading development (e.g., Ehri, 1987) and skilled adult reading (e.g., Coltheart, 1978). Chapter 3 reviews the evidence for the phonological processing deficit hypothesis.

However, since 1980, considerable convergent evidence has been amassing for a specific visual processing deficit in both children and adults with dyslexia, although the hypothesis is no longer of visual memory deficits. Reading involves processing of both high spatial frequency visual information (fine detail; e.g., actual letters in any one fixation) and low spatial frequency visual information (coarse detail; e.g., general word shape in the periphery of vision). Much of the recent research has been conducted within the theoretical context of two parallel spatial frequency channels or pathways in the visual system – the magnocellular (M) pathway and the parvocellular (P) pathway (Breitmeyer, 1980; Livingstone & Hubel, 1987). The P pathway is most sensitive to high spatial frequency information, and the M pathway to low spatial frequency information (Lovegrove, 1996). The M pathway is also involved in the processing of temporal or movement information, including rapid sequencing and detection of dynamic changes in time. Both children and adults with dyslexia show visual temporal processing deficits. The second causal hypothesis of dyslexia, the temporal processing deficit hypothesis, argues developmental dyslexia arises from deficits in M pathway function, in the presence of unimpaired P pathway function. There is evidence of similar temporal processing deficits in the auditory system (and in the somatosensory system; see Farmer & Klein 1995). Auditory temporal processing plays a role in the perception of speech sounds, which is important for the
development of phonological processing. In this way, some conceptualisations of the temporal processing deficit hypothesis subsume the phonological processing deficit hypothesis via this association with auditory temporal processing (e.g., see Frith’s, 1997, model). While auditory temporal processing abilities have been related to reading via their role in speech perception and phonological processing, visual temporal processing abilities have been related via their potential role in orthographic processing, or the ability to recognise letter sequences as whole words or word segments (Cornelissen et al., 1998; Talcott et al., 2000). Thus, while the hypothesis is of a generalised pan-sensory deficit in temporal processing, specific deficits in different sensory modalities may be related to deficits in different specific reading subskills. Chapter 4 reviews evidence for the temporal processing deficit hypothesis.

This chapter begins by reviewing some of the current issues regarding the definition and diagnosis of dyslexia, and the need to identify reliable early indicators of dyslexia; or, at least, of significant risk for reading problems. Phonological processing and visual and auditory temporal processing all constitute potentially useful early indicators of dyslexia. This chapter finishes with a review of the way in which auditory and visual temporal processing and phonological processing relate to theoretical models of reading development.

2.1 Issues in the definition and diagnosis of developmental dyslexia

There is a need to identify those individuals requiring special reading intervention and remediation; however, if dyslexia represents the extreme tail of a normal distribution, no clearly defined cut-off point for defining what constitutes dyslexia exists. The current definition of developmental dyslexia is an unexpected difficulty in reading, not explained by inadequate education, low intelligence, sensory impairment, or socio-economic deprivation (Critchley, 1970; DSM-IV, American
Psychiatric Association, 1994). This negative or exclusionary type of definition has been widely criticised (e.g., Lundberg, 1999; Lyon, 1995; Rutter, 1978). Dyslexia is a neurological disorder, and Denckla (1993) pointed out that neurological diagnosis requires not only exclusions of alternative causes (such as environmental or emotional factors) but also inclusions (such as cognitive deficits). There are no inclusion criteria in the current definition of dyslexia, and problems with the exclusionary criteria used. For example, children from a low socio-economic background or with low IQ would not be diagnosed with dyslexia, despite showing reading difficulties. The implication of this is that these children may be ineligible for the full extent of available remedial services.

In reality, unexpected difficulty in reading is defined as a discrepancy between reading ability and IQ (Rutter & Yule, 1975). The conventional criterion used is a minimum deficit of 1.5 to 2 years in reading age compared with mental age or, often, compared simply with chronological age or grade level. There are several problems with this discrepancy approach; for example, the severity or meaning of an absolute discrepancy changes with increasing age. At 8 to 9 years of age, only 3% of children showed a 2-year reading retardation, compared with 25% at 13 to 14 years of age (Applebee, 1971). Recent conceptual and empirical studies showed there is no valid basis for this IQ discrepancy approach to identifying dyslexia (Fletcher et al., 1998; Fletcher et al., 2002; Sternberg & Grigorenko, 2002). For example, Sternberg and Grigorenko pointed out a classification of reading disabled would apply to a child with near-genius level of IQ who is reading at an age-appropriate level, but not to a child with an IQ of 95 whose reading shows a 2-year lag. In any case, IQ and reading do not share a linear relationship across the range of abilities (Shapiro, 1998), nor does IQ predict response to remediation (Hatcher & Hulme, 1999; Stage, Abbott,
Jenkins, & Berninger, 2003). Stronger correlations exist between various measures of reading and more specific cognitive factors than between reading measures and IQ. For example, in a review of published studies, Scarborough (1998a) reported lower median correlations between later reading and IQ at school entry ($r = 0.37$ for Verbal IQ and $r = 0.26$ for Performance IQ) than between later reading and phonological awareness ($r = 0.42$) and letter naming ($r = 0.53$) at school entry. These stronger correlations support the use of specific cognitive impairments as inclusion criteria to define dyslexia.

Another problem with the current approach is that diagnosis generally occurs around Grade 3 or 7 to 8 years of age (the earliest point at which a 1.5- to 2-year deficit is observable), which has major ramifications for intervention. Strag (1972) noted that 82% of those identified with dyslexia in the first two grades of school achieve normal reading scores with remediation; compared with only 46% of those diagnosed at Grade 3; and only 10 to 15% of those diagnosed between Grade 5 and 7. The Committee on the Prevention of Reading Difficulties in Young Children recommended avoidance, at all costs, of deferring intervention until third or fourth grade (Snow, Burns, & Griffin, 1998). Not only do the discrepancy criteria delay implementation of treatment, they provide no inherent strategies for that treatment (Sternberg & Grigorenko, 2002). For this reason, some have argued that assessment of domain specific inclusion factors is essential to diagnosing dyslexia and informing treatment (e.g., Share, McGee, & Silva, 1991; Torgeson & Wagner, 1998).

Research has already identified some potential inclusion factors associated with increased risk of dyslexia. In 1994, the International Dyslexia Society (IDS) redefined dyslexia as a specific language based disturbance of constitutional origin, with characteristic difficulties in decoding single words, usually reflecting
phonological processing deficits, that were unexpected based on age and cognitive ability, and were not due to generalised developmental disability or to sensory impairment (Lyon, 1995). This clearly characterised phonological processing deficits as the primary defining characteristic. S. E. Shaywitz (1998) described the following phonologically based tests as useful for identifying children at risk for dyslexia at school entry: letter identification, letter-sound association, phonological awareness, verbal memory, rapid naming, and expressive vocabulary. This perspective constitutes what Laasonen et al. (2001) called a centralist theory of dyslexia – the one central cause is hypothesised to be linguistic, specifically, a core phonological processing deficit (Stanovich, 1986).

However, dyslexia is increasingly regarded as a multifactor trait. Multiple gene systems, called quantitative trait loci, interact with environmental factors to produce a continuous range of risk for dyslexia or continuous phenotypic variation (Olson & Gayán, 2001; Snowling et al., 2003; Vellutino, Fletcher, Snowling, & Scanlon, 2004). When the risk arising from the interaction of genetic and environmental factors exceeds a threshold, the classical dyslexic phenotype occurs. There is ample evidence that dyslexia involves a more complex constellation of deficits and anomalies than simply phonological processing deficits; these are summarised in Table 2.1 (see also Miles, 1993; Reid, 1998; Spafford & Grosser, 1996).

The perceptual and multifactor hypotheses more adequately encompass this range of associated deficits (Laasonen et al., 2001). Perceptual impairments (such as visual and auditory temporal processing deficits) are either directly causally related to phonological and orthographic processing deficits (perceptual hypothesis), or are

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1 See Section 3.1.1 for comment on the place of letter identification in batteries of phonological processing measures.
related to other impairments (such as attentional deficits) that are directly causally related to the phonological and orthographic impairments (multifactor hypothesis).

Table 2.1

*Deficits and Anomalies Associated with Dyslexia*

<table>
<thead>
<tr>
<th>Deficit/Anomaly</th>
<th>Representative studies</th>
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<tbody>
<tr>
<td>Thalamic anomalies</td>
<td>Galaburda, Menard, &amp; Rosen, 1994;</td>
</tr>
<tr>
<td></td>
<td>Livingstone, Rosen, Drislane, &amp; Galaburda, 1991</td>
</tr>
<tr>
<td>Perisylvian anomalies</td>
<td>Galaburda, Sherman, Rosen, Aboitz, &amp; Geschwind, 1985</td>
</tr>
<tr>
<td>Cerebellar impairment</td>
<td>Nicolson &amp; Fawcett, 1999; Rae et al., 1998</td>
</tr>
<tr>
<td>Phonological Processing deficits</td>
<td>Bradley &amp; Bryant, 1983; Lundberg, Olofsson, &amp; Wall, 1980</td>
</tr>
<tr>
<td>Letter knowledge deficit</td>
<td>Badian, 1993</td>
</tr>
<tr>
<td>Impaired rapid naming speed</td>
<td>Denckla &amp; Rudel, 1976; Ramus, et al., 2003</td>
</tr>
<tr>
<td>Impaired verbal short-term memory</td>
<td>Grogan, 1995; Mann &amp; Liberman, 1974</td>
</tr>
<tr>
<td>Language deficits</td>
<td>Scarborough, 1990</td>
</tr>
<tr>
<td>Visual temporal processing deficits</td>
<td>Brannan &amp; Williams, 1988a; Cornelissen,</td>
</tr>
<tr>
<td></td>
<td>Richardson, Mason, Fowler, &amp; Stein, 1995; Eden, Stein, M. H. Wood, &amp; F. B. Wood, 1995</td>
</tr>
<tr>
<td>Auditory temporal processing deficits</td>
<td>Reed, 1989; Tallal, 1980; Witton et al., 1998</td>
</tr>
<tr>
<td>Binocular instability</td>
<td>Eden, Stein, &amp; F. B. Wood, 1993</td>
</tr>
<tr>
<td>Automaticity deficits</td>
<td>Nicolson &amp; Fawcett, 1993</td>
</tr>
<tr>
<td>Motor deficits</td>
<td>Nicolson &amp; Fawcett, 1994a</td>
</tr>
</tbody>
</table>
The phonological and orthographic impairments then result in the reading difficulties. Lyon (1995) pointed out that the IDS definition did not intend to preclude other possibilities, such as temporal processing deficits. Revision of the definition would occur should the role of other deficits emerge "from studies characterised by methodological rigour" (p. 13). The purpose of the current study was to determine whether a potentially causal role exists for early temporal processing ability in early reading development. In order to ensure methodological rigour, several factors (including environmental factors) were controlled.

It is also important to recognise dyslexia is a developmental disorder. As Snowling (2000) noted, this means the behavioural features of the disorder will change with development and via environmental interactions. Thus, any single definition may have difficulty adequately encompassing this changing manifestation. Snowling argued that a "primary aim of research on dyslexia is therefore to describe the pattern of difficulties observed in affected individuals and how these difficulties change with age" (pp. 26 – 27). Furthermore, she advocated research that focuses not only on the observable behavioural manifestations but also – and more importantly – on the underlying cognitive and biological bases, a multiple-levels approach, and how these, along with the behavioural manifestations, change with development. The current study is embedded within this developmental multiple-level paradigm.

2.1.1 *A Multiple-levels Approach*

Table 2.1 demonstrates deficits and anomalies exist at both the cognitive and biological levels associated with dyslexia. Various multiple-levels frameworks have been developed (Fletcher et al., 2002, Fletcher et al., 1995; Frith, 1985; 1997; Lundberg, 1999). These frameworks take into account the factors that Denckla (1993) emphasised as being necessary exclusions for a neurological disorder (such as
Fletcher et al. (1996) identified factors that were important to consider at each level of this model. Important aspects of the behavioural manifestation were recognition of real words; recognition of non-words; reading and listening comprehension; and spelling. They identified eight factors at the cognitive level: phonological awareness; rapid naming; verbal and non-verbal short-term memory; vocabulary; speech production; perceptual-motor function; and visual attention. They identified the psychosocial factors that potentially affect children's reading as motivation to learn; previous intervention experiences; presence of affective disorder; parental marital or family dysfunction; and the quality of the school. A developmental history and a family history of reading or spelling problems were important in revealing biological factors, such as brain damage and a potential
dyslexic genotype, which may also produce reading problems. Snowling et al. (2003) argued that cognitive factors (such as language skills and attention) and environmental factors (such as print exposure and teaching method for reading) interact with any genetic risk to either exacerbate or compensate for that risk.

As shown in Figure 2.1, environmental factors may directly affect or interact with any level in the model. Fletcher et al. (1996) identified the child’s family situation, past learning history, and school and community resources as relevant environmental factors to consider. The early home literacy environment and early teaching practices are important factors in early reading development. Vellutino et al. (2004) argued that the majority of early reading difficulties reflect environmental limitations, rather than underlying biological and cognitive deficits. Vellutino et al. (1996) found 9.0% of children met the typical IQ discrepancy definition for dyslexia at the start of Grade 1. After one semester (minimum 15 weeks) of intervention (30 minutes daily one-on-one) in mid-Grade 1, the word identification and non-word reading scores of the majority of those children had improved to average levels (reading scores above the 30th percentile). At the end of that semester, only 1.5% of children still met the discrepancy criterion. Part of the change in reading status may be due to the unreliability of the IQ discrepancy definition at this early age; it is difficult to establish a 1.5 to 2 year reading deficit in a child who has been reading for only one term. The group who improved to average levels did not differ significantly from the control group (who had average reading scores at the start of Grade 1) on initial measures of the early literacy environment, such as print awareness, concepts of print, and general knowledge. Thus, it is unclear how Vellutino et al. (2004) could argue that that the majority of early difficulties reflect environmental limitations, when those who improved readily did not appear to have poorer early literacy
environments. One possibility is that the degree of environmental enrichment in interaction with other cognitive and perceptual factors is important. Some children may require greater environmental stimulation to enhance less well-developed cognitive and perceptual skills, and for this group, intensive early intervention might be sufficient to improve reading to normal levels.

There is substantial evidence from other studies that early literacy environment affects early reading, but that only certain types of literacy experiences are relevant to early reading. The frequency of parental reading to the child might not affect reading (Scarborough, Dobrich, & Hager, 1991). Sénéchal, LeFevre, Thomas, and Daley (1998) found the frequency of storybook exposure did not predict a significant percentage of variance in kindergarten (n = 110) and first grade (n = 58) children's literacy skills. However, parental reports of frequency of teaching children to print and read words was a significant predictor of children's literacy skills (decoding, invented spelling, alphabet knowledge, and print concepts), accounting for 7% of the variance, after age, IQ, and parent reading experience were controlled. There was no significant relationship between the frequency of these parental teaching practices and the frequency of storybook exposure. Using Danish children, Elbro, Borsrøm, and Petersen (1998) obtained similar null results for frequency of parental reading to children at Preschool, although Olofsson and Niedersoe (1999) found the frequency of parental reading to the child had a weak, albeit significant, effect on reading.

Foy and Mann (2003) showed the frequency of parental teaching to read and print words was also significantly correlated with phoneme awareness (r = .37) in 4-to 6-year-old children, after the effects of age were removed. There was a direct relationship between this practice and children's letter knowledge and vocabulary. Burgess, Hecht, and Lonigan (2002) also found that active pre-school home
environment practices such as shared reading or teaching rhyme games were more strongly related to reading development outcomes than were passive practices such as the parent reading to the child. Meyer, Wardrop, Stahl, and Linn (1994) found similar effects regarding classroom literacy practices. There was a negative relationship between the length of time the Preschool teacher spent reading to children and development in reading abilities, whereas there was a positive relationship between the length of time spent in active practices such as teaching letter-sound connections and reading development.

2.1.1.1 Implications for the current study

In the context of this multiple-levels approach, the current study examined the ability of cognitive and perceptual factors (phonological and temporal processing) to predict variance in behavioural measures (single word identification, reading rate, non-word decoding, and orthographic processing). Various control measures, drawn from each level of the model, were included. Developmental history (parent report) was included in order to exclude children with potential brain damage. Parents also reported any family history of reading and spelling difficulties. Measures of attentional vigilance, early home environment, school, and verbal short-term memory were obtained in order to partial out their effects. This allowed the unique effects of temporal and phonological processing on reading ability to be determined.

2.1.2 Is Dyslexia a Homogeneous Disorder?

There may be different subtypes of dyslexia, with different defining characteristics, which adds to the difficulty in defining dyslexia. Identification of both the defining characteristics of distinct subtypes and the specific underlying deficits is important to designing more specific and, hence, effective diagnostic tools and remedial approaches. It is also important for research. Some of the non-
significant and contradictory results found in research (detailed in Chapters 3 and 4) may be a result of using a heterogeneous sample of dyslexic subtypes, not all of which exhibit a particular effect (Martin, 1995). This section provides a brief description of the subtypes and the empirical evidence supporting them.

Differences exist in the ways of classifying individuals into subtypes, and in the terminology used. Boder (1973) used the person’s overall reading and spelling of unknown regular words that adhered to the regular grapheme-phoneme conversion rules (GPC rules) versus known words. Coltheart and colleagues (Castles & Coltheart, 1993; Coltheart, Masterson, Byng, Pryor, and Riddoch (1983) used reading scores on regular words (that conformed to GPC rules); irregular words (that did not conform to GPC rules); and non-words (that conformed to GPC rules but were not real words).

In dysphonetic dyslexia (Boder, 1973) or developmental phonological dyslexia, (Coltheart et al; Temple & Marshall, 1983) problems occur in decoding or spelling unknown regular words or non-words. Known or sight words are recognised immediately as complete visual gestalts. Castles and Coltheart (1993) found 64% of their sample of 56 dyslexic children demonstrated a developmental phonological dyslexia pattern, comparable with 67% of Boder’s sample of 107 children with dyslexia (aged 8 to 16 years), who demonstrated dysphonetic dyslexia. In dyseidetic dyslexia (Boder) or developmental surface dyslexia (Coltheart et al.) the opposite difficulties occur – an impaired ability to perceive letters and words as whole configurations or gestalts, but no dysfunction in phonetic analysis skills. Boder hypothesised that reading and spelling relied on letter-by-letter phonetic analysis, and was therefore slow and laborious. Irregular words were not read correctly, but were read phonetically; for example, talk would be pronounced as talc. Spelling errors
were phonetic, or regularisation, errors; for example, *talk* would be written as *tork*.

By contrast, reading and spelling of regular words was adequate. Forty-six percent of Castle and Coltheart's sample showed developmental surface dyslexia, which was much greater than the 10% of Boder's sample with dyseidetic dyslexia. However, Castle and Coltheart's methodology has been criticised (Snowling, Bryant, & Hulme, 1996; Stanovich, Siegel, Gottardo, Chiappe, & Sidhu, 1997). Using a reading-age matched control group to compare reading performance, instead of the chronological age-matched control group that Castles and Coltheart used, resulted in very few of the dyslexics showing a surface subtype (Stanovich et al., 1997). In the mixed or dysphonetic-dyseidetic subtype, there are impairments in both visual and phonetic functions. Boder found 23% of her sample showed a mixed subtype (Castles and Coltheart did not include this).

Some argue phonological dyslexia represents a genuine, specific deficit in phonological processing, but that surface dyslexia simply represents a more general delay in word recognition, possibly due to mildly depressed phonological skills coupled with limited reading experiences (Manis, Seidenberg, Doi, McBride-Chang, & Peterson, 1996; Stanovich, Siegel, & Gottardo, 1997). Castles, Datta, Gayán, and Olson (1999) found a strong genetic influence on phonological dyslexia, whereas environment more strongly influenced surface dyslexia. Thus, the relative strengths of and interaction between environmental and cognitive factors might produce different characteristic reading difficulties.

The work on dyslexia subtypes involved children old enough to have normally developed skilled reading. Models of normal early reading development propose a series of stages in which visually based pre-reading strategies precede phonetic analysis strategies, before orthographic strategies are established, allowing automatic
reading by sight (Ehri, 1987; Frith, 1985). Before children reach the latter automatic stages of skilled sight-reading, there is a reliance on phonetic analysis and difficulty with unknown irregular words. Thus, beginner readers show characteristics that resemble developmental surface dyslexia. Through increasing phonological awareness, learning orthographic rules, and exposure to words via reading experiences, their sight word vocabulary increases. Again, the dual roles of cognitive skills (phonological and orthographic awareness) and environment (exposure to print, reading experience) combine to determine characteristic reading abilities or difficulties.

2.2 Models of Normal Reading Development

The first stage in reading development is a pre-reading stage (Ehri, 1987). Frith (1985) called this the logographic stage to reflect the fact that children can read logographs, for example, *McDonalds* is recognised by the golden arches (M), or *stop* is recognised in the context of the road sign. The orthography or spelling sequences of words remain largely unanalysed. Recognition is via the use of these partial visual and contextual cues. For this reason, Ehri called this stage visual cue reading.

Ehri (1987) proposed that as soon as children have some letter-sound knowledge, they begin to use that to access pronunciations and move into phonetic cue or partial alphabetic reading. The phonetic cues used range from syllables, which are the smallest independently articulated segments of speech (Wagner & Torgeson, 1987), to individual phonemes, which are the smallest meaningful units of speech sounds (Rack, 1994). Children only move into the third stage, which Ehri called phonemic mapping or full alphabetic reading, when they can segment speech at the phonemic level and utilise that in decoding words. Frith (1985) proposed that the need to spell words moves children into what she called the alphabetic stage, which
covered Ehri's phonetic cue and phonemic map reading stages, during which they begin to attempt to read words using GPC rules. Therefore, at this stage in reading development children would make regularisation errors with irregular words. Thus, in this way, their reading is like that of older children or adults with surface dyslexia.

Seymour (1999) proposed that the style of teaching reading affected the relative development of logographic foundations, involving the acquisition of a sight word vocabulary; and alphabetic foundations, involving knowledge of GPC rules. A whole language approach (children are taught to recognise words as visual wholes and via use of contextual cues) emphasised a logographic foundation. A phonics approach (explicit teaching of phonological decoding strategies) emphasised alphabetic foundations. Thus, this environmental factor affects reading characteristics, so it is important in both diagnosis of and research into children's reading to consider these aspects of the school or classroom environment.

The skills of the earlier stages then merge in the final stage – the orthographic (Frith, 1985) or the consolidated alphabetic (Ehri, 1987) stage – resulting in fluent, automatic reading. Sight word vocabularies grow and children remember an increasing number of larger orthographic units, such as –ing and –ight. Children utilise orthographic strategies (e.g., knowing that –ight has the same pronunciation across different words) in reading words. They also acquire and utilise higher-level orthographic rules (e.g., the magic e on the end of a word makes the vowel say its own name, as in game). Children read words as orthographic units, without phonological conversion, via recognition of larger spelling sequences. They can also read unknown or non- words by analogy to lexical entries for orthographically similar known words (Glushko, 1979; Marcel, 1980; O'Shaughnessy & Swanson, 2000; Treiman, Goswami, & Bruck, 1990).
Ellis and Large (1988) measured the skills of 40 children from 5 to 8 years of age, at 12-month intervals. They confirmed the nature of reading changed over the first three years of schooling in ways consistent with these models. Initially, reading relied on a combination of letter knowledge and short-term memory; thereafter, it relied on letter-sound knowledge, the correspondence between auditory and visual patterns, analysis of visual patterns, and syntactic skills. While letter recognition was an important early predictor of reading, it was no longer useful within a year or two of reading having commenced. Phonological awareness facilitated early letter recognition and reading acquisition, consistent with Ehri's (1987) proposal that phonological skills were important from the earliest point in reading.

Ehri (1997) argued that, in dyslexia, there is difficulty in advancing from the partial to the full alphabetic phase due to underlying phonological impairments. In terms of acquiring a sight word vocabulary necessary for automatic fluent reading, dyslexic readers would form only partial grapheme-phoneme links, often only utilising the more visually salient initial and final graphemes while overlooking medial graphemes. Rack et al. (1992) noted that different degrees of phonological deficit would become restrictive at different points in Ehri’s developmental sequence. If children could only segment at coarse levels (such as at the level of syllables) they could move into phonetic cue reading, but could not proceed into phonemic map reading as it requires finer segmentation ability (at the level of individual phonemes). However, Rack et al. argued that most dyslexics were able to acquire some word recognition skills beyond that predicted by their phonological skills. This shows that factors other than phonological processing are important to reading development, perhaps in compensating for any deficit in phonological processing skills. As discussed previously, greater environmental enrichment may interact with weaker
phonological skills to enhance reading development. Stronger perceptual or memory abilities may enhance reading by allowing a greater sight-word lexicon to be acquired.

In Frith's (1985) model, developmental phonological dyslexia results when development fails to proceed beyond the logographic stage. Reading remains largely tied to visual and contextual cues. Heavy reliance on a whole language or whole word teaching strategy could have a similar effect (Seymour, 1999). There would be little ability to read non-words or unfamiliar words because the alphabetic principle (use of GPC rules) was not developed. Reading may progress if the child was told what written words were, or developed other strategies. However, Snowling, Stackhouse, and Rack (1986) found that only two of seven phonological dyslexics were truly logographic; the others had progressed into the alphabetic stage, but with very poor phonological processing skills. However, almost half of their small sample also had speech impairments, so it is unclear at to whether their difficulties were a result of the speech deficit, the reading deficit, or a combination of both. In Frith's model, developmental surface dyslexia results when development fails to proceed from the alphabetic to the orthographic stage. These children would have reasonable reading skills (especially for regular words), but great difficulties in spelling (which relies more heavily on precise orthographic representations). Attempts to write irregular words would involve regularisation errors.

Another implication to arise from these models is that auditory and visual temporal processing deficits would also become restrictive at different points. If (as is hypothesised) auditory temporal processing underlies phonological processing, a deficit would arrest development at a similar stage as phonological processing deficits; that is, at a partial alphabetic or logographic point. Ehri (1987) would argue that without acquisition of the full alphabetic principle, children's ability to acquire
automatic sight-word reading would also be severely impaired. Deficits in visual temporal processing are likely to arrest development at a later point, because they have been associated with orthographic processing; therefore, movement into the final automatic stages would be limited. Research into early reading development requires a longitudinal design in order to evaluate changes occurring in reading, and at what point and in what way particular deficits in the underlying cognitive or perceptual level affect manifest reading ability at the behavioural level.

2.3 Summary and current research emphasis

Due to the inadequacies of the current definition and diagnostic criteria for dyslexia, an urgent need exists to identify underlying factors that can be measured at a pre-reading point, and that reliably predict subsequent reading ability. Longitudinal research can identify the relationships between cognitive and perceptual, biological, environmental, and psychosocial factors and specific aspects of reading, as well as how these relationships emerge or change with development. The current study extends existing research into underlying predictors of reading by examining – for the first time – the ability of pre-reading measures of temporal and phonological processing to predict subsequent reading ability, while controlling for cognitive, biological, and environmental factors. One of the broader outcomes of identifying specific deficits at the cognitive, perceptual, and biological levels will be the refinement of inclusion criteria for defining dyslexia. Secondly, by identifying pre-existing factors that are potentially causal, it will provide a basis on which to formulate remediation programs that target these specific causal deficits before reading instruction commences. Thirdly, it will provide a clearer operational definition of dyslexia (and dyslexia subtypes) for research purposes (Lyon, 1995).
CHAPTER 3: THE PHONOLOGICAL PROCESSING DEFICIT HYPOTHESIS OF DYSEXIA

The general expression of the centralist theory of dyslexia is the phonological processing deficit hypothesis. Phonological processing refers to “the use of phonological information (i.e., the sounds of one’s language) in processing written and oral language” (Wagner & Torgeson, 1987, p. 192). According to the phonological processing deficit hypothesis, dyslexia results from a deficit in the ability to use phonological information to process written language (or orthography) and oral language (Stanovich, 1988; Vellutino, 1979; Wagner & Torgeson). An inability to detect and process speech sounds critically limits necessary pre-reading skills (such as the ability to detect rhymes) as well as later reading skills (such as the ability to decode orthographic units into phonological units in order to decipher the written word; Wagner & Torgeson). Higher order linguistic processes (such as vocabulary and aspects of syntax) remain intact; however, the basic deficit in decoding words blocks access to higher order processes that allow comprehension (S. E. Shaywitz, 1998). Thus, poor comprehension often results from a more basic problem in single word decoding. For these reasons, single word decoding is the focus of much reading research, including the current study.

Phonological processing may be important in reading because an awareness of phonemes may be necessary to understand the alphabet, the letters of which are largely representations of phonemes (Wagner & Torgeson, 1987). Another possible reason is that words that share phonological similarity (e.g., those that rhyme) usually share spelling sequences. *Light* and *night* rhyme because of the shared ending -*ight*. Thus, phonological awareness and orthographic awareness are related (Bradley, 1988; Goswami & Bryant, 1992). Even beginning readers understand the connection
between rhyme and shared spelling and use it to help spell or read new words (Goswami, 1986, 1988). Explicitly teaching this connection produced better reading progress (Bradley, 1988).

### 3.1 Measures of Phonological Processing

There are many different phonological processing measures. Table 3.1 gives examples of some common phonological awareness tasks. Apart from the phonological processing component, these tasks vary on a range of cognitive factors, including short-term memory demands, stimulus comparison, and processing of task instructions. Despite this, Stanovich, Cunningham, and Cramer (1984) found 10 phonological awareness tasks all loaded on a single factor. These tasks included a range of task types, locations in the word of the target phonological unit, and task instructions. The seven non-rhyming tasks loaded strongly on this factor. Performances on these non-rhyming tasks at kindergarten (mean age 6;2 years) showed significant moderate to strong correlations with Grade 1 reading performance. Rhyme Choice had a moderate loading and the two other rhyme tasks had very weak loadings on this factor, due to ceiling effects within the data. Performances on the phonological tasks differed significantly between skilled and less skilled reader groups (formed by a median split of Grade 1 reading scores). Stanovich et al. concluded these different phonological tasks tapped a single construct and that the different extraneous cognitive processes associated with them were not responsible for their predictive power with reading.

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2 Throughout this paper, notation of the form 6;2 is used to indicate years; months of age (i.e., 6 years and 2 months). Occasionally, the notation of 6.5 years is also used to refer to 6 and one half years.
Table 3.1

*Examples of Phonological Awareness Tasks*

<table>
<thead>
<tr>
<th>Task</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phoneme Detection</strong></td>
<td></td>
</tr>
<tr>
<td>1) Rhyme detection task</td>
<td>Which of the following words sounds like <em>cat</em>?</td>
</tr>
<tr>
<td></td>
<td><em>CAN, CAR, MAT, POT</em></td>
</tr>
<tr>
<td>2) Alliteration task</td>
<td>Which of the following words starts with the same sound as <em>cat</em>?</td>
</tr>
<tr>
<td></td>
<td><em>RAT, POT, CAN, MAT</em></td>
</tr>
<tr>
<td><strong>Phonological Segmentation</strong></td>
<td></td>
</tr>
<tr>
<td>1) Phoneme deletion tasks</td>
<td>Say <em>cart</em> without saying the <em>/c/</em> sound</td>
</tr>
<tr>
<td>2) Non-word decoding</td>
<td>Pronounce <em>gop</em></td>
</tr>
<tr>
<td><strong>Phoneme Blending</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tell me what this word is: */c/………/a/………/t/</td>
</tr>
<tr>
<td><strong>Phonological Re-arrangement</strong></td>
<td></td>
</tr>
<tr>
<td>1) Phoneme Reversal Task</td>
<td>Say <em>cat</em>. Now say it again, but this time, put the <em>/c/</em> sound last and the <em>/t/</em> sound first</td>
</tr>
<tr>
<td>2) Spoonerism Task</td>
<td>Reverse the initial phonemes from the following two words to produce two new words: <em>Chuck Berry</em></td>
</tr>
</tbody>
</table>

Others have confirmed rhyming and non-rhyming tasks load on separate factors. Hatcher and Hulme (1999; Hatcher, Hulme, & Ellis, 1994) found phoneme blending, phoneme segmentation, and phoneme deletion (see Table 3.1) measured in 7-year-
olds loaded on a Phoneme Manipulation factor, which was a significant predictor of reading scores at the end of an intervention. A separate Rhyme factor was not a significant predictor of reading after the intervention. A third factor, Phonological Memory, was loaded on by alliteration (Table 3.1), digit span, and non-word repetition. Muter, Hulme, Snowling, and Taylor (1997) obtained two similar factors, which they called Phonological Segmentation and Rhyming, with a small sample of beginner readers. Consistent with Hatcher and Hulme’s findings, they also found that only the Phonological Segmentation factor significantly predicted Grade 1 reading and spelling. The dissociation between segmentation and rhyming abilities held through to 9 years of age (Muter & Snowling, 1998). Wagner, Torgeson, Laughon, Simmons, and Rashotte (1993) found two factors. Blending tasks loaded on a phonological synthesis factor. Phonological segmentation and rime/onset awareness tasks loaded on a phonological analysis factor. In a large study (\(N = 315\) children from Kindergarten to second grade), Schatschneider, Francis, Foorman, Fletcher, and Mehta (1999) confirmed this two-factor model provided the best fit. However, they pointed out the correlations between factors was large enough (around .87) to consider them representative of a unitary construct of phonological awareness.

In a comprehensive review of phonological processing studies, Wagner & Torgeson (1987) noted there were three relatively isolated bodies of research on phonological processing. The vast majority of studies used tasks that assessed phonological awareness. Phonological awareness included awareness of phonological strings, syllables, phonemes, and phonetic features (Morais, 1991). The second body of research measured what they called phonological recoding skills for lexical access. This included lexical decision tasks (e.g., deciding whether a letter string was a real word or not) and rapid automatised naming tasks (e.g., naming letters, digits, colours,
or objects as fast as possible). The third body concerned phonological recoding in order to maintain information in working memory. This included auditory-verbal short-term memory tasks. They argued that even though studies like Stanovich et al.’s (1984) found that various measures loaded on a single latent variable, very few studies had incorporated tasks from all three areas. In a reanalysis of data from longitudinal predictive studies carried out by Mann (1984; Mann & I. Y. Liberman, 1984), which used all three types of measures, Wagner & Torgeson concluded phonological skill was general to some degree across all three task types, but that each type made an independent contribution to reading development. Using all three types of measures together accounted for approximately 75% of the variance in early reading ability. Snowling (2000) argued the common basis to these various aspects of phonological processing lay in the specificity of the underlying phonological representations. However, there is no conclusive support for this hypothesis (Foy & Mann, 2001; Wessling & Reitsma, 2001).

3.1.1 Letter Naming

Letter naming is often included with batteries of phonological processing measures, but is not itself a measure of phonological processing. However, there is a relationship between letter naming and phonological processing, which is at least partially due to letter-sound knowledge. Adams (1995) argued that the names of letters contain information about the sound of that letter, so provide a link to phonological information. However, Muter et al. (1997) argued that the relationship is reciprocal, such that underlying phonological skills are essential for initial learning of letter names and sounds, but that once learned, this letter knowledge is critical for further development in reading.
Pre-school letter naming was the most important predictor of Grade 1 phonemic awareness, accounting for 10.70% of the variance after the effects of age and verbal IQ were controlled (Badian, 1995). It also significantly predicted various Grade 1 literacy skills, including word reading, reading comprehension, and spelling (Badian, 1995; Gallagher, Frith, & Snowling, 2000; Muter et al., 1997), and Grade 2 reading group status (disabled versus normal; Catts, Fey, Zhang, & Tomblin, 2001). Muter and Snowling (1998) found a significant bivariate correlation between letter naming at 4 years and prose reading at 9 years; however, once the effects of IQ were partialled out, this became non-significant. In a review of 24 studies conducted between 1976 and 1996, Scarborough (1998a) found a median correlation of 0.53 between letter naming around school entry and subsequent reading ability. The median correlation between school-entry letter sound knowledge and subsequent reading was very similar, \( r = 0.56 \). By comparison, across the same studies, the median correlation between phonological processing at school-entry and subsequent reading was 0.42. Letter knowledge and phonological awareness made independent contributions to early reading (Bradley & Bryant, 1991; Share, Jorm, MacLean, & Matthews, 1984). In support of this, Bradley and Bryant (1983) found training that linked phonemic segmentation of words to letters of the alphabet enhanced reading development.

Adams (1995) outlined several possible reasons why letter name knowledge is consistently a strong predictor of reading ability. It is not only the accuracy but also the speed of naming letters that strongly predicts reading acquisition (Badian, 1993). Adams argued that greater fluency in letter identification frees conscious resources for processing and comprehending the word or manipulating the phonological segments within that word.
However, the predictive ability of letter naming may not be specific to reading development. Muter and Snowling (1998) found letter naming at 4 and 5 years of age was also a significant predictor of arithmetic skill at 9 years of age. One possible explanation of this is that early letter naming is highly correlated with early digit naming, and digit naming and subsequent arithmetic skill are causally related. It is also possible they are related because arithmetic, letter naming, and reading all involve symbol use. Scanlon and Vellutino (1996) also found high error rates (both false negatives and false positives) in the use of letter identification at kindergarten to predict those who were at risk of reading difficulties. This could reflect a non-specific relationship, but it could also indicate other factors are also important to accurate prediction of this risk. Early letter name knowledge probably also reflects environmental factors, like the time spent by parents in teaching this to children. Once exposed to letter names at school, other children might very rapidly acquire this knowledge, making up for a less enriched early environment. In those children whose poor letter naming reflects underlying cognitive, perceptual, and/or biological deficits, gains may not be made so readily with formal instruction, and the predicted risk for reading difficulties might be more enduring. However, within the context of a battery of early predictors, letter naming accounts for additional independent variance in early reading to phonological processing, and so makes a useful additional measure in the early prediction of reading abilities.

3.2 Normal Development in Phonological Processing

Phonological processing shows a characteristic developmental progression between about 3 and 6 years of age. From 3 years of age, children are able to isolate and detect relatively large phonological units (such as syllables) and can recognise rhymes (MacLean, Bryant, & Bradley, 1987). Syllables correspond to identifiable
articulatory bursts, so they are the smallest independently articulated segments of speech (Wagner & Torgeson, 1987). Therefore, syllables are the easiest and earliest phonological units for which children develop conscious awareness. Rhyming words involve units that are usually between syllables and phonemes in size, often sharing the same rime (Treiman, 1985). The onset in a word is the initial consonant/s, and the rime is the vowel and any remaining consonants. Awareness of onset and rime allows children to detect both alliteration (shared onset) and rhyme (shared rime). By 5 years of age, children can group words on the bases of shared onset or rime (Bowey, 1994; Treiman & Zukowski, 1991). For example, treat and trick share the onset tr-. Sack and black share the rime -ack.

Phoneme awareness refers to the awareness of words as sequences of discrete phonemes. Phonemes are single meaningful units of speech sound (Rack, 1994). For example, cat is composed of /c/ /a/ /t/ in sequence. Phoneme awareness tasks include counting phonemes, deleting phonemes, and segmenting words into phonemes (see Table 3.1). Phonemes are more difficult to separate from the acoustic stream of speech because unlike syllables, they have no distinct boundaries. Thus, phoneme awareness generally develops only when children start school and begin reading instruction, at around 5 to 6 years of age (Ball, 1993; I. Y. Liberman, Shankweiler, Fischer, Carter, 1974; I. Y. Liberman, Shankweiler, A. M. Liberman, Fowler, & Fischer, 1977, Treiman, 1985; Treiman & Zukowski, 1991). Learning to read and link graphemes to phonemes appears to assist with this development (Ehri, 1987; although see Lundberg, 1991, for contrary evidence).

I. Y. Liberman et al. (1974) found that 46% of 5-year-olds (Preschool); 48% of 6-year-olds (Kindergarten); and 90% of 7-year-olds (Grade 1) could segment words into syllables. However, no 5 year olds, 17% of 6-year-olds, and 70% of 7-year-olds
could segment into phonemes. Using Liberman et al.’s criteria, Treiman and 
Zukowski (1991) extended the findings to include shared onsets and rimes. For the 
onset-rime task, 56% of 4-year-olds, 74% of 5-year-olds, and 100% of 6-year-olds 
reached criterion. Goswami (1997) reported similar results cross-culturally. Bowey 
(1994) found letter knowledge contributed to onset and phoneme awareness among 
non-readers. A higher percentage of non-readers with high letter knowledge exhibited 
awareness of onset, initial phoneme, and final phoneme than non-readers with low 
letter knowledge.

Carroll, Snowling, Hulme, and Stevenson (2003) disagreed slightly with this 
developmental progression, finding no differences in the abilities of 3- and 4-year-
olds to detect syllables or rimes. They suggested development moves from awareness 
of large phonological units of syllables and rimes to awareness of the smaller 
phonological units of phonemes. Furthermore, large unit awareness at around 4 years 
strongly predicted phoneme awareness at around 5 years. They also found a weaker, 
but significant, path from articulation accuracy at around 4 years to phoneme 
awareness at around 5 years. They speculated a relationship might exist between the 
process of refining the earlier global phonological representations into the 
segmentally organised representations necessary for phonemic awareness, and the 
accuracy of articulation.

According to Fowler (1991), developmental changes in underlying phonological 
representations of words drive the changes seen in phonological processing. 
Gallagher et al. (2000) argued that poorly specified phonological representations at 
the start of literacy development in children with dyslexia resulted in impaired reading 
development. Elbro et al. (1998) found the distinctness of phonological 
representations in the mental lexicon in Danish pre-readers (6-year olds) significantly
predicted poor versus good phoneme-awareness group membership in Grade 2. They concluded the quality of phonological representations was an important determinant of both phoneme awareness and the phonological recoding skills used in reading. Lack of distinctness in phonological representations could be due to auditory temporal processing deficits. This would interfere with early speech perception from which phonological representations are constructed.

3.3 Phonological Processing Ability and Reading

There are consistent, strong bivariate relationships between phonological awareness and children’s reading ability (Adams, 1995; Bowey, 1994, 1995; Bradley & Bryant, 1983, 1985; Goswami, 1990; Share et al., 1984; Stanovich et al., 1984). The better the child’s ability to detect syllables, (Mann & I. Y. Liberman, 1984), rhymes (Bowey, 1994; 1995; Bradley & Bryant, 1983; Lundberg et al., 1980), or phonemes (Lundberg, et al., 1980; Stanovich, et al., 1984; Tunmer & Nesdale, 1985), the quicker and more successful reading development will be. However, Tunmer and Nesdale found the relationship between phonological awareness and word decoding was non-linear, such that phonological awareness is a necessary (but not sufficient) condition for the acquisition of word decoding skills. The relationship between phonological awareness and reading is also reciprocal, with reading development contributing to further development of phonological skills (see Vandervelden & Siegel, 1996; Wagner & Torgeson, 1987, for reviews). However, Wagner, Torgeson, and Rashotte (1994) showed there was a stronger predictive relationship between early phonological skill and subsequent reading than between reading and later growth in phonological processing. They concluded there was a stronger causal relationship from phonological processing to reading than vice versa.
3.3.1 Studies of Phonological Awareness

Most existing research has focused on phonological awareness. Phonological awareness requires conscious awareness of and ability to manipulate the phonological structure of language (Snowling, 2000). Several longitudinal studies found relationships between pre-school phonological awareness and later reading ability in unselected samples of children (Bowey, 1994; 1995; Bradley & Bryant, 1983; Bryant, MacLean, Bradley, & Crossland, 1990; Ellis & Large, 1987; Lundberg et al., 1980; Stanovich et al., 1984). Cross-sectional studies with older English speaking (Betourne & Friel-Patti, 2003) and French-speaking children (Plaza & Cohen, 2003) showed a similar relationship between phonological awareness and reading to those found in the longitudinal studies. For example, in seventeen 10-year-old English-speaking children, phonological awareness measures accounted for 34% of the variance in non-word reading and 12% of the variance in word identification (Betourne & Friel-Patti). Some phonological awareness deficits persisted into adolescence and adulthood in those with dyslexia or poor reading skills. Remediated and well-compensated adolescents and adults (who had a childhood diagnosis of dyslexia, but current reading scores in the normal range) showed quite marked phonological processing deficits. These included poorer fluency in decoding unfamiliar words; slower and less accurate performance on spoonerism and phoneme deletion tasks; and spelling difficulties (Fawcett & Nicolson, 1994b, 1995; Gallagher, Laxon, Armstrong, & Frith, 1996; Miles, 1993; S. E. Shaywitz et al., 1999; S. E. Shaywitz et al., 2003; Wilson & Lesaux, 2001; Yap & van der Leig, 1994). The greatest difference between university students with dyslexia and those with average reading ability was in the time taken to perform a spoonerism task, in which one must
reverse the initial phonemes of two words; for example, *Chuck Berry* becomes *Buck Cherry* (Gallagher et al., 1996; Paulesu et al., 1996; Wilson & Lesaux, 2001).

In their classic longitudinal study, Bradley and Bryant (1983) found the rhyme and alliteration detection abilities of 4- and 5-year-old children (*N* = 368) accounted for a significant amount of variance (47.98% for 4-year-olds and 29.88% for 5-year-olds) in single word reading scores measured three years later. When IQ, verbal ability, age, and memory were controlled, these skills still uniquely accounted for significant (albeit reduced) percentages of variance in later word reading (10% for 4-year-old predictors and 4% for 5-year-old predictors). Other longitudinal studies found rhyme detection at 4 to 5 years was the most important predictor of single word reading ability or discriminator of good versus poor reading-ability groups, two to three years later (Bryant et al., 1990; Ellis & Large, 1987). Bryant et al. found rhyme and alliteration detection contributed both directly and indirectly (via phoneme detection) to word reading. However, they did not control for the autoregressive effects of pre-existing reading ability and phonological skills. Failure to control for this autoregressive effect is a common criticism of many of the longitudinal studies that demonstrated purported causal links between early phonological skills and later reading (Rack, Hulme, & Snowling, 1993).

Many other studies found only modest or non-significant relationships between rime awareness and reading (Lundberg, Frost, & Peterson, 1988; Lundberg et al., 1980; Muter et al., 1997; Nation & Hulme, 1997). Using a longitudinal design, Muter and colleagues (Muter et al., 1997; Muter & Snowling, 1998) failed to find a predictive link between pre-school rime awareness (at 4 and 5 years of age) and subsequent reading ability at 6 years. However, their sample size was quite small (*n* = 38). Other studies found rhyme detection reached ceiling after 6 years, and was no
longer correlated with or predictive of reading (Nation & Hulme, 1997; Stanovich et al., 1984). In a longitudinal study, Locke et al. (1997) found a significantly lower percentage of at-risk children (with at least one parent with dyslexia) reaching an 81% correct criterion on rhyme detection between 3;6 and 4;6 years than non-risk children (no familial history of dyslexia). However, after 4;6 years, the differences were no longer significant, with 100% of the control group and 81.3% of the risk group at criterion. This may indicate slower acquisition of this skill in at-risk children, who do eventually develop rhyme awareness. Perhaps the rate at which these skills develop, or the age to reach a criterion, may also be useful predictors of later reading ability or of risk for dyslexia.

In a review of the relationship between rhyme detection and reading, Morais (1991) concluded rhyming ability was not critical to reading acquisition, and that rhyming ability did not promote phonemic awareness. What was critical was the ability to segment at the level of the phoneme, and this required instruction in the written code. However, Bowey (2002) argued that while rime sensitivity does predict subsequent word reading, phoneme sensitivity might be a better predictor; although age, exposure to reading instruction, and the task used are important factors to consider. Phoneme sensitivity in younger children is too undeveloped to predict significant variance in later reading, so rime awareness may be a better predictor. After school entry, phonemic sensitivity may be the better predictor because of ceiling effects in rime awareness.

When the autoregressive effects of pre-existing reading were controlled, Lundberg et al. (1980) showed performance on kindergarten phonological measures that required analysis of phonemes was more strongly predictive of Grade 1 reading achievement than those that required analysis of syllables, like rhyme tasks. Their
Scandinavian sample ($N=143$) was much older at kindergarten (7 years of age) than were the pre-school aged children in many of the studies reviewed here already. Using a similar autoregressive approach with 70 Latvian children, Sprugevica and Høien (2003) showed kindergarten phoneme segmentation and deletion ability uniquely accounted for 4.90% of the variance in word reading at mid-Grade 1, which was significant. However, by the end of Grade 1, these kindergarten measures did not account for a significant percentage of variance. With English-speaking children, Muter et al. (1997) found by Grade 2 neither Preschool segmentation nor rhyming abilities predicted reading, although both made significant contributions to the prediction of Grade 2 spelling ability.

Other studies used a between-groups design to examine the difference in phonological awareness between a group of average or good readers and a group with dyslexia or with poor reading. The poor reader/dyslexic groups performed more poorly on phonological awareness tasks than did the normal or good reader groups (Bradley & Bryant, 1983, 1985; MacLean, et al., 1987; Mann, 1984; Rosner & Simon, 1971; Share et al., 1984; Snowling et al., 1986; Stanovich, 1982, 1988; Wagner & Torgeson, 1987). Poor or dyslexic readers were slower in producing rhyming words (Snowling et al.), and less accurate on phoneme segmentation and on rhyme and alliteration detection tasks (Bradley & Bryant, 1983, 1985; MacLean et al; Mann; Share, et al.; Snowling et al.).

3.3.1.1 Phonological Awareness Intervention Studies

Strong support for a causal role for a specific phonological deficit in dyslexia comes from intervention studies with children (Wagner & Torgeson, 1987). Teaching phoneme awareness to pre-readers improved subsequent reading acquisition (Bradley & Bryant, 1983; Byrne & Fielding-Barnsley, 1991, 1993, 1995; Lundberg et al.,
However, the gains of these interventions were mainly in non-word reading skills, not in general word identification (Byrne & Fielding-Barnsley, 1993; Olson, Wise, Johnson, & Ring, 1997). The significant effects on non-word decoding continued up to 6 years after the intervention (Byrne, Fielding-Barnsley, & Ashley, 2000).

Byrne et al. (2000) found both the actual level of phoneme awareness achieved in the intervention program and the rate of acquisition accounted for independent components of variance in a variety of reading skills (non-word reading, word identification, comprehension, and spelling) 6 years later. Children who met the criteria for dyslexia in Grade 5 had taken longer to acquire phonemic awareness during the Preschool intervention, despite eventually acquiring a secure level of awareness. By the first year of school, they were already scoring lower on reading tests than the children who showed a faster rate of acquisition during the intervention, and who did not meet the criteria for dyslexia at Grade 5.

However, prevention of later reading problems required more than just phoneme awareness training, because reading also involves orthographic processing (Byrne et al., 2000). The success of pure phonological intervention programs has been limited. In several training studies, a combination of phonological awareness and visual orthographic training (e.g., alphabet training or text reading) produced significantly better reading and spelling outcomes than either phonological awareness training alone or no training (Bradley, 1988; Bradley & Bryant, 1983; Hatcher et al., 1994). Thus, visual orthographic skill is also essential for successful reading development.

An issue for these intervention studies is that a consistent proportion of children show very little growth in explicit phonological awareness after intervention (e.g., Hecht & Close, 2002; Lundberg et al., 1988; Torgeson & Davis, 1997). Hecht and
Close found those who did best were those who entered the intervention with better phonological awareness. Torgeson and Davis found the children who were weakest in phonological awareness, rapid naming, and verbal ability showed the least growth in phonological segmenting and blending skills over a 12-week intervention. Compton (2000) found rapid naming speed was the only factor that uniquely predicted growth in both word and non-word reading skills in his intervention group. Stage et al. (2003) found children with triple deficits in rapid naming speed, phonological processing, and orthographic processing showed the slowest growth in word and non-word reading after intervention in first grade. These deficits, of course, are exactly those that characterise children with dyslexia. Thus, the very children who most need the intervention are those who are likely to improve the least. Results of interventions may also be weaker when delivered by Preschool classroom teachers than by highly trained specialists (Byrne & Fielding-Barnsley, 1993), although small significant differences that extended to Grade 2 resulted from teacher-conducted intervention (Borstrøm & Elbro, 1997).

3.3.1.2 Conclusions from Phonological Awareness Studies

There is considerable evidence that phonological awareness at the pre-reader or beginner reader phase significantly predicts subsequent reading, and in older children significantly differentiates those with and without dyslexia. Overall, the ability of phonological awareness measures to predict reading ability is modest. In 27 studies conducted between 1976 and 1996, Scarborough (1998a) found a median correlation of 0.42, which represented less variance in reading than that accounted for by letter naming. He concluded phonological awareness at pre-school was a better predictor of superior reading than of reading problems. At this age, floor effects on these
phonological processing tasks possibly masked any relationship in the poor readers. Thus, a normative design may be better for investigating the relationship between reading and phonological awareness than the often-used dyslexic versus control between-groups design.

Scarborough (1998a) also concluded the modest ability of school-entry phonological awareness measures to predict subsequent reading was because, at school entry, the majority of children did not yet have fully developed phonological awareness, particularly not phoneme awareness. This is more critical to reading skills than earlier developing aspects, like detection of syllables or onset-rime. Therefore, it might be better to use phonemic awareness in early Grade 1 to predict reading difficulties, rather than using pre-school rhyme awareness. Bowey (2002) pointed out that age, amount of reading instruction, and tasks used affect the relationship between phonological awareness and subsequent reading ability. Different measures of phonological processing are better predictors of reading at different points in development. This is very important to consider in designing early predictive studies or in interpreting their results.

However, there is not always a clear-cut relationship between phonological awareness and reading problems. Bradley and Bryant (1985) found that around 15% of the control group from their 1983 study, who were good at phonological processing, became poor readers. By contrast, only around 25% of the children who were weakest at phonological processing ended up as poor readers. Snowling et al. (2003) measured the reading skills in 56 children, who were considered at-risk for dyslexia (at least one parent being dyslexic) from 3;9 years to 8;0 years. At 8;0 years, 66% of the at-risk group had composite reading scores (letter knowledge, phonological awareness, comprehension, and spelling) that were one standard
deviation or more below the mean of the not-at-risk control group. The remaining 34% had scores within one standard deviation of the control group, so were considered unimpaired. However, this unimpaired at-risk sub-group scored significantly lower than the control group on non-word reading, but not significantly differently to the impaired at-risk group. Snowling et al. concluded the unimpaired at-risk group had compensated for poor underlying phonological skills, possibly utilising other language skills, such as vocabulary or short-term verbal memory. These other language skills were better in this group than in the impaired at-risk group, although still significantly poorer than in the control group.

Thus, there are consistent findings that not all children with poor phonological skills end up as poor readers and that some with good phonological skills read less well than would be predicted by their phonological processing abilities. This supports a multifactorial model, in which a specific dyslexic profile occurs only when the interaction of genetic and environmental risk factors exceed a certain threshold. Before formal education, children may differ in phonological awareness due to differences in the frequency with which parents expose them to activities that teach them about the phonological structure of language, such as reciting nursery rhymes. Once at school, or in a formal intervention program, children whose poorer phonological skills are due to environmental factors (rather than to cognitive, perceptual, or biological factors) will soon catch up. Those children who have biologically based deficits are likely to continue to experience problems in both phonological processing and subsequent reading. This group may also constitute the majority of the treatment-resistant children.
3.3.2 Studies of Rapid Automatised Naming

Wagner and Torgeson (1987) identified a second body of research into phonological recoding for lexical access, which involved the ability to access the lexical referent (representation in the mental lexicon or word store) of a written word or object by recoding the written symbols into a phonological representation. Geschwind (1965) originally proposed that the cognitive components involved in colour naming would make a good early predictor of reading performance, as both tasks involved applying a verbal label (a spoken colour name or word) to an abstract visual stimuli (the colour patch or written word). Building on this idea, Denckla and Rudel (1976) developed a rapid automatised naming (RAN) task and found naming speed, rather than accuracy, differentiated children with dyslexia from control children and from children with general learning disability. Characteristic RAN deficits occurred in those with dyslexia across many languages (see Wolf & Bowers, 1999; Wolf, Bowers, & Biddle, 2000). Tasks involved naming speed for colours, objects, letters, and digits. Naming speed was slowest for objects.

Object naming speed at preschool age significantly predicted Grade 1 reading ability ($r = −.35$; Wolf, 1984). Wolf, Bally, and Morris (1986) found speed on all of the rapid naming tasks at preschool significantly differentiated between dyslexia and good reading in 8-year-olds. In his meta-analysis of 14 longitudinal studies published from 1987 to 1996, Scarborough (1998a) reported a median correlation between rapid automatised naming tasks measured before school entry and subsequent reading achievement of 0.40. With older samples, results were more variable. Rapid naming speed for objects differed significantly between groups of children, adolescents, and adults with dyslexia and chronological age-matched control groups (Fawcett & Nicolson, 1994a; Kinsbourne, Rufo, Gamzu, Palmer, & Berliner, 1991). Griffiths and
Snowling (2001) also found significant differences on combined digit and object naming speed between their group with dyslexia (mean age 12;8 years) and a chronological age-matched control group, but no significant difference to a reading-age matched control group (mean age 9;0 years). Thus, the choice of control group may affect results. No significant difference in performance to that of younger children with equivalent reading abilities is consistent with a delay rather than a deficit.

Many studies of the relationship between rapid naming speed and reading ability did not control for the autoregressive effect of pre-existing reading ability. After controlling pre-existing reading ability, Torgeson, Wagner, Rashotte, Burgess, and Hecht (1997) found rapid letter and digit naming did not account for unique variance in word identification, non-word reading, reading speed and efficiency, passage comprehension, and orthographic accuracy in third to fifth grades. However, Badian (1993) found rapid letter and object naming speed were still strong differentiators of poor versus adequate readers aged 6 to 10 years.

Rapid automatised naming speed showed different relationships to different reading sub-skills. Badian (1993) found that rapid letter naming speed was the largest unique contributor to variance in word identification, whereas rapid object naming speed was the largest unique contributor to variance in reading comprehension. Wolf (1991) attributed the stronger relationship of object naming to comprehension to the shared component of semantic processing. In general, rapid naming speed was a more important predictor of word identification than of non-word decoding (Bowers, 1995; Torgeson et al., 1997). However, these tasks may only predict variance in word identification skills in poor readers, not in average readers (Cardosa-Martins & Pennington, 2004; Compton, 2003; Meyer, Wood, Hart, & Felton, 1998a;
Scarborough, 1998b). Torgeson et al. found the strongest bivariate correlations between letter and digit naming speed and reading rate from third to fifth grade ($r = .15$ to $.39$).

There were developmental changes in rapid automated naming speed, which could explain differences between studies with different age groups. From first through to eighth grades, there was a similar steady improvement in response time to all rapid naming tasks, with speed approaching asymptote around Grade 8 (Meyer, Wood, Hart, & Felton, 1998b). Griffiths and Snowling (2001) found a significant moderate correlation ($r = -.43$) between age and rapid naming speed in a sample of dyslexic and control readers aged 7;0 to 15;7 years. However, with age controlled, significant moderate correlations between naming speed for digits and objects and single word identification and non-word reading were still found. Schatschneider, Carlson, Francis, Foorman, and Fletcher (2002) demonstrated developmental changes in the relationships between naming speed and reading sub-skills. They found rapid naming speed accounted for similar amounts of variance in Grade 1 word identification, passage comprehension, and reading rate; but by Grade 2, naming speed was more highly predictive of reading rate than of other reading sub-skills. This indicates that at least part of the relationship between naming speed and reading is related to shared variance associated with processing speed, or more specifically, with speed of lexical access.

The relationship between reading sub-skills and naming speed also differed across ages, depending on the type of rapid naming task used. Some studies found a significant relationship between rapid naming of letters and/or digits, but not rapid object and/or colour naming, and reading in the early grades (Compton, 2003; Manis, Doi, & Badha, 2000). However, in the studies he reviewed, Scarborough (1998a)
found similar correlations between early reading and school-entry digit and letter naming and colour and object naming. Meyer et al. (1998b) also found speed on all Grade 1 naming tasks (letters, digits, objects, colours) was a strong predictor of reading through to Grade 8.

Debate continues over whether RAN tasks are simply measures of phonological processing. Snowling (2000) argued that degraded phonological representations in dyslexia slow down the speed of rapid naming. Thus, this is another aspect of the core phonological processing deficit. However, Wolf and colleagues (Wolf & Bowers, 1999; Wolf et al., 2000) argued that naming speed deficits constitute a separate deficit in reading disability, independent of the phonological deficit (although see Torgeson & Burgess, 1998; Vellutino et al., 2004, for alternative viewpoints). In support of this, Wagner et al. (1993) found the model of best fit for measures taken on normative samples of kindergarten and Grade 2 children was one with two underlying abilities; one of phonological awareness and phonological working memory, and one of rapid naming. After accounting for the variance due to syntactic awareness, phonological processing, and phonological short-term memory, Plaza and Cohen (2003) showed rapid naming speed (objects, letters, and digits) still accounted for a significant additional 8% unique variance in literacy skill (word and non-word reading, reading comprehension, and word and non-word spelling) in French-speaking first grade children. However, after accounting for IQ and phonological awareness in English-speaking children measured from second to fourth grade, Catts, Gillespie, Leonard, Kail, and Miller (2002) found rapid naming speed for objects did not account for significant additional variance in word reading.

Rapid naming speed and phonological processing were related to different specific reading sub-skills (Manis et al., 2000). Manis, Seidenberg, & Doi (1999)
found Grade 1 rapid letter- and digit- naming speed was a stronger predictor of Grade 2 orthographic processing (pseudohomophone choice, word-likeness judgement, and irregular word reading) than was Grade 1 sound deletion. Grade 1 sound deletion was a stronger predictor of Grade 2 non-word reading and passage comprehension. Grade 1 naming speed and sound deletion accounted for similar percentages of unique variance in Grade 2 word identification. These relationships held after partialling out the autoregressive effects of Grade 1 reading skills. Manis et al. argued that the stronger relationship between naming speed and orthographic skill arose because both relied on arbitrary associations between symbols and sounds. The stronger relationship between sound deletion and non-word reading arose because both relied on rule-governed phonological segmentation skills. Word identification involved both orthographic and phonological skills, explaining the similar relationships with both naming speed and sound deletion. Vellutino et al. (2004) argued that the separation between rapid naming speed and phonological awareness might arise from environmental factors. For example, teaching in the home or early primary school that emphasised letter recognition and general knowledge (names of objects and colours) over phonological awareness skills may result in better performance on rapid naming tasks and weaker performance on phonological tasks.

Children with double deficits in phonological processing and naming speed were more resistant to remediation and less likely to generalise training to other words than were those with a single deficit, even after accounting for their initially poorer reading ability (Bowers & Ishaik, 2003). However, Schatschneider et al. (2002) found those with double deficits had lower phonological processing scores than those with a single phonological processing deficit, due to the correlation between rapid naming speed and phonological processing. Thus, it was not clear whether the poorer
reading of those with a double deficit was due to the more severe phonological processing deficits, or to the addition of a naming speed deficit.

The model developed by Wolf, Bower, and colleagues (Wolf & Bowers, 1999; Wolf et al., 2000) incorporated attention, perceptual, conceptual, memory, lexical, and articulatory processes in rapid naming; a similar sequence of processes that also characterise reading. Initial activation of attention processes leads to activation of visual processing. The resulting visual percept of the stimulus is compared with stored mental representations in the lexicon. Phonological processing is important in turning the stored visual representation into a phonological representation for naming. Motor commands then translate the phonological representation into an articulated response. With rapid serial naming tasks, there is the added complexity of demands of rapidity and serial processing (Wolf et al., 2000).

Visual and auditory temporal processing and phonological processing deficits are likely to interfere at different points in this model. The low spatial frequency visual channel (called the Magnocellular or M pathway) provides information about the global shape of the stimulus within 60 to 80 ms of presentation. The slower high spatial frequency channel (called the Parvocellular or P pathway) provides more finely detailed information about the stimulus around 150 to 200 ms post-presentation. Impairments in the M pathway exist in dyslexia (this is fully reviewed in Chapter 4), which would result in degradation of the global information. This early global information also feeds back and aids in processing the fine detail by the P pathway (Bullier, 2001), so would result in problems in making rapid visual discriminations and in rapidly naming stimuli. Kinsbourne et al. (1991) found significant strong correlations ($r = .51$) between rapid object naming speed and
thresholds on a visual temporal order judgement task, which involves the M pathway, in compensated adults with childhood dyslexia and control participants.

Degraded phonological representations would interfere at the point at which stored visual representations are converted into phonological representations in order to name the stimulus. The hypothesis is that impaired auditory temporal processing underlies the degraded phonological representations in dyslexia (Chapter 4 also reviews this). Kinsbourne et al. (1991) also found a significant moderate correlation \(r = .30\) between auditory temporal order judgement thresholds (a measure of auditory temporal processing) and rapid object naming speed.

Inability to switch attention rapidly would interfere with naming speed in serial naming tasks. Obregon (1994; cited in Wolf et al., 2000) found dyslexic readers took longer to disengage from the previous stimulus, perceive and recognise the next stimulus, access the lexicon and retrieve the label, and then articulate that label. Hari and Renvall (2001) related slowness in shifting attention across sequential stimuli to impairments in the cortical area to which the M pathway projects. Thus, it is possible that rapid naming tasks reflect underlying impairments in both temporal processing and in phonological processing (or in phonological representations).

However, Kail, Hall, and Caskey (1999) presented another explanation. They argued that the relationship between reading and rapid naming speed occurred only because both relied on rapid processing speed. They found processing speed, indicated by performance on a visual matching task (speed to find two matching symbols in a series), accounted for a significant independent component of variance in naming speed in a normative sample of 7- to 13-year-olds. Supporting this hypothesis, Catts et al. (2002) found rapid naming of objects did not account for significant additional variance in word identification in second and fourth grades \(N = \)
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279), after accounting for variance due to processing speed (composite score on a range of reaction time tasks) and IQ. However, Ramus et al. (2003) found significant differences between groups of adults with and without dyslexia on rapid naming of digits and objects remained, after the effects of processing speed were partialled out in an ANCOVA. This indicated the relationship between reading ability and rapid naming speed was due to more than just processing speed.

3.3.2.1 Summary and Current Research Emphasis

Controversy continues over exactly what is measured by rapid automatised naming (RAN) tasks, and the nature of their relationship to reading. Significant relationships were evident between RAN speed and phonological processing, processing speed, and auditory and visual temporal processing. However, even after accounting for variance in reading due to other factors (including IQ, processing speed, phonological processing, and pre-existing reading ability), RAN speed accounted for a moderate amount of additional variance (Badian, 1993; Catts et al., 2002; Plaza & Cohen, 2003; Ramus et al., 2003). This relationship was stronger for word identification and reading rate than for word decoding skills (Bowers, 1995).

In the current study, a Rapid Automatised Naming of objects task was included with the set of phonological processing measures. This was to ensure that the range of skills Wagner and Torgeson (1987) identified as phonological processing was covered. It does not imply the task was viewed simply as a measure of phonological processing, but rather Rapid naming speed was expected to explain different components of the variance in reading measures to the other phonological processing measures; in particular, it was expected to show stronger relationships with word identification, reading rate, and orthographic processing, than with non-word
decoding. Furthermore, the study allowed identification of the independent versus common variance in reading between the RAN task and measures of auditory and visual temporal processing.

3.3.3 Phonological Processing in Working Memory and Reading

The third body of phonological processing research identified by Wagner and Torgeson (1987) examined the relationship between phonetic re-coding to maintain material in working memory and reading. This is particularly important for beginning readers for whom decoding is a slow letter-by-letter decoding process. Letter sounds must be temporarily stored then blended into words. The more efficient the basic phonetic re-coding, the more cognitive resources are available for the more difficult task of blending the phonemes into words. This work derives from Baddeley’s (1982) model of working memory and its application to beginning reading. Verbal information is stored in the phonological loop. The classic tasks used to measure phonological short-term memory are memory span tasks (e.g., digit span).

When presentation is verbal (auditory), digit span tasks utilise the phonological loop, but contrary to Wagner and Torgeson's conceptualisation, the stimuli do not need to be re-coded into a phonological form. However, these stimuli are stored in phonological forms within the phonological loop. Preschool verbal short-term memory predicted subsequent reading ability (Grogan, 1995; Mann & Liberman, 1984). Molfese, Molfese, and Modgline (2001) recommended inclusion of a measure of Preschool verbal short-term memory as a predictor of early reading ability. Compensated adults who had a childhood diagnosis of dyslexia continued to show phonological short-term memory deficits (Paulesu et al., 1996). Snowling (2000) attributed this to degraded phonological representations. However, others showed individual differences in auditory-verbal short-term memory do not account for
unique variance in reading development, after accounting for variance due to phonological awareness, rapid naming speed, or speech rate (McDougall, Hulme, Ellis, & Monk, 1994; Wagner et al., 1994). Jeffries and Everatt (2004) found digit span significantly differentiated primary and secondary school students with dyslexia from age-matched controls, but it did not differentiate those with dyslexia from other special education needs children. This indicated the memory deficit was non-specific and might derive from the attention demands of the task, as opposed to the phonological processing demands. It might also indicate verbal short-term memory deficits are common to a range of developmental disorders. Torgeson and Burgess (1998) argued for more research to determine what unique role, if any, problems in short-term memory played in causing reading difficulties. The current study incorporated digit span as a control task for the potential phonological memory demands of the other phonological awareness and the auditory temporal processing tasks. These tasks shared many generic task demands, such as auditory attention, with the digit span task.

3.4 Genetic Studies of Phonological Processing and Reading

Support for a causal phonemic-phonological deficit in reading also comes from large-scale twin studies. These found significant genetic components to both phonological and orthographic skills in reading (Olson, Forsberg, & Wise, 1994; Olson, Wise, Conners, Rack, & Fulker, 1989). Heritability estimates for both phonological ability and orthographic ability were around 0.60 (Gayán & Olson, 2001; Olson, 1999). There was a large common component to the heritability of phonological and orthographic skills, but also independent genetic variance (Gayán & Olson). The estimated heritability component of the reading deficit in developmental phonological dyslexia was 0.67, compared with the estimated shared environment
influence of 0.27 (Castles, Datta, Gayàn, & Olson, 1999). By contrast, developmental surface dyslexia showed a weaker, but still significant, heritability component of 0.31, and a stronger shared environmental influence of 0.63. This is consistent with surface dyslexia representing a more general delay in word recognition (possibly due to mildly depressed phonological skills) along with more limited reading experience (Manis et al., 1996; Stanovich et al., 1997).

Sibling-pair linkage analyses identified a quantitative trait locus on chromosome 6p21.3 for phonological decoding and orthographic choice deficits (Davis, Gayàn, et al., 2001). Evidence for an effect of this locus on rapid naming speed was not substantive, although there is also high heritability (around 0.60) for rapid naming speed (Davis, Knopik, Olson, Wadsworth, & De Fries, 2001). This supported the conclusion of independent relationships between reading and phonological processing, orthographic processing, and rapid naming speed.

It is important to note there is no single genetic cause of reading problems (Castles et al., 1999; Gilger & Kaplan, 2001; Grigorenko, 2001). This is one explanation for the heterogeneity of dyslexic profiles. Multiple genes acting alone or in concert give rise to multiple phenotypic deficits. If faulty genes affect neurodevelopment, they are unlikely to affect only one specific region, but rather are more likely to affect multiple areas to varying degrees (Gilger & Kaplan). Furthermore, the link from genotype to phenotype is a distant and indirect one, and environmental factors act all along the way to exacerbate or ameliorate the effects of those genes.

3.5 Underlying Biological Correlates of Phonological Processing Deficits

Language processing takes place in the perisylvian areas (surrounding the Sylvian fissure), particularly in the left hemisphere. These areas include Broca's area
(left inferior temporal gyrus); Wernicke's area (the superior temporal gyrus); the insula; and the supramarginal gyrus (see Figure 3.1). At autopsy, Galaburda et al. (1985) found foci of myelinated glial scarring and ectopias in the perisylvian region in the brains of adults who had dyslexia. Ectopias are accumulations of misplaced neurons that interrupt the laminar organisation of neurons in the cortex (Banich & Scalf, 2003). Based on the well-documented developmental progression in prenatal brain development, this morphological abnormality occurred between the 5th and 7th months of prenatal development (Hynd & Hiemenz, 1997). Geschwind (Galaburda et al., 1985) concluded that early \textit{in utero} immunological attack was a likely cause.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{brain_diagram.png}
\caption{Cortical areas involved in word reading and phonological and orthographic processing. Figure adapted from Gazzaniga, Ivry, and Mangun (2000, p.71).}
\end{figure}

Positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) studies investigated whether there were functional differences in this region during performance of phonological processing tasks in those with dyslexia.
compared with control readers. As the neural activity within an area increases, local
blood flow increases. fMRI detects the resultant increased ratio of oxygenated to
deoxygenated haemoglobin (Joseph, Noble, & Eden, 2001), and PET tracks cerebral
blood flow using injected radioisotope traces (Demb, Poldrack, & Gabrieli, 1999).
fMRI is safer than PET to use with children, as it does not involve injection of
radioactive isotopes. Both techniques have very high spatial resolution in the order of
millimetres (Demb et al.). Imaging studies showed decreased activation in temporal,
occipital, and parietal areas in those with dyslexia during phonological and
orthographic processing tasks (see Demb et al.; Joseph et al.; Zeffiro & Eden, 2000).
Phonological processing produced activation in the left posterior superior temporal
gyrus (including Wernicke's area), the left inferior frontal gyrus (part of Broca's area),
and the left insula (which joins these two areas); although substantial variation was
found in the areas activated across studies (Burton, 2001; Paulesu et al., 1996).
Burton attributed differences between studies to differences in the phonological tasks
used; differences in the modality of stimulus presentation (auditory versus visual); and
differences in the responses required (e.g., passive processing versus active response),
as well as to individual differences in anatomical architecture. She concluded
activation of different areas of the inferior frontal gyrus occurred in tasks that
involved phonological processing of aurally presented speech and orthographic
processing of visually presented words or letters.

Using fMRI with 8- to 10-year-olds during a rhyme task, Temple et al. (2001)
found left temporo-parietal activation remained at baseline in the children with
dyslexia, whereas the control children showed activation. Comparison of activation
during control tasks indicated activation in this area was specifically due to
phonological processing, differences, which held when IQ was controlled. By
contrast, both groups showed left frontal activation during this task, although the group with dyslexia showed greater activation in the left inferior frontal gyrus than the control group, and the control group showed greater activation in posterior frontal regions. On an orthographic task (matching letters), those with dyslexia showed significantly less activation in the extrastriate region of the occipital-parietal area. The control children showed significantly more activation in the right occipito-temporal cortex. Pugh et al. (2001) found developmental differences in brain activation in the right temporal posterior and left inferior frontal gyrus regions between 7- to 17-year-olds with and without dyslexia. Skilled automatic reading was more strongly associated with increased activation in the left ventral regions in normally developing readers. B. A. Shaywitz et al. (2002) also found greater activation in the left occipito-temporal region was associated with greater accuracy in non-word reading in a similar-aged sample. The older dyslexic readers showed increased activation around the left and right inferior frontal gyri during the most difficult phonological task (non-word rhyming). In adults with dyslexia, S. E. Shaywitz et al. (1998; 2003) found similar frontal inferior gyrus activation. Furthermore, the adults whose reading had improved by Grades 9 and 10 showed more activation in the right superior frontal and middle temporal gyri and in the left anterior cingulate gyrus than those whose reading had remained persistently poor throughout school (S. E. Shaywitz et al., 2003). They concluded that, with development, frontal regions became activated during phonological processing in those with dyslexia to compensate for the disruption in the posterior regions, which showed greater activation during these tasks in control groups.

There is evidence that remediation affects brain activation in these regions, at least in children. Six- to 9-year-olds showed greater activation in the inferior frontal
and posterior middle temporal gyri during a letter identification task after 8 months of reading intervention than was present before the intervention (B. A. Shaywitz et al., 2004). No initial differences due to the type of reading intervention were found; however, one year after the intervention ended, those who received training in the alphabetic principle continued to show greater activation in this temporo-parieto-occipital region than those who received other intervention.

Using PET scan during a rhyming task with adult males with developmental dyslexia, Paulesu et al. (1996) found no activation in the insula, less activation than control males in Wernicke's area, and no differences in activation in Broca's area. During a phonological short-term memory task, the dyslexia group showed no activation in the insula, no difference to the control group in activation in Wernicke's area, and less activation in Broca's area. They concluded the insula might be important in linking Broca's area (which was important for phonological segmentation) to the supramarginal gyrus and Wernicke's area (which were important in phonological short-term memory). Tasks of greater complexity may place more demands on connectivity between these two areas via activation of the insula. This would explain the slower time to perform the Spoonerism task by adults with dyslexia (around five times more slowly) than by control adults. However, others found activation in the insula during phonological tasks in both children (Temple et al., 2001) and adults (Rumsey et al., 1997) with dyslexia.

Despite a variety of paradigms and analysis techniques used in these imaging studies, the consistent finding is of disruption in the left temporo-parietal regions. Temple (2002) argued that the finding of similar neural differences between dyslexic and control groups with samples of children and adults was evidence of a causal relationship between the neural abnormality and the phonological processing and
reading deficits. What is less clear at this point is whether there is more activation in the left inferior frontal gyrus region in those with dyslexia. It is also unclear at this point whether altered neural activation patterns in adults or children with dyslexia are a cause of the phonological and orthographic deficits or a consequence of spontaneous or remediation-induced neural compensation. Longitudinal imaging studies would answer these questions.

3.6 Summary and Conclusions

Convergent evidence from prospective longitudinal studies, intervention studies, genetic studies, and imaging studies support a causal role for phonological processing in reading development. However, it also seems evident phonological processing ability alone cannot explain reading ability. Around 75% of the variance in reading is accounted for when multiple measures of phonological processing are used. However, once other factors like age, pre-existing reading ability, verbal ability, IQ, and memory are controlled, phonological processing accounts for around 10% or less of unique variance in reading (Wagner & Torgeson, 1987). While successful intervention is strong evidence of a causal role for phonological processing in reading ability, persistent reading problems remain after phonological intervention. In general, the success of the interventions is only modest.

It is essential to consider these relationships in the context of developmental models. Different measures of phonological processing show stronger or weaker relationships with reading ability at different points in development, providing an explanation for some inconsistent findings within the literature. This is consistent with models of normal reading development (Ehri, 1987; Frith, 1985) in which phonological and orthographic skills (and therefore, auditory and visual perceptual skills) differ in importance at different stages of reading development. Added to this,
is the constant interaction with environmental factors, which is often not considered in research.

One of the difficulties for the phonological processing deficit hypothesis is that it cannot explain the range of deficits, including perceptual deficits characteristic of dyslexia (Chapter 4 reviews these). Furthermore, phonological processing deficits could be a result of some more basic impairment in dyslexia, like impaired auditory temporal processing. This remains a contentious hypothesis. According to some researchers, the deficits in dyslexia have a linguistic basis (e.g., Vellutino, 1979), specifically that of underlying speech perception deficits (see Brady, 1997 for review). Tallal and colleagues (e.g., Tallal, 1980; Tallal, Miller, & Fitch, 1993) argued a more general underlying auditory temporal processing deficit exists. The auditory temporal processing deficit results in degraded phonemic representations, which in turn result in phonological processing deficits. The following chapter explores this temporal processing deficit hypothesis in more detail.
CHAPTER 4- THE TEMPORAL PROCESSING DEFICIT

CAUSAL HYPOTHESIS OF DYSLEXIA

According to the temporal processing deficit hypothesis, dyslexia is a result of deficits in processing temporal (very brief rapidly presented or changing) stimuli in the visual (Lovegrove, 1996) and auditory systems (Tallal, 1980; Tallal et al., 1993); there is also some evidence of deficits in the somatosensory system (Farmer & Klein, 1995). This hypothesis can potentially explain the phonological processing deficits and reading problems, as well as many of the non-reading characteristics. This chapter first examines the evidence for a relationship between auditory temporal processing and phonological processing and reading, before examining evidence for a relationship between visual temporal processing and reading.

4.1 Auditory Temporal Processing Deficits in Dyslexia

The strongest proponents of the phonological processing deficit hypothesis argued that dyslexia is a specifically linguistic deficit, arising from underlying deficits in speech perception (Brady, 1997; Vellutino, 1979). Speech perception requires the segregation of speech signals from background noise and attention to the auditory patterns within speech (Bailey & Snowling, 2002). The spectral shape must be determined. The spectrum of a sound is the plot of the amplitude at each frequency component in the sound (Deutsch & Richards, 1979). The frequency of the sound is the number of completed cycles of vibration in a 1-second period. Thus, a 20Hz frequency refers to 20 vibration cycles per second. There is a relationship between the frequencies of pure tones and the pitch of the sound (Deutsch & Richards). The amplitude of a soundwave refers to the distance from rest of the sound wave. The greater the amplitude (or distance) of a pure tone, the louder the tone sounds (Deutsch
Detection and discrimination of amplitude and frequency modulations in speech is necessary for speech perception. Temporal resolution of both slow changes over the utterance and rapid consonantal changes (in the order of milliseconds; Phillips, 1993) is required. For example, the timing of the critical acoustic parameters, or the voice onset time, that distinguish /ba/ from /pa/ is only 40 ms (Banich & Scalf, 2003). The primary auditory cortex can time events with better than millisecond accuracy so is involved in speech perception.

Difficulty in resolving brief or rapidly changing acoustic signals may disrupt early speech perception (Farmer & Klein, 1995). Phonemes occur within a steady acoustic stream. They do not represent independent articulatory bursts, as syllables do. They also differ acoustically depending on the position of co-articulation. For example, the /o/ in top is different acoustically to the /o/ in tog. The formation of stable phonemic representations requires the ability to segment the acoustic stream into chunks of time and to form neural representations based on the consistency and frequency of the particular neural firing patterns generated. For phonemic representations, segmentation of chunks in the order of tens of milliseconds is required. Chunking over longer durations, in the order of hundreds of milliseconds, allows representations of syllables or words (Tallal, 2003).

Benasich and Tallal (2002) observed differences in rapid auditory processing thresholds in infancy around the time of formation of phonemic representations, between 6 and 12 months. Difficulty in rapid segmentation of the acoustic stream may prevent establishment of stable and invariant phonemic representations, which may then underlie the phonological deficits found in dyslexia. Accurate representations of larger units, like syllables and words, may still be possible, allowing some aspects of reading to develop.
The question is whether the auditory temporal processing deficit in dyslexia is specific to speech perception. Brady (1997) argued that it is and so should not occur when processing non-speech stimuli. Tallal and colleagues (e.g., Tallal, 1980; Tallal et al., 1993) argued that processing of brief or rapidly changing speech and non-speech sounds, where the timeframe is in the tens of milliseconds, should be affected. Anatomical, physiological, and psychophysical studies supported Tallal’s hypothesis of deficits in processing both speech and non-speech sounds. However, some null and conflicting results have ensured that the specificity of the auditory deficit and its relationship to phonological processing and to reading remains inconclusive and controversial. There are also some methodological issues in existing research regarding sample selection, experimental and control task design, and the reliability of auditory temporal processing measures (McArthur & Bishop, 2001). The following section reviews the empirical evidence for the auditory temporal processing deficit hypothesis, highlighting these issues.

4.1.1 Anatomical and Physiological Evidence of Auditory Temporal Processing Deficits

Galaburda et al. (1994) examined the Medial Geniculate Nucleus (MGN) from the brains of five dyslexic adults and seven matched controls at post-mortem. There were significant left-right differences in the dyslexic group. The MGN neurons were smaller in the left hemisphere than in the right hemisphere in brains of those with dyslexia. This did not occur in the brains of the controls. There were also more small and fewer large neurons in the left MGN of dyslexics, compared to controls. However, there were no differences between controls and dyslexics in neurons in the right hemisphere and no difference in mean neuronal area. Large neurons are important for processing the frequency and amplitude changes that signal phonetic
contrasts (Rauschecker, 1998). Galaburda et al. concluded the reduced number of large neurons in the left hemisphere, which is important for language processing in most people, could result in impaired processing of rapid temporal auditory transitions, and that this could underlie the phonological deficits found in dyslexia.

There is also anatomical abnormality in the planum temporale (PT) in those with dyslexia. The PT is a small triangular shaped area in the posterior part of the superior temporal gyrus, extending through the Sylvian fissure. It overlaps with Wernicke's area in the left hemisphere, and with the secondary auditory cortex. In PET studies, this region was activated, particularly in the left hemisphere, during dichotic listening tasks (Hugdahl, Brønnick, Law, Kyllingsbæk, & Paulson, 1999). In 68% of the normal reader population, there is leftward asymmetry in the PT. This reflects the focus of language processing in the left-hemisphere of the majority of the population. However, Galaburda et al. (1985) found either symmetry or larger right hemisphere PT (reversed asymmetry) in three of the five brains (at post-mortem) from dyslexic adults. Furthermore, the symmetrical PT of the dyslexic brains were also generally larger than the asymmetrical PT in the sample of normal brains.

Consistent with this autopsy finding, magnetic resonance imaging (MRI) revealed reversed PT asymmetry in 13 out of 19 adolescents with dyslexia (mean age 14 years). By comparison, only 5 out of 17 of the control group showed reversed asymmetry (Larsen et al., 1990). Each of the dyslexic group who had phonological impairments showed symmetrical PTs. Of those with mixed phonological and orthographic impairments, half showed asymmetrical PT, and half showed symmetrical PT. Thus, there was a stronger relationship between PT abnormality and dyslexia in which there was phonological difficulty. This is one of few studies to correlate functional measurements with the structural measurements.
However, not all studies found evidence of differences in symmetry (Hugdahl & Heiervang, 2003; Rumsey et al., 1997). In their sample of children, Hugdahl and Heiervang found the left PT in the dyslexic group was 10% smaller than the control group, despite showing similar leftward asymmetry. They concluded it was the size of the left PT rather than the lack of asymmetry that was relevant to phonological processing and dyslexia. Rumsey et al. interpreted their discrepant results as being due to differences in the subtypes among the dyslexic samples studied, with differences more likely in those with phonological developmental dyslexia.

Magnetoencephalography (MEG) studies also showed differences in activation in cortical areas, including the PT. MEG involves recording the very weak magnetic fields formed by populations of neurons working in synchrony (Service, Helenius, & Salmelin, 2003). The characteristic negative response that occurs around 100 ms post-stimulus (N100m) is an indicator of primary auditory cortical reactivity. The N100m response receives contributions mainly from the supratemporal auditory cortex, which is immediately posterior to the primary auditory cortex and includes the PT. Using a temporal order judgement task (described in detail in Section 4.1.2.1), Nagarajan et al. (1999) found a suppressed N100m response to the second stimulus of the sound pair in the group with dyslexia at short inter-stimulus intervals (ISIs). The group with dyslexia were also poorer at judging the order of the two sound stimuli. Mice who spontaneously develop cortical ectopias similar to those found in Galaburda et al.'s (1985) post-mortem study of dyslexic brains showed similar suppressed responses (Frenkel, Sherman, Bashan, Galaburda, & Loturco, 2000). Helenius, Salmelin, Richardson, Leinonen, and Lyytinen (2002) also found delayed N100m response to speech sounds containing rapid frequency transitions, /ta/, in Finnish-speaking adults with dyslexia compared to controls, but no differences with rapid
sequential presentation of non-verbal tones. Their tones were of longer duration than those used by Nagarajan et al., which might explain the difference. Furthermore, Nagarajan et al.’s dyslexic sample was specifically selected for their auditory temporal processing deficits, whereas Helenius et al.’s was not.

The purely acoustic features of the stimuli elicit a second response, the N100m’ response, after the initial N100m response. Renvall and Hari (2002) found the N100m’ increased in relation to increased noise duration in adult controls (n = 11), but in the group with dyslexia (n = 9), there was no increase in the left hemisphere and a much weaker increase in the right hemisphere. This was interpreted as evidence of weakened attentional capture in the auditory system. Hari and Renvall (2001) hypothesised that dyslexia results from attentional impairments arising in the posterior parietal cortex (PPC).

Using same-different judgements of /ga/-/ka/ consonant-vowel speech signals that varied in voice-onset-time, Breier, Panagiotis, et al. (2003) found relatively greater left temporoparietal activation in control children (n = 12), and relatively greater right temporoparietal activation between 300 and 700ms post-stimulus onset in the children with dyslexia (n = 11; aged 8.4 to 12.6 years). This temporoparietal region includes the auditory association cortex. With gender and IQ controlled, right temporoparietal activation was significantly negatively related to phoneme deletion (r = -.52) and rapid naming speed for objects (r = -.49). Thus, greater right hemisphere activation in this region was associated with poorer phonological processing.

Thus, there is convergent evidence of anatomical and functional differences in the MGN, PT, and temporoparietal auditory association areas in the left hemisphere of both children and adults with dyslexia. This is consistent with impaired auditory temporal processing and, in particular, with difficulties in processing the rapid
temporal processing and early reading

phonetic contrasts in speech, and with phonological processing deficits.

Psychophysical tasks that involve processing in these neurological areas also show a
deficit in auditory temporal processing in dyslexia and a relationship between this and
phonological processing and reading.

4.1.2 Psychophysical Evidence

Various psychophysical tasks have demonstrated a significant auditory temporal
processing deficit in both children and adults with dyslexia, and significant
relationships with reading and phonological processing across a wide range of
abilities. There are two broad categories of psychophysical tasks. The first involves
processing of rapid sequential auditory stimuli. The auditory temporal order
judgement task, which the current study used, falls in this category. Tasks in the
second category involve dynamic processing of rapidly changing auditory stimuli.
The following sections review the evidence from both categories of tasks.

4.1.2.1 Tasks Involving Rapid Sequential Auditory Stimuli

These tasks include temporal order judgement tasks, gap detection or click
fusion tasks, auditory saltation, and auditory pitch segregation.

Temporal Order Judgement Task. In the auditory temporal order judgement
task (TOJ; also referred to as a Repetition Task, Tallal & Piercy, 1973), participants
either determine the correct order of two or more rapidly presented auditory stimuli
(e.g., Heath, Hogben, & Clark, 1999), or simply determine which tone came first (e.g.,
Reed, 1989). Stimuli may be non-verbal tones (e.g., low, 100Hz, and high, 305 Hz,
tones) or natural or artificial speech sounds (e.g., /ba/ and /da/). In the common two
stimuli task (e.g., with high, H, and low, L frequency tones), there are four possible
orders (H H, H L, L L, L H). Tallal and Piercy found language-impaired children (6.9
to 9.3 years old) were significantly less accurate than control children in processing the order of pairs of brief non-verbal tones (durations of 75 or 125 ms) separated by inter-stimulus intervals (ISIs) of less than 150 ms. However, they were not significantly different to the control group for any ISIs with longer tone durations (250 ms), or for long ISIs (428 ms) with any tone duration. In other words, there was a specific difficulty in processing brief tones separated by short ISIs. More recently, Waber et al. (2001) found less accuracy on this task in the group with learning disability ($n = 94$, aged 7 to 11 years) compared to the age-matched control group ($n = 226$) at short ISIs (10, 50, 100 ms), even with longer stimulus durations of 250 ms. Thus, Waber et al. concluded the difficulty was in processing stimuli presented in rapid succession, rather than in processing stimuli presented for brief durations.

Tallal (1980) extended the findings of Tallal and Piercy (1973) to children with dyslexia (aged 8 to 12 years old). These children were reading at least one grade below that expected for their chronological age. She found significantly less accurate judgement at short ISIs (up to about 305 ms) in the group with dyslexia ($n = 20$), compared to the control group of younger average readers ($n = 12$; mean age = 8.6 years). There were no significant differences with long ISIs (428 ms). The number of errors on the TOJ task showed a strong significant positive correlation ($r = .81$) with the number of errors made on non-word reading. Tallal's group has replicated these findings several times (see Stark, Tallal, & McCauley, 1988). Reed (1989) also found similar TOJ differences between 7- to 10-year-old dyslexic (reading at or below the 22$^{nd}$ percentile on the Wide Range Achievement Test, WRAT, reading subtest) and control groups (reading above the 40$^{th}$ percentile on the WRAT subtest) with both non-verbal tones and speech syllables. The syllables, /ba/ and /da/, differed solely on the basis of the initial stop consonant in the first 35 ms, followed by an identical
steady state vowel for the remainder of the 250 ms duration. TOJ of steady state vowels alone produced no significant between-group differences. She concluded there was a selective impairment in dyslexia in processing both rapidly changing (syllables) and briefly presented auditory stimuli (tones). There were similar significant between reader-group differences in verbal TOJ performance in French-speaking children, showing these relationships occur across languages (de Martino, Espesser, Rey, & Habib, 2001; Habib et al., 2002). Booth, Perfetti, MacWhinney, and Hunt (2000) examined performance on 2- and 3- tone auditory TOJ tasks (100 ms ISIs) by a sample of 35 children and adolescents with dyslexia (aged 11 to 18 years). Performance significantly predicted an additional 19% of the variance in word identification and non-word reading and an additional 9% in irregular word reading, after accounting for the effects of age and IQ. Thus, performance on the auditory TOJ task covaried with reading ability.

However, not all studies found a selective impairment for judging order when ISIs were short. Using similar criteria for classifying reading ability groups as Reed (1989), Nittrouer (1999) found only a trend toward between-group differences at short ISIs in 8- to 10-year-olds ($p = .052$). However, she had very dissimilar group sizes (93 controls versus 17 poor readers), which could also explain the failure to reach significance. Others found significant differences between control groups and groups of poor or dyslexic readers at both short (8 to 300 ms) and long (428 ms) ISIs (Cestnick & Jerger, 2000; Waber et al., 2001). Share et al. (2002) found their group of children with dyslexia ($n = 17$) were significantly poorer than the control group ($n = 301$) at judging order with long ISIs, but did not differ with short ISIs. However, they found greater variance with short ISIs in the dyslexic group than in the control group. That, and the uneven sample sizes, may have prevented detection of a
significant effect. When Share et al. compared the dyslexic group to a more closely matched same-age sample \((n = 18)\), there was greater homogeneity of variance across groups and a greater difference between means for the short ISI condition, although this still failed to reach significance, \(p = .08\). When compared to a younger reading-age control group, the difference on the long ISI task disappeared. There was also a problem with Share et al.’s task. Half of all trials involved reporting order of two tones of the same pitch (e.g., low-low). On these trials, order errors are not possible. Any errors are only of discrimination. Klein (2002) showed there was a similar percentage difference between Share et al.’s groups at short ISIs as at long ISIs, although this difference only reached significance at long ISIs. He argued that the results were more indicative of a general temporal processing deficit than of a deficit at long ISIs only.

Share et al.’s results show the type of control group, reading versus chronological age-matched, may affect the results obtained. Reed (1989) and de Martino et al. (2001) used age-matched control groups. Marshall, Snowling, and Bailey (2001) found a significant between-group difference when the group with dyslexia \((n = 17; \text{mean age} = 12;4 \text{ years})\) was compared to an age-matched control group, but not when compared to a younger, reading-age matched control group. This was consistent with a delay in development of TOJ performance in dyslexia, rather than a deficit. However, Tallal (1980) found significant between-group differences using a control group who were younger than the group with dyslexia.

Even when there were significant between-group differences, not all participants in the group with dyslexia performed below the level of the control group. Only 23.5% of Marshall et al.’s (2001) sample with dyslexia scored below the lowest scoring control children on the task. This was a lower percentage than the 45% who
were less accurate in Tallal's (1980) study. In adults, Ramus et al. (2003) found the scores of approximately 31 to 44% of their dyslexic group were in the bottom fifth percentile of scores from the control group, with the remainder scoring higher. Two studies categorized children with dyslexia based on their auditory temporal processing skills and examined whether those groups differed significantly on measures of phonological processing and reading. It was expected those with poorer temporal processing skills would have poorer phonological processing and poorer reading. Share et al. (2002) found children who scored zero on the nonverbal TOJ task at short ISIs at school-entry were significantly poorer at phoneme segmentation at school-entry, but did not differ on phoneme segmentation or reading measures once at school. Consistent with this, Bretherton and Holmes (2003) found no significant differences between their primary school-aged good and poor tone-processors on phonological processing or reading measures.

These inconsistent results may reflect the heterogeneous nature of dyslexia (see Martin’s, 1995, argument). In the majority of studies reporting significant between-group differences, there was greater variability in the group with dyslexia than in the control group (McArthur & Bishop, 2001). It may also reflect the continuous nature of both reading and auditory temporal processing abilities. A normative approach may provide a more useful design than the between-groups one to study the relationship between reading and temporal processing.

Few studies have used a normative approach with a wide range of reading abilities to examine the relationship of auditory TOJ accuracy to phonological processing and reading skills. According to the temporal processing deficit hypothesis, there should be positive linear relationships between auditory temporal processing and phonological processing and reading. With a normative sample of 82
children, aged 6;6 to 13;6 years, Marshall et al. (2001) produced results convergent with those from between-group designs. After partiallling out the effects of age and non-verbal cognitive ability, there were significant moderate to strong linear relationships between non-verbal TOJ accuracy and rhyme detection and reading skill, but not with phoneme awareness. Using their combined sample (\(n = 318\)), Share et al. (2002) found non-verbal TOJ accuracy (at both short and long ISIs) at school entry (mean age 5;4 years) was significantly weakly correlated with phoneme segmentation at school-entry and in second grade, and with word reading accuracy and rate and non-word reading accuracy in second and third grades. In general, these relationships remained significant when attention and the number of trials taken to learn the TOJ task were controlled. These results differ slightly from those obtained when Share et al. looked at between-group differences.

Studies with older samples also found significant between-group differences on auditory TOJ. Adolescents with dyslexia were significantly less accurate than reading- and age- matched controls (Farmer & Klein, 1993). With all groups combined, there were significant moderate correlations (\(r\) from 0.30 to 0.48) between TOJ accuracy (collapsed across short ISIs) and word identification, non-word reading, and phonological awareness. In adults with dyslexia (\(n = 32\)), Booth et al. (2001) found performance on a 2- and 3-tone TOJ task accounted for a significant additional 12 to 16% of variance in word identification, non-word reading, and irregular word reading, after variance due to age and IQ was accounted for. Significant differences in auditory TOJ accuracy were also found between average and above average adult readers (Au & Lovegrove, 2001a); between university students with dyslexia and either compensated dyslexic or control university students (Edwards, Walley, & Ball,
2003; Ramus et al., 2003); and between a non-university sample with severe dyslexia and a control group (Kinsbourne et al., 1991; Watson & Miller, 1993).

However, not all studies with adults found significant between-group differences. Chiappe, Stringer, Siegel, and Stanovich (2002) did not find significant differences on this task between poor adult readers (word reading below the 25th percentile; \( n = 30 \)) and either age-matched controls \( (n = 32) \) or reading-level matched control children \( (n = 31) \). However, they used different stimulus parameters to most of the other studies reviewed. Their short ISIs ranged from 10 to 25 ms, and their long ISIs, from 30 to 100 ms. Generally, ISIs up to 305 ms are considered short and ISIs of 428ms are long. Thus, all of Chiappe et al.'s. ISIs were short.

Two studies with adults did not find significant differences on auditory TOJ between compensated dyslexic (childhood diagnosis of dyslexia but adult reading in the normal range) and control groups (Edwards et al., 2003; Kinsbourne et al., 1991). Edwards et al. concluded compensated dyslexics did not have a lingering auditory temporal processing deficit. However, as these two studies were cross-sectional, there are several possible interpretations. The first is that the auditory temporal processing deficit is not causally related to dyslexia, because adults with dyslexia continue to experience difficulties even when reading scores are at normal levels (Fawcett & Nicolson, 1994a; 1995; Gallagher et al., 1996; Miles, 1993; S. E. Shaywitz et al., 1999; S. E. Shaywitz et al., 2003; Wilson & Lesaux, 2001; Yap & van der Leig, 1994). The second is that the auditory deficit is amenable to change, and improved auditory temporal processing resulted in improved reading by adulthood. Intervention in auditory temporal processing in children resulted in greater activation of the auditory cortex, which may underlie this compensation (Temple et al., 2003). The third interpretation is the compensated dyslexics never had auditory temporal
processing deficits, as less than half of those with dyslexia show these deficits (Marshall et al., 2001; Ramus et al., 2003; Tallal, 1980). To be able to differentiate between these explanations requires longitudinal data collected over a substantial period of development.

In combined adult samples with a wide range of reading abilities, significant relationships were found between auditory TOJ accuracy and word reading (Ahissar, Protopopapas, Reid, & Merzenich, 2000; Au & Lovegrove, 2001a), non-word reading (Ahissar et al.; Chiappe et al., 2002; Edwards et al., 2003), and phoneme deletion ability \( (r = .34, \text{ Chiappe et al.}) \). However, Watson and Miller (1993) found no significant relationship between auditory TOJ accuracy and phonological processing. The relationship with word reading was not explained by differences in non-verbal ability (Ahissar et al.). Ahissar et al. found stronger correlations between TOJ accuracy and word and non-word reading in their control group (almost 50% of the variance explained) than in their dyslexic group (less than 20% of the variance explained). In general, these results indicate that, rather than being a specific deficit isolated to those with dyslexia, auditory temporal processing ability covaries with a wide range of reading and phonological processing skills. This also supports the use of a normative approach.

Some have argued that the auditory TOJ deficit only occurs in dyslexia with co-morbid conditions, such as specific language disability (SLD) or attention deficit-hyperactivity disorder (ADHD). Tallal and Piercy (1973) showed there was significantly poorer TOJ accuracy in the group of SLD children than in the control group. In Tallal's (1980) study, those with dyslexia and concomitant oral language problems showed the auditory temporal processing deficit, whereas those with no oral language problems did not (Tallal et al., 1993). Heath et al. (1999) found
significantly higher thresholds (shortest ISI at which order could be judged correctly) for their reading plus language disability group (RDLD) than for the reading disability only group (RD) or the control group, which did not significantly differ. They further categorised the RD group as low or high language ability. The low language ability group had significantly higher auditory TOJ thresholds than the high language ability group. The high language group had thresholds similar to the control group whereas the low language group had thresholds similar to the RDLD group. They concluded those with reading disability only (no oral language problems) do not have an auditory temporal processing deficit, but that half of those with concomitant oral language problems do. However, the entire RD group had non-word reading difficulties, the severity of which increased with increasing language deficits. These findings contradicted Tallal’s hypothesis of auditory temporal processing problems underlying phonological processing deficits. These studies show it is important to consider the impact of language ability when looking at the relationship between auditory temporal processing and phonological processing and reading abilities.

It is also important to consider the impact of differences in attention. Between 15 to over 50% of children with ADHD also have dyslexia; the difference in percentages due to differences in the way dyslexia was defined (Dykman & Ackerman, 1991; Semrud-Clikeman et al., 1992). Breier, Fletcher, Foorman, Klaas, and Gray (2003) showed the presence of ADHD was associated with a general reduction in the ability to detect tone-onset-time asynchrony, a task similar to TOJ. However, Waber et al. (2001) found no significant change to the difference between learning impaired and non-learning impaired groups on the auditory TOJ task when children with ADHD were excluded.
Some researchers have questioned whether deficits on the TOJ task are due to a deficit in auditory temporal processing. Brady (1997) noted TOJ tasks initially require identification of stimuli and then judgement of order. Studdert-Kennedy and Mody (1995) argued that the differences found with TOJ tasks were due, not to a temporal processing deficit, but to deficits in discriminative capacity. Mody, Studdert-Kennedy, and Brady (1997) found the typical TOJ deficit of poor readers \( n = 20 \) Grade 2 children only occurred with phonetically similar pairs of syllables like /ba/ and /da/, for which identification was difficult. However, those who were poor at that judgement did not show deficits with less phonetically similar pairs such as /ba/ and /sa/. They concluded poor readers could judge the temporal order of rapidly presented stimuli, but only when they were first able to identify them. However, Denenberg (1999) identified several methodological and statistical flaws in Mody et al.’s study, including sample characteristics, power, and violations of the assumptions of the analyses, which might explain these contradictory results. Other evidence also counters an interpretation in terms of faulty discriminative capacity. de Martino et al. (2001) obtained significant between-group differences using quite distinct consonants, /p/ and /s/. Significant between-group differences also occur with other auditory temporal processing tasks, like gap detection (reviewed in the following section), that do not require identification of stimuli. Furthermore, the lack of significant between-group differences on simple stimulus identification tasks, which involve only discriminative capacity, also argues against this interpretation (Farmer & Klein, 1995; Wright, Bowen, & Zecker, 2000).

Studdert-Kennedy and Mody (1995) argued that there is confusion over what constitutes temporal processing. According to them, TOJ tasks involve processing of brief stimuli that are presented in rapid succession, whereas true temporal processing
requires perception of duration, sequence, relative timing, or rhythm. Yet, by Studdert-Kennedy and Mody’s own definition, TOJ tasks are temporal because they involve perception of sequence (reporting the order) or of relative timing (reporting which stimulus occurred first). Watson and Miller (1993) assessed the latent variable of auditory temporal processing using 1) the standard tone TOJ, 2) judgement of duration of a single tone, 3) judgement of temporal separation in a sequence of 6 tones, and, 4) detection of an extra tone varying in duration and loudness in a sequence of nine tones. They found significant between-group differences on the tone TOJ task only. This is consistent with difficulty in processing rapid sequences of auditory stimuli.

*Gap Detection Tasks.* In gap detection tasks, two noise stimuli of a particular duration (e.g., 200 or 700 ms bursts of white noise) are presented with either a silent gap of varying duration in between (target) or with no gap (continuous noise reference stimulus). Varying the gap duration allows a detection threshold to be calculated. Dutch-speaking children (van Ingelghem et al., 2001) and English-speaking adolescents with dyslexia (Farmer & Klein, 1993) required significantly longer gaps in order to perceive two separate auditory stimuli than did control groups. Gap detection thresholds were strongly negatively correlated with one-minute real word reading rate and non-word reading scores (van Ingelghem et al.). Thus, poorer gap detection was associated with slower reading rate and poorer phonological decoding. However, Schulte-Körne, Deimel, Bartling, and Remschmidt (1999) found no significant differences between 12-year-old German spelling disabled and control groups. Differences in selection criteria (reading disability versus spelling disability) may explain the different results.
After controlling for IQ, average adult readers needed significantly longer gaps than above average adult readers did for accurate detection, (Au & Lovegrove, 2001a), but no differences were found between groups of poor adult readers and either age-matched or reading-age matched controls (Chiappe et al., 2002). However, with combined samples of poor and average adult readers, gap detection accuracy was significantly moderately correlated with phoneme deletion accuracy ($r = .34$; Chiappe et al.), but not with word or non-word reading (Ahissar et al., 2000; Chiappe et al.).

**Auditory saltation.** In the auditory saltation illusion, a series of binaural clicks, half left-ear leading and half right-ear leading, are presented in rapid succession. At short ISIs (around 30 ms), the clicks are perceived to jump from ear to ear. This is the auditory saltation illusion. At longer ISIs (around 90 to 120 ms), the illusion disappears, and half are heard as left ear clicks and half as right ear clicks. Hari and Kiesilä (1996) found a group of adults with dyslexia ($n = 10$) perceived an auditory saltation illusion at significantly longer ISIs than the control group did ($n = 20$ university students). The differences were highly significant at an ISI of 150 ms, and, at 500 ms, 80% of the dyslexic group still perceived saltation. This task had no discriminative demands, yet showed that successive percepts in a rapid sequence interfered with each other at much longer ISIs in those with dyslexia than in those with normal reading. However, Kronbichler, Hutzler, and Wimmer (2002) found no significant differences in auditory saltation between a group of 20 Grade 7 German boys with dyslexia (scores below the 10th percentile on reading fluency and spelling) and an age-matched control group ($n = 20$; reading fluency and spelling above the 20th percentile). There may not have been enough separation between the reading abilities of these two groups to detect weak auditory saltation differences. A problem with the auditory saltation task is it involves both temporal (the rapid sequence) and
spatial (the leading ear) components. Thus, it may not be as pure a measure of
temporal processing as the other measures reviewed.

*Auditory pitch segregation.* A continuous stream of alternating high-low-high-
low frequencies is perceived as alternating when ISIs are long, or when there are
small frequency separations. However, it is perceived as two separate streams of
different frequencies (pitch) when ISIs are short, or when there are large frequency
differences. Helenius, Uutela, and Hari (1999) showed this segregation occurred at
almost double the ISI (208 ± 24 ms) in a group of adults with dyslexia (n = 13)
compared to the control group (n = 18; 127 ± 9 ms). These results indicated sluggish
processing of rapid sequential stimuli. Hari and Renvall (2001) proposed this was due
to sluggish shifting of auditory attention between stimuli. For control participants,
there were no significant correlations between the threshold ISI and naming speed,
oral reading, or lexical decision time. However, for the group with dyslexia, there
was a significant correlation between the threshold ISI and naming speed (r = .72).

4.1.2.2 *Tasks Involving the Perception of Rapidly Changing or Dynamic Stimuli*

The second category of auditory temporal processing tasks involves perception
of stimuli that show dynamic changes. Tasks in this category include frequency and
amplitude modulation detection.
Amplitude Modulation and Frequency Modulation Detection. Amplitude or frequency modulation refers to changing the carrier soundwave in order to change the amplitude (loudness) or the frequency (pitch) of the sound (Deutsch & Richards, 1979). These modulations are present in most biological sounds (Ribaupierre, 1997). Detection thresholds for frequency of a tone were examined at modulation rates of 2-, 40-, and 240- Hz (Ramus et al., 2003; Talcott et al., 2000, 2003; Witton et al., 1998; Witton, Stein, Stoodley, Rosner, & Talcott, 2002). Two- and 40- Hz FM can be tracked in real time (in other words, they involve auditory temporal processing), so should be impaired in dyslexia and correlated with reading and phonological processing. By contrast, 240-Hz FM exceeds the critical modulation frequency, so the first pair of spectral side bands extends beyond the bandwidth of a single auditory filter and tracking depends on spectral mechanisms. Thus, because it is non-temporal, 240-Hz FM should not be impaired in dyslexia, nor should it be correlated with reading or phonological processing.

In a small normative sample of 10-year-olds (N = 32), Talcott et al. (2000) found there was a significant correlation between 2-Hz FM sensitivity and phonological processing (composite measure of non-word reading and spoonerism task, after the effects of word reading ability, verbal ability, non-verbal ability, and verbal short-term memory were removed (partial r = .49). There were no significant partial correlations with 240Hz FM.

Compared to age-matched controls, there were significant impairments for 2-Hz FM (Ramus et al., 2003; Witton et al., 1998) and 40-Hz FM (Witton et al.) detection in English-speaking adult dyslexics, and for 2-Hz FM detection in Norwegian adolescent poor readers (Talcott et al., 2003). By contrast, there were no significant differences between adult dyslexic and control groups for 240-Hz FM detection.
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(Ramus et al.; Witton et al., 1998; 2002). Using a combined sample, Witton et al. (1998) found 2-Hz FM detection accounted for 16.4% of the variance in non-word reading ($p < .05$), after IQ was controlled.

Amplitude modulation (AM) detection thresholds also differed between reading ability groups. Slower amplitude modulations (AM), between 4 and 16Hz, are important for the intelligibility of speech. Rapid changes in amplitude near the onset of sounds are important for onset-rime awareness in children (Goswami & Bryant, 1990). Individual differences in detection in 8-year-olds strongly predicted phonological processing, even after age, IQ, and vocabulary were controlled (Richardson, Thompson, Scott, & Goswami, 2004). Adult dyslexics were significantly less sensitive than controls at detecting 20-Hz AM (McAnally & Stein, 1997; Menell, McAnally, & Stein, 1999; Witton et al., 2002), but showed no significant differences for 2-Hz AM (Witton et al.). However, there was substantial overlap between the groups, even when there were significant mean differences.

There were significant correlations between AM detection threshold as a function of modulation frequency and rate and accuracy measures of word and non-word reading. Differences in IQ could not explain those relationships. Electrophysiological studies supported the psychophysical results. McAnally and colleagues (McAnally & Stein; Menell et al.) found smaller evoked potential responses to AM in a group of adults with dyslexia than in the control group.

The frequency and amplitude modulations at which significant between-group differences occurred were in excess of those that would impair speech comprehension in adults; however, Witton et al. (2002) suggested impairments at these modulations could affect earlier stages of language development, resulting in degraded phonological representations. In normally developing children, AM sensitivity is still
developing up to around 7 years of age (Hall & Grose, 1994) and FM discrimination
is still immature at 9 months (Aslin, 1989), around the time at which phonological
representations are forming.

4.1.2.3 Relationships between Measures of Auditory Temporal Processing

Very little research has examined whether different tasks measure the same
underlying construct of auditory temporal processing. McArthur and Bishop (2001)
highlighted this as an important issue. There should be significant correlations
between performances on these tasks, and a single sample with dyslexia should show
impairments across a range of different auditory temporal processing measures. A
few studies have included multiple measures of auditory temporal processing, but few
have provided data regarding relationships between these measures.

Au and Lovegrove (2001b) found auditory TOJ and gap detection tasks did not
load on the same factor in a factor analysis. Gap detection loaded separately with IQ,
suggesting it may measure some aspect of general cognitive ability, rather than
temporal processing. Studies have found little similarity in performance between
these two measures, confirming they are not measuring the same construct. Ahissar et
al. (2000) found no difference in gap detection thresholds between their adult dyslexic
and control groups, but did find significant differences in TOJ thresholds. This was
one of the few studies to look at relationships between auditory temporal processing
measures of rapid sequencing and dynamic changes. They found significant strong
correlations between auditory TOJ and frequency discrimination in both the dyslexic
and control groups, with around 45% of the variance shared between these two tasks.
This supported a common underlying construct being assessed by these two tasks, auditory temporal processing, with each task measuring different aspects of that construct. Ramus et al. (2003) found significant impairments, relative to the control group, on both 2-Hz FM detection and auditory TOJ thresholds in the same sample of dyslexic adults. This suggested a general auditory temporal processing deficit. Unfortunately, they did not provide correlations between these measures. By contrast, Chiappe et al. (2002) found no significant between-group differences on either TOJ or gap detection and no significant correlation between verbal TOJ and gap detection sensitivity in their adult sample.

Using dynamic temporal tasks, Witton et al. (1998) found significant correlations between the thresholds for 2- and 40-Hz FM ($r = .42$). After removing the effects of IQ and reading ability, there was no significant correlations between either of these and 240-Hz FM detection (Talcott et al., 2000; Witton et al., 1998, 2002). This indicated different underlying auditory mechanisms were operating for detection of low frequency (temporal) and high frequency (non-temporal) modulations. There were no significant correlations between detection thresholds for 2-Hz FM and 20-Hz AM, both of which were impaired in the dyslexic readers (Witton et al., 2002). Thus, there was not a specific impairment in processing all slow modulations. Furthermore, 2-Hz FM and 20-Hz AM accounted for independent components of variance in word reading.
Ahissar et al. (2000) found relationships of different strength between reading skills and nine different auditory measures in 102 English-speaking adults who either had or did not have a childhood diagnosis of dyslexia. There were significant moderate to strong correlations between word identification and auditory TOJ, frequency discrimination, and frequency discrimination under backward masking in both the dyslexic and control groups. The two frequency discrimination measures showed significant correlations with non-word reading in the control group only, but Auditory TOJ showed a significant correlation with non-word reading in both the control and dyslexic groups. Differences in non-verbal ability did not explain these results. There were no significant relationships between gap detection and word or non-word reading. This varied pattern of performance on these tasks might be due, in part, to differences in other task demands, such as memory load, and to the complexity and temporal demands of the tasks. Unfortunately, they did not report correlations among performances on the various auditory measures.

From these studies, it is unclear that the gap detection task is a useful measure of temporal processing. This may explain the failure by a few studies to find correlations with reading (Ahissar et al., 2000) or significant between-group differences (Schulte-Körne et al., 1999). Auditory TOJ showed significant correlations with other dynamic measures of temporal processing. Therefore, it is considered a more useful rapid sequencing measure of temporal processing for use with children.
4.1.3 Intervention studies

Tallal, Miller, Jenkins, and Merzenich (1997) reported improvements in speech perception and language ability in seven SLD children after six weeks training, which involved temporal discrimination exercises and speech in which the duration of the speech signal was prolonged by 50% and the fast transitional elements (3 to 30 Hz) were made louder (amplitude enhanced). Using similar intensive temporal-phonological training, Habib et al. (2002) found improvements in phonological awareness, non-word reading, and auditory TOJ performance in French-speaking children with dyslexia (mean age 9;6 years) after 5 weeks. Overall, there was no significant change in word reading ability, although regular word reading improved significantly for children aged 7 to 8 years, suggesting training may have more impact on reading at an earlier point in its development. After eight weeks of intervention, Temple et al. (2003) found not only behavioural improvements, but also increased activation (detected by fMRI scans) in the left temporo-parietal region of children with dyslexia. These results indicate auditory temporal processing is amenable to change and that this may positively influence reading. However, Gillam, Frome Loeb, and Friel-Patti (2001) found Tallal et al.'s (1997) intervention did not produce significantly better outcomes for children with dyslexia than more traditional interventions.

It is not clear which aspect of the training – the temporal discrimination exercises, time expansion, or amplitude modulation – are responsible for the improvement found in some studies (McAnally, Hansen, Cornelissen, & Stein, 1997; Studdert-Kennedy, 2002). For example, McAnally et al. found expanded CVC syllables did not improve the ability to identify stimuli of adolescents with dyslexia.
There needs to be more research regarding the outcomes of auditory temporal processing intervention on subsequent reading.

4.1.4 Development in Auditory Temporal Processing

Auditory processing is still developing during the early primary school years. Tallal (1976) found control group children performed as well as adults from 8;6 years on her auditory TOJ task. Using a similar range of ISIs (10 and 150 ms) and stimulus duration (75ms), Marshall et al. (2001) found a significant age effect in a normative sample. The 6- to 7-year-old group ($n = 31$) was significantly less accurate than the 11- to 13-year-old group ($n = 16$), with performance by the oldest group approaching ceiling. The performance of the 8- to 9-year-old group ($n = 35$) did not differ significantly from the other two age groups. In a combined sample of learning impaired and control children aged 7 to 11 years, Waber et al. (2001) found a significant decrease in the number of errors with increases in age. Gap detection thresholds reach adult levels around 6 years of age (Wightman et al., 1989). Auditory fusion, the perception of two rapid successive repetitions of the same waveform as a single sound, takes even longer to develop, becoming mature only after about 9 years of age (Davis & McCroskey, 1980). Sensitivity to AM at modulation rates (5- to 200-Hz) reach adult levels at around 7 years of age (Hall & Grose, 1994).

Thus, it is important when using these tasks to consider the impact of development on performance. Young children are at risk for floor effects, which may result in no significant differences being found between dyslexic and control groups. Similarly, after late childhood, the control group is at risk of ceiling effects, which again may also result in failure to find significant between-group differences. However, these developmental studies were cross-sectional. Longitudinal data is
Temporal processing and early reading

needed. One of the aims of the current study was to examine longitudinally the development in auditory TOJ accuracy from Preschool to Grade 2.

4.1.5 Genetic Studies

There is little knowledge about genetic influences on auditory temporal processing in dyslexia. Bishop et al. (1999) found shared environment, rather than genes, was the most likely explanation for similarities on auditory TOJ performance between twins aged 7 to 13 years. However, her sample comprised language impaired and non-language impaired children. It is unclear if those results generalise to reading impaired versus non-reading impaired children.

4.1.6 Conclusions and Current Research Emphasis

Not all between-group design studies found significant differences in auditory temporal processing. Differences in the type of control group may account for some of the discrepant findings. Furthermore, not all children and adults with dyslexia show poorer auditory temporal processing than the control group, which would also explain the inconsistent findings. Ramus (2003) calculated only 39% of dyslexic participants, on average, showed an auditory deficit, relative to control group performance. A normative design overcomes these difficulties and is consistent with the conceptualisation of reading ability and temporal processing abilities as continuously distributed individual differences. When combined groups or normative samples were used, there were generally significant correlations between performance on these auditory measures and measures of reading and phonological processing (Ahissar et al., 2000; Au & Lovegrove, 2001a; Chiappe et al., 2002; de Martino et al., 2001; Edwards et al., 2003; Farmer & Klein, 1993; Marshall et al., 2001; Ramus et al., 2003; Tallal, 1980). Only two studies failed to find this relationship (Bretherton & Holmes, 2003; Watson & Miller, 1993).
Studies with adult samples produced less consistent results than those with child or adolescent samples. As Bailey and Snowling (2002) noted, a failure to find a significant auditory temporal processing deficit in well-compensated adult dyslexics does not rule out the possibility of a developmentally earlier deficit that contributed to the reading problems. Ahissar et al. (2000) argued that the failure to find relationships between reading ability and auditory temporal processing abilities in adult dyslexics could be due to reading having been remediated to the normal range while the auditory deficits remained relatively unaffected. However, auditory temporal processing may also be compensated for in adults. For example, Edwards et al. (2003) found no significant differences in TOJ accuracy between compensated adult dyslexics and controls. Therefore, children may be more suitable to study the relationship between reading and auditory temporal processing, before the effects of compensation or remediation affect any relationship.

The current study examined performance on a non-verbal auditory TOJ task in a normative sample of beginner readers, using a longitudinal design. Auditory TOJ tasks have been the most extensively used, in both between-groups and normative designs, and consistently showed significant relationships with reading. They have also been used with Preschool-aged children (Tallal & Piercy, 1973), unlike the other auditory temporal processing tasks reviewed. There are also analogous visual TOJ tasks (reviewed in the following section), which the current study also included. This allowed a direct comparison of temporal processing across these two modalities. Evidence suggests auditory TOJ is measuring the same construct as the dynamic auditory measures reviewed here. There is doubt over what construct the gap detection task is measuring.
4.2 *Visual Temporal Processing Deficits in Dyslexia*

The visual temporal processing deficit in dyslexia has been associated with impairments in the magnocellular or M pathway, which processes temporal information as well as low spatial frequency information about global location. There is evidence the parallel parvocellular or P pathway, which processes high spatial frequency information about fine detail, is unimpaired. A difficulty for the M deficit hypothesis has been the lack of a role for the M pathway in the perception of fine detail that is obviously important in reading. However, there are several explanations as to the role the M system plays in reading, and how an impaired M system may contribute to dyslexia. Breitmeyer (1980; Breitmeyer & Ganz, 1976) originally argued that the M system suppressed perception by the P pathway during saccades so information from one fixation did not persist into and overlap the perception from subsequent saccades. Evidence the M system, not the P system, is actually inhibited during saccades challenged this hypothesis (Burr, Morrone, & Ross, 1994; although see Castet & Masson, 2000, for contrary evidence). Stein (2003) also argued that overlapping percepts from one fixation to the next should result in maximum superimposition of letters around the boundaries of a saccade, which are at about seven character spaces. However, letters spaced that widely are not confused by dyslexic readers (Cornelissen, Hansen, Gilchrist, et al., 1998).

More recently, there have been alternative explanations of the role of an M system dysfunction in reading problems. The M pathway is involved in binocular stability, and binocular instability is related to reading difficulties (Cornelissen, Bradley, Fowler, & Stein, 1991; Eden, Stein, & F. B. Wood, 1993; Eden, Stein, M. H. Wood, & F. B. Wood, 1993; Stein, 1994a). Stein argued that binocular instability was sufficient to explain the unstable perceptions, impaired sense of visual direction,
visual confusion, and characteristics visual reading errors found in dyslexia. As further evidence of a causal relationship between binocular instability and reading problems, reading improved under monocular conditions (Cornelissen, Bradley, Fowler, & Stein, 1992; Stein & Fowler, 1985). It also improved after occlusion of one eye for several months (Stein, 1994a), although only in around half of the dyslexic group and only in younger children (Stein, 2003).

Shapley (1992) concluded one function of the M pathway might be to gate signals carried on the P pathway into the cortex. Input from the M pathway reaches higher cortical areas (such as area MT) earlier than P pathway input, feeds back, and influences the processing of input from the P pathway at areas V1 and V2 (Girard, Hupé, & Bullier, 2001; Nowak, Munk, Girard, & Bullier, 1995). Hupé and colleagues (2001; Hupé et al., 1998) concluded this feedback played an important role in figure segmentation, because it allowed combination of the global analysis, fed back from area MT, with the detailed representation characteristic of areas V1 and V2. Therefore, this integrated model posits global-to-local and, most likely, 3D to 2D processing, in direct contrast to Marr’s (1982) local-to-global, 2D to 3D model. Thus, although the M pathway does not process information on fine detail that is important in reading, the global information it carries guides processing of that fine detail. If the M pathway is sluggish, this feedback system may be disturbed. M pathway information may not reach the higher cortical areas sufficiently ahead of P pathway information for the global computations performed in those higher areas to be fed back to, and influence, the local processing of the P pathway information in V1 and V2. This may result in either lower or less synchronised activation in V1 and V2. Poorer processing of fine detail may occur, and reading problems are a possible end-result.
Another explanation focuses on the role of the posterior parietal cortex (PPC) in attention. The M pathway provides the dominant input to the posterior parietal cortex. The PPC is sensitive to direction of motion and gaze and is involved in eye-movement control, visuo-spatial attention, and peripheral vision. Thus, it would play an important role in reading. Attentional shifting to target locations is an essential precursor to saccades (McPeek, Maljkovic, & Nakayama, 1999), and attentional shifting and eye movement both involve activation of similar areas in the parietal, frontal, and temporal cortex (Corbetta et al., 1998). The right intraparietal sulcus region is important in capacity-limited attentional processing (Marois, Chun, & Gore, 2000). Stein and Walsh (1997) argued that slight impairments in the M pathway at lower levels like the Lateral Geniculate Nucleus (LGN) might multiply up to greater deficits in the PPC. Lesions (actual or chemically induced) of the PPC can produce acquired dyslexia with characteristic reading errors, such as letter omissions and letter naming errors (Brunn & Farah, 1991). In milder forms, damage to the M pathway, either at lower levels or at the higher cortical level, could produce the characteristic temporal processing deficits seen in developmental dyslexia. Findings of what they called a prolonged cognitive integration window lead Hari and Renvall (2001) to propose there is sluggish attentional shifting across a range of sensory modalities in dyslexia. Once engaged, attention was slower to disengage in those with dyslexia, compared to control readers. This can explain the characteristic deficits on many tasks, including rapid automatised naming (Obregon, 1994, in Wolf et al., 2000), TOJ accuracy (Ulrich, 1987), temporal dot task (Conlon, Sanders, & Zappart, 2004), and transparent motion (Hill & Raymond, 2002), in which rapid attentional shifting is needed (the latter tasks are described in Section 4.2.3.2 and 4.2.3.3). In addition, sluggish attentional shifting explains difficulties found in dyslexia on visual search.
tasks (Vidyasagar & Pammer, 1999), and in the speed of and difficulty in making
shifts in visual attention (Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000;
Hari, Valta, & Uutela, 1999).

4.2.1 Parallel Visual Pathways: The Magnocellular and Parvocellular
Pathways

Segregation of the M and P visual pathways is already evident in retinal
ganglion cells (Kaplan & Shapley, 1986). About 10% of ganglion cells in the primate
retina are M cells, so named for their large soma. They have extensive dendritic fields
that receive input from a large number of mainly rod, but also some cone,
photoreceptors across the entire retina. They have large, thickly myelinated axons,
which allow rapid transmission. About 80% of primate ganglion cells are P cells.
They are densest in the foveal and parafoveal regions, have small soma, and have
smaller dendritic fields, which receive input almost entirely from cone photoreceptors
(Kaplan & Shapley). The axons are smaller, more thinly myelinated and, therefore,
conduction velocity is slower (Lennie, Trevarthen, van Essen, & Wässle, 1990).

Figure 4.1 shows the location of the visual areas within the brain. Figure 4.2
illustrates the anatomical projections of the M and P pathways. Separate pathways are
distinguishable to the early primary visual cortex (area V1), beyond which the
anatomical separation is less complete. The M ganglion cells project back to the two
Figure 4.1. Location of visual areas V1 to V4 and Area MT (V5) within the cortex. (a) Presents the Magnocellular ("Where") and Parvocellular ("What") systems (from Gazzaniga et al., 2000, p.77). (b) Presents view of cortex with sulci opened out to display the actual locations of visual areas normally concealed within (from Lennie et al., 1990, p.125).
Figure 4.2. Schematic Representation Of Anatomical Projections Of Magnocellular And Parvocellular Pathways From The Level Of The Retina Through To The Extra-Striate Cortex (derived from Talcott et al., 1998).
ventral (magnocellular) layers, I and II, of the dorsal lateral geniculate nucleus (dLGN), and the P cells project to the dorsal layers, IV to VI (Perry, Oehler, & Cowey, 1984). The ventral M layers send thickly myelinated axons to layer IVCα in area V1 of the visual cortex (also referred to as area 17 or the striate cortex), whereas the dorsal P layers project to layer IVCβ in V1. From here, the M pathway projects to layer IVB and then to the blobs of layer III. The P pathway projects to IVA and the blobs and interblobs of layer III (Lennie et al., 1990). It is in the blobs that the M and P pathways first converge to some extent (Shapley, 1992). However, while there is no longer complete anatomical segregation, the M pathway provides more input to the extra-striate area of the middle temporal cortex (Area MT, also called area V5) and to the dorsal stream of the occipital cortex, which projects mainly to the posterior parietal cortex. From IVB, projections either go directly to Area MT (V5) or go via the thick stripes of area V2 and area V3 (Lennie et al., 1990). Area MT is involved in perception of motion (Newsome, Wurtz, Duersteler, & Mikami, 1985). Projections from area MT go via the superior temporal cortex to the posterior parietal cortex (PPC), which is involved in spatial constancy and figure-ground segregation (Lehmkuhle, 1993). In contrast, the P pathway provides more input to the ventral stream, which projects mainly to the inferotemporal cortex. From IVA, the P pathway projects to the thin stripes of area 18 (Livingstone & Hubel, 1984), and then to V4 and the inferotemporal cortex (Lennie et al.). The inferotemporal cortex is involved in perception of form and shape (Mishkin, Ungerleider, & Macko, 1983). The M pathway also projects to the inferotemporal cortex (Merigan & Maunsell, 1993). Although the M and P pathways anatomically converge in areas beyond IVC, input from M neurons reaches V1 around 20 ms earlier than input from P neurons (Nowak et al., 1995). Thus, there is temporal segregation of input to these higher cortical
areas. The first activity that arrives at V1 and higher areas of the cortex is carried on the M pathway. Due to its functional properties, it is ideal for a first-pass global analysis of the visual scene (Bullier, 2000). These two pathways differ in their chromatic, spatial, and temporal sensitivity (Table 4.1). About half of the M cells are broadband; they give the same response to all wavelengths of light, so are effectively colour-blind. The remaining Type IV M cells are sensitive to red light. All P cells respond to colour (Kaplan & Shapley, 1986). Due to their larger dendritic fields, M cells respond to low spatial frequency information; P cells to high spatial frequency information. M cells are about eight times more highly sensitive to contrast than P cells (Kaplan & Shapley). Contrast refers to the luminance difference between the dark and light areas of a pattern. The average conduction velocity of M pathway is about 21 m/sec, compared to about 13 m/sec for P cells, so the visual latency of M cells is shorter than that of P cells (Shapley, 1992). M cells respond at stimulus onset and offset or to visual transients (Shapley & Perry, 1986). They are sensitive to high temporal frequency, so are involved in the detection of motion (Lennie et al., 1990). Area MT, to which the M pathway projects, is involved in processing motion (Newsome et al., 1985). P cells are sensitive to low temporal frequency or slowly moving stimuli (Shapley).

In summary, any low temporal/high spatial frequency, coloured stimulus will preferentially stimulate the P pathway. Any high temporal/low spatial frequency stimulus, which has low luminance contrast, will preferentially stimulate the M pathway. There is physiological and anatomical evidence of abnormalities in the M pathway in dyslexia, so this aspect of the temporal processing deficit hypothesis is often referred to as the magnocellular deficit hypothesis. Convergent supporting
evidence comes from physiological, anatomical, and psychophysical studies, which are reviewed in the following sections.

Table 4.1

*Functional and Anatomical Properties of the Magnocellular and Parvocellular Pathways*

<table>
<thead>
<tr>
<th>M PATHWAY</th>
<th>P PATHWAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitive to high temporal frequency-</td>
<td>Sensitive to low temporal frequency</td>
</tr>
<tr>
<td>rapidly moving stimuli</td>
<td></td>
</tr>
<tr>
<td>Detect motion</td>
<td>Not sensitive to motion</td>
</tr>
<tr>
<td>Transient response to stimulus onset</td>
<td>Sustained response</td>
</tr>
<tr>
<td>and offset</td>
<td></td>
</tr>
<tr>
<td>Sensitive to low spatial frequency-</td>
<td>Sensitive to high spatial frequency-</td>
</tr>
<tr>
<td>global pattern</td>
<td>fine detail</td>
</tr>
<tr>
<td>Respond to low contrast</td>
<td>Respond to high contrast</td>
</tr>
<tr>
<td>Colour “blind”</td>
<td>Colour vision</td>
</tr>
<tr>
<td>Large axons- fast transmission</td>
<td>Smaller axons- slower transmission rates</td>
</tr>
<tr>
<td>Short latency</td>
<td>Longer latency</td>
</tr>
<tr>
<td>More dense in periphery of retina</td>
<td>More dense around fovea</td>
</tr>
<tr>
<td>Large cells</td>
<td>Smaller cells</td>
</tr>
</tbody>
</table>

4.2.2 *Physiological and Anatomical Evidence*

Visual evoked potentials (VEPs) provide information about the time course of the sensory or cognitive processing of visual stimuli with millisecond resolution. VEPs are extracted from EEG data by averaging brain responses to several equivalent trials of a stimulus. The VEP components are designated by their polarity, positive or negative, and by the latency of their maximal amplitude in milliseconds. The negative evoked potential, which occurs about 100 ms post-stimulus (N100) represents the
response to the sensory activity from the stimulus. The positive wave with latency of 100 – 150 ms (P100) is related to early visual perception (Breznitz, Shaul, & Gordon, 2003).

Groups of adults and children (8- to 11-year-olds) with dyslexia showed delayed N100 and P100 responses, relative to the control groups, to visual stimuli designed to stimulate the M system, (Lehmkuhle et al., 1993; Livingstone et al., 1991). Lehmkuhle et al. found when uniform field flicker, which engages and masks the response of the M pathway, was introduced, the control readers also showed longer latency. Thus, with the M system response compromised, the VEPs of the control group closely resembled those of the dyslexic group. Livingstone et al. interpreted these delayed VEPs as consistent with impairment in the M pathway at the level of V1 or earlier. By contrast, there were no significant between-group differences to stimuli designed to stimulate the P system. To clarify their VEP findings, Livingstone et al. examined the brains of five adult developmental dyslexics and five controls at post-mortem. The dyslexics’ brains showed selective atrophy (27% smaller than controls) and disorganisation in the M layers of the dLGN that was consistent with the slowed VEP response in the M pathway. The P layers showed normal cell structure. Using the same brains, Jenner, Rosen, and Galaburda (1999) examined area VI. Rather than the expected finding of similar selective atrophy and disorganisation in the M layer IVCo, they found leftward asymmetry in neuronal size in the controls' brains, but symmetry in the dyslexics' brains. In other words, in the controls’ brains the M layer neurons were larger in the left hemisphere than the right. As language processing predominantly occurs in the left hemisphere, this asymmetry is consistent with specialisation for language functions (including reading). In the dyslexic brains, these left hemisphere neurons were not larger, which may result in reading deficits.
There are some contradictory VEP findings. Victor, Conte, Burton, and Nass (1993) failed to find VEP differences between dyslexic and control groups to M system-specific stimuli. However, differences in sample selection may explain this. They relied on self-reported history of unexpected reading failure rather than a more formal assessment and their subjects ranged from 6 to 46 years old. Farrag, Khedr, and Abel-Naser (2002) found no significant differences between a group of Grade 4 Arabic-speakers with dyslexia and a control group to M system-specific stimuli, but a significantly delayed P100 to P system-specific stimuli for the dyslexic group compared to the control group. This was consistent with an impaired P pathway. No studies have replicated this.

fMRI studies showed decreased activation in a group of adults with dyslexia, relative to an age-matched control group, in both V1 and area MT while performing M pathway-specific tasks: speed discrimination (Demb, Boynton, & Heeger, 1998) and visual motion detection tasks (Eden et al., 1996). No differences in activation occurred during conditions designed to stimulate the P system: stationary pattern stimuli (Eden et al.) or high mean luminance conditions (Demb et al.). Section 4.2.3.3 discusses these findings in detail. Using similar tasks with magnetoencephalography (MEG) recordings, Vanni, Uusitalo, Kiesilä, and Hari (1997) failed to find significant between-group differences in activation between Finnish-speaking adult dyslexic and control groups, but found a trend for longer latencies for the dyslexic group. They interpreted the longer latencies as possibly being due to increased P pathway contribution (with slower transmission) to area MT in the dyslexic group, presumably in compensation of the diminished M pathway input.

Another technique that has produced convergent results of M pathway abnormality is magnetic resonance spectroscopy, which characterises the biochemical
activity of the brain. Cellular density, cellular energy, and neuronal density were assessed in 14 dyslexic and 15 non-dyslexic age-matched males (Rae et al., 1998). The dyslexic group showed a reduced total of cell membranes in the temporoparietal lobe, with no concomitant decrease in neuronal volume. This was consistent with altered size of neurons. There was evidence indicative of fewer larger neurons in the cerebellum in the dyslexic group. The largest output from the posterior parietal cortex is to the contralateral cerebellar hemisphere. Thus, they concluded abnormality in the M system continued through from the PPC to the cerebellum.

4.2.3 Psychophysical Evidence

Most evidence of M pathway impairment in developmental dyslexia comes from psychophysical studies. Many different psychophysical tasks demonstrated differences between samples of both children and adults with dyslexia and control groups. The earliest work linking M system impairment and dyslexia came from Lovegrove and colleagues, who examined spatial contrast sensitivity. As in the auditory temporal processing literature, there is also evidence from tasks that focus on rapid sequential processing, such as visual TOJ tasks, and tasks that focus on dynamically changing stimuli, such as motion detection. These different tasks measure the M system at different levels; for example, motion detection tasks measure the higher cortical level of area MT.

4.2.3.1 Spatial Contrast Sensitivity Studies

Contrast sensitivity is the reciprocal of the minimum amount of contrast required to detect a pattern. The spatial contrast sensitivity function (CSF) is the plot of contrast sensitivity against spatial frequency. In macaque monkeys, lesions of the M layers of the LGN resulted in impaired contrast sensitivity for stimuli of lower
spatial and higher temporal frequencies (Merigan & Maunsell, 1990). Lovegrove and colleagues (Lovegrove et al., 1980, 1982; Martin & Lovegrove, 1984; Slaghuis & Ryan, 1999) found significantly reduced contrast sensitivity in groups of children with dyslexia compared to control groups at low to medium spatial frequencies. Mason, Cornelissen, Fowler, and Stein (1993) confirmed these results. Uniform field flicker masking resulted in reduced contrast sensitivity in normal readers, who then performed like the group with dyslexia (Martin & Lovegrove, 1988; Slaghuis & Ryan). Some evidence shows impaired contrast sensitivity may only occur in phonological or mixed developmental dyslexia (Borsting et al., 1996; Slaghuis & Ryan; Spinelli et al., 1997).

However, Skottun (2000) argued that many of the spatial frequencies (e.g., 4 cycles/degree) at which deficits occurred in the dyslexic groups were in the range more likely to stimulate the P pathway neurons. Furthermore, Cornelissen et al. (1995) showed reduced contrast sensitivity only occurred under low luminance conditions; the significant between-groups difference disappeared in children (aged 8 to 12 years) under the higher luminance conditions normally experienced during reading. Using computer simulation, Stuart, McAnally, & Castles (2001) showed greater inattention in the dyslexic group could explain the significant between-group differences.

The only longitudinal predictive study in the magnocellular deficit literature measured the spatial contrast sensitivity function. Lovegrove et al. (1986) measured this function in 201 children at kindergarten (mean age 5;11 years) and showed it significantly predicted reading ability (measured by the Neale Analysis of Reading Ability test) around 2 years later (mean age 8;3 years). This relationship was not explained by differences in memory or receptive vocabulary. Importantly, this study
used a normative sample and demonstrated this aspect of M system function was significantly related to reading across a wide range of abilities. Unfortunately, it has remained the only longitudinal predictive study to date. Similar studies using other measures of the M system, specifically those related to the temporal processing functions of this pathway, are needed. The current study was designed to meet that need. Instead of spatial contrast sensitivity, pre-school measures of visual rapid sequential processing were used as predictors of subsequent reading ability.

4.2.3.2 Tasks Involving Rapid Sequential Visual Stimuli

Visual Temporal Order Judgement Task. Like the auditory analogues, visual temporal order judgement tasks (TOJ) involve judging the order of two rapidly presented sequential visual stimuli. Visual TOJ tasks are sensitive measures of information transmission speed (Ulrich, 1987). According to the general threshold model of temporal-order judgement, there must be a minimal difference between the arrival times of responses to the two visual stimuli at a temporal comparator for order to be correctly perceived. If the two visual responses arrive too closely together, the comparator cannot distinguish the order and perceives them as simultaneous. The ISI between the stimuli and the transmission latencies of the visual signals from the retina to the comparator determine whether the order is correctly perceived (Stelmach & Herdman, 1991). If, in dyslexia, the transmission speed in the M pathway is impaired or sluggish, the minimal ISI needed for perceptual separation of the two stimuli should be longer. In other words, at short ISIs, the group with dyslexia would be less accurate at judging order than the control group, because the signals from the two stimuli would reach the comparator too closely together temporally for the order to be detected. Ulrich’s explanation of the visual TOJ task focussed on attention switching,
attentional dwell time, and the time taken to detect the first stimulus before switching attention to the other stimulus. As soon as the presence of the first stimulus is registered, attention switches to the other stimulus. If attentional dwell time is prolonged or attentional shifting is sluggish, longer ISIs would be required between the two stimuli to allow time for the switch. At short ISIs, the second stimulus would have occurred by the time the attention switched, resulting in the incorrect decision that the second stimulus must have arrived simultaneously with or before the first stimulus.

Visual TOJ has not been studied as often as auditory TOJ. Tallal and Piercy (1973) also tested their language-impaired sample on a visual TOJ task with two green light flashes (75ms duration), but found no significant between-group differences at either short or long ISIs (30 to 305 ms and 428 ms, respectively). A very early study (Muller & Bakker, 1968, cited in Bakker & Satz, 1970) presented two-stimuli sequences of red and yellow light flashes to boys (mean age 12 years) who were either two or four years behind the population norm in reading, despite having normal IQ. Stimulus duration was 100 ms and ISI was 75 ms. The 2-year lag group performed significantly more accurately ($M = 71\%$ correct) than did the 4-year lag group ($M = 58\%$ correct), indicating a positive relationship between degree of M system impairment and reading impairment. There was no control group of average readers against which to compare these results.

In other studies, 8- to 12-year-olds who were reading at least one year below grade level had significantly higher thresholds (ISI required to achieve 75% accuracy) when judging the order of verbal stimuli (BOX and FOX) than age-matched good readers, who were reading at least one year above grade level (Brannan & Williams, 1988a; May, Williams, & Dunlap, 1988). Brannan and Williams reported similar
between-group differences for non-verbal stimuli (# and &). Using the combined sample, they found the minimum ISI required to judge order correctly accounted for 44% of the variance in reading level when stimuli were non-verbal and 30% of the variance when stimuli were verbal. Cacace, McFarland, Ouimet, Schreiber, and Marro (2000) found longer TOJ thresholds, compared to controls, for both auditory and visual stimuli in four children with dyslexia (aged 9 to 11 years), who were resistant to school-based remediation. Unfortunately, all of these studies involved very small samples (n from 4 to 7).

Other studies found no significant between-group differences on visual TOJ, despite finding significant differences on verbal and nonverbal auditory TOJ tasks in the same sample (Heim, Freeman, Eulitz, & Elbert, 2001; Reed, 1989). Ceiling effects on the visual tasks may explain these null results. The stimulus-onset-asynchrony thresholds for Heim et al. were extremely low. Seven participants from the dyslexic group and one from the control group had thresholds of 4 ms or less, which does not seem possible. Farmer and Klein (1993) found a trend toward between-group differences in a sample of adolescents. However, with the groups combined, TOJ performance was significantly moderately correlated with word identification (r = .33), non-word reading (r = .36), and phonological awareness (r = .30).

In adults, Kinsbourne et al. (1991) found the severe dyslexic group had significantly higher thresholds (i.e., longer ISIs required for correct order judgements) than the control group did. However, the recovered dyslexic group did not differ significantly from either the control group or the severe dyslexic group on visual (or auditory) TOJ thresholds. With the combined sample, thresholds were significantly correlated with Gray Oral Reading scores, r = -.39. Lower thresholds were associated
with poorer reading. Thresholds were also significantly correlated with rapid naming speed for objects, which was the best between-groups discriminator. They concluded visual and auditory TOJ thresholds were as useful for discriminating the severe dyslexic group from the control group as the more discriminating among the verbal tasks they used (verbal fluency and verbal memory tasks).

**Gap Detection Task.** Gap detection tasks have also been used with visual stimuli. van Ingelghem et al. (2001) found their sample of 10- to 12-year-old Dutch children with dyslexia required significantly longer gaps than the age-matched control group to perceive two light flashes. Gap detection thresholds were significantly correlated with one-minute word reading ($r = -.47$) and non-word reading scores ($r = -.66$). Thus, less sensitive visual temporal processing was related to lower reading scores. However, Farmer and Klein (1993) failed to find a significant between-groups difference with adolescents, despite finding a significant difference on the auditory gap detection task. With adults, Chiappe et al. (2002) found no significant between-group differences on either the visual or the auditory gap detection tasks. However, they did find gap detection sensitivity was significantly moderately correlated with single word reading scores ($r = .25$ and .26) and phonological processing ($r = .36$ and .32). It is unlikely differences in sample selection or severity of reading disability between the studies explain the contradictory findings, because two studies (Farmer & Klein; van Ingelghem et al.) had quite severely impaired dyslexic participants. Chiappe et al. also had a group whose reading was at or below the 25th percentile. Task differences could not explain the results either. van Ingelghem et al. and Farmer and Klein both used light flashes separated by gaps, whereas Chiappe et al. used two gratings separated by gaps. However, Farmer and Klein suggested their range of ISIs and step sizes (neither reported) might have been too broad to detect subtle group
differences. Developmental differences may explain the different results. Van Ingelghem et al., who found significant between-group differences, had a younger sample than the other two studies, which failed to find differences. Doubt as to whether gap detection tasks measure the construct of temporal processing or general cognitive ability were raised in Section 4.1.2.3 (see Au & Lovegrove, 2001b). This means differences in IQ between the samples may also lead to different results.

A related measure is the temporal-integration-of-form task. Stimuli are presented in a rapid temporal sequence, but also separated spatially in such a way that if the ISI is short, the perception is of simultaneous stimuli that overlap, forming one integrated form. Figure 4.3 illustrates a typical integration-of-form task. When the ISI is longer, the perception is of two individual stimuli, occurring in rapid succession. This task has a more objective criterion (the detection of a fused percept) than the gap detection tasks (perception of a continuous stimulus versus the perception of a gap between two stimuli). Groups of adolescents and adults with dyslexia needed longer ISIs than age-matched control groups to detect two separate stimuli (Chase & Jenner, 1993; Farmer & Klein, 1995; Martos & Marmolejo, 1993), regardless of whether stimuli were verbal or non-verbal (Boden & Brodeur, 1999). This was interpreted as longer duration of visible persistence. Visible persistence refers to the continued perception of a stimulus after it has been physically removed, that is indistinguishable from the actual presence of the stimulus (Lovegrove, 1994). With ISIs shorter than the duration of visible persistence, there is overlap between successive percepts. By contrast, there was no significant between-group difference on an integration-of-colour task, which stimulates the P pathway (Chase & Jenner). However, Hogben, Rodino, Clark, and Pratt (1995) found no significant difference between groups of reading-disabled and control boys (aged 8 to 9 years) on a
temporal integration task. Their task involved a 4 x 4 matrix of dots. A percentage of dots were presented, followed by a variable ISI, and then all, except one, of the remaining dots. When integrated the perception was of a 4 x 4 display of dots with one dot missing. The task was to indicate the position of the missing dot. This task probably also involved spatial processing, which is a P system function.

Figure 4.3. A Temporal Integration-of-form Task.

Note: At short ISIs, the percepts of the vertical and horizontal line stimuli overlap and a cross is perceived.

Temporal Dot Task. Eden, Stein, Wood, M. H., and Wood, F. B. (1995) examined rapid sequential versus simultaneous build-up on the visual system, via a temporal (M pathway) versus a spatial (P pathway) dot counting task. Grade 5 children (10- to 12-year-olds) viewed three to eight dots, which were presented either in rapid succession in the same spatial location (temporal dot task) or simultaneously for 500ms at different random spatial locations (spatial dot task). The task was to count the dots. In the temporal dot task, the ISIs were long enough to ensure visible persistence was not a problem. With verbal short-term memory controlled, there was
a significant difference between the control group \((n = 39)\) and the dyslexic \((n = 26)\) and backward reader \((n = 12)\) groups on the temporal dot task, but no significant differences on the spatial dot task. With the combined sample \((N = 93)\), performance on the temporal dot task was more strongly correlated with scores on the Basic Reading Cluster of the Woodcock Johnson Psycho-educational Battery \((r = .40)\) than was performance on the spatial dot task \((r = .28)\), although both reached significance. There were significant moderate correlations between both tasks and phonological processing (a pig latin task; \(r = .33\) for the temporal task, \(r = .37\) for the spatial task). In a stepwise multiple regression analysis, phonological processing, verbal IQ, age, and temporal dot score (entered in that order) accounted for 73\% of the variance in reading ability, with each predictor making a significant unique contribution. At the final step, the temporal dot score accounted for an additional 9\% of the variance in word identification. Conlon et al. (2004) reported similar between-group effects with university students. After accounting for the effects of IQ and verbal short-term memory, temporal dot accuracy uniquely accounted for 19.27\% of the variance in word identification. The spatial dot task did not make a significant unique contribution.

Booth et al. (2000) examined the relationship between temporal dot performance and measures of orthographic and phonological processing in 35 children and adolescents (aged 11 to 18 years) and 32 adults with dyslexia. After partialling out the effects of age and IQ, temporal dot performance accounted for significant additional variance in both orthographic (irregular word reading) and phonological (non-word reading) skills in the children and adolescents. However, after also partialling out performance on an auditory TOJ task, temporal dot accuracy only accounted for significant additional variance in orthographic processing. Thus,
auditory temporal processing accounted for all of the variance shared between this visual temporal processing task and phonological processing, but the visual task accounted for unique variance in orthographic processing. Results with the adult sample differed. After partialling out the effects of age and IQ, temporal dot performance did not account for significant additional variance in either orthographic or phonological skills. They argued that this was due to amelioration over the course of development of the orthographic difficulties, to which the visual temporal processing problems were related. Hierarchical multiple regression analyses with a standard word identification task, which included a mix of irregular and regular words, supported this interpretation. With the children, performance on the temporal dot and the auditory TOJ tasks accounted for a significant percentage of common variance in word identification, but neither accounted for significant unique variance. With the adults, the temporal dot task did not account for significant variance in word identification. However, the auditory TOJ task accounted for significant unique variance. Few studies to date have examined the unique contributions of auditory versus visual temporal processing to different reading, phonological, and orthographic skills. The current study aimed to do this using a normative sample in contrast to the sample with dyslexia used by Booth et al.

In contrast to Booth et al.’s (2000) finding in their sample of adult dyslexics, Conlon et al. (2004) found the temporal dot task independently accounted for almost 20% of the variance in the same word identification task. Sample differences may explain the different results. Conlon et al. used a combined sample of dyslexic and control university students, whereas Booth et al. (2000) used only adults with dyslexia who attended a centre for adults with learning disorders. Thus, Conlon et al. had a wider range of reading abilities, which may explain the stronger relationship between
temporal dot score and word identification. Once again, stronger relationships between temporal processing and reading ability were obtained using a more normative sample. Furthermore, Conlon et al.'s dyslexic group, although significantly poorer at reading than the control group, were well-remediated with a reading level at or above Grade 7, compared to an average level of Grade 6 in Booth et al.'s sample. There was also more variability in IQ in Booth et al.'s group, although in both studies the effects of IQ were partialled out in the regression analysis.

4.2.3.3 Tasks Involving the Perception of Rapidly Changing or Dynamic Stimuli

Flicker Sensitivity Function. Whereas spatial contrast sensitivity function is determined with static stimuli, flicker sensitivity function is determined using gratings that move back and forth across one cycle at various speeds. This provides a more direct test of the motion-sensitive M pathway. Using a 2-cycle/degree grating, flickering at frequencies between 5 Hz and 25 Hz, Martin and Lovegrove (1987) found adolescents (mean age = 13;8 years) with quite severe reading difficulties (up to 5 years below age expectation) had reduced flicker sensitivity at all temporal frequencies (flicker rate) compared to an age-matched control group, but most markedly at the highest temporal frequencies. Using a 2-cycle/degree grating, flickering at frequencies between 5 Hz and 25 Hz, Martin and Lovegrove (1987) found adolescents (mean age = 13;8 years) with quite severe reading difficulties (up to 5 years below age expectation) had reduced flicker sensitivity at all temporal frequencies (flicker rate) compared to an age-matched control group. This was most marked at the highest temporal frequencies. This was confirmed when slightly younger, less severely disabled readers were compared to both age-matched and reading-age matched control groups (Brannan & Williams, 1988b; Cornelissen,
Mason, Fowler, & Stein, 1993; Felmingham & Jakobson, 1995; Lovegrove, McNicol, Martin, McKenzie, & Pepper, 1989). Similar results were obtained with adults (Talcott et al., 1998). Using the combined sample and a regression approach, Brannan and Williams found flicker sensitivity accounted for 56% of the variance in reading ability in 8- to 12-year-olds.

Not all studies found significant between-group differences in either children (Barnard, Crewther, & Crewther, 1998) or adults (Hayduk, Bruck, & Cavanagh, 1996). However, in the Barnard et al. study, it was possible uniform field flicker masking from the surrounding background suppressed M function in the good readers, producing the null result. Using a large sample of twins and their siblings (8;0 to 19;6 years) and a task based on that of Martin and Lovegrove (1987), Olson and Datta (2002) found lower reading ability was associated with lower sensitivity to both M pathway (1 cycle/degree, 10 Hz) and P pathway (8 cycles/degree, 1 Hz) stimuli. However, their participants were less severely reading disabled than Martin and Lovegrove’s and they used photopic viewing conditions, under which selective participation of the M pathway in detecting the flicker is not guaranteed (Klein, 2002). Amitay, Ben-Yehudah, Banai, and Ahissar (2002) found reading disabled Hebrew adults \( n = 30 \) were significantly less sensitive than the control group on both flicker sensitivity and a control spatial frequency discrimination task (a non-magnocellular task). Olson and Datta and Amitay et al. interpreted their results as evidence of general perceptual processing deficits rather than a specific M system deficit. However, Chase and Stein (2003) pointed out several concerns with Amitay et al.’s results, including a lack of adequate power, poor task specificity, problems in the method of calculating \( z \)-scores, and problems in the sample selection.
Flicker sensitivity appears to be related to phonological processing ability. In a factor analysis, Lovegrove et al. (1989) found flicker sensitivity loaded on the same factor as phonological processing and reading. Lovegrove (1993) argued that this reflected a common underlying process, a generalised temporal processing deficit that also explained the phonological processing deficits. Olson and Datta (2002) found a significant relationship between phonological decoding ability and flicker sensitivity. Borsting and colleagues (Borsting, et al., 1996; Ridder, Borsting, Cooper, McNeel, & Huang, 1996) found flicker sensitivity deficits only occurred in adults with phonological or mixed developmental dyslexia, not in those with surface developmental dyslexia. However, there were some methodological problems with Ridder et al.'s study. Subtype groups were small and they differed significantly on age and IQ. However, an explanation based on IQ should result in overall performance deficits, yet deficits only occurred in the frequencies specific to M system function and not in other frequencies.

*Motion Detection.* Macaque monkeys with lesioned M layers in dLGN showed deficits on a speed discrimination task (Maunsell & van Essen, 1983). Demb, Boynton, Best, and Heeger (1998; Demb, Boynton, & Best, 1998) presented adult university-enrolled dyslexic and control groups with two moving 0.4 cycles/degree sine-wave gratings in succession at low mean luminance. One moved at a constant 20.8 degrees/second; the other moved at a higher, variable speed. The task was to determine which of the two stimuli moved at the faster rate. The dyslexic group ($n = 5$) had significantly higher speed discrimination thresholds than the control group ($n = 5$); that is, they required a significantly greater difference in speed between the two stimuli to correctly determine the faster stimulus. Demb and colleagues also tested the hypothesis that the specific M system deficit occurred on a continuum. With the
sample combined, the speed discrimination threshold was strongly correlated with reading rate ($r = -.84$), and moderately correlated with non-word reading ($r = -.45$) and reading comprehension ($r = -.42$). These results were very similar to the correlations between neural activation measured using fMRI and the various reading measures (Demb, Boynton, & Heeger, 1998). The bivariate correlation between activation in area MT and reading rate was 0.80. Correlations between activity in V1 and reading rate were weaker, but still significant. There were also strong correlations between the psychophysical thresholds and the level of activation in area MT ($r = -0.79$) and V1 ($r = -0.65$). This showed greater activation in the M pathway was associated with greater sensitivity to differences in speed. There was no significant correlation between either the psychophysical threshold or level of brain activation and word identification. This is not surprising because the dyslexic group were bright university students, with well-compensated reading accuracy. Reading rate is a better discriminator of dyslexic versus control groups in that population (Lefly & Pennington, 1991). Unfortunately, these studies involved small samples and two out of the five participants with dyslexia had ADHD and were on Ritalin (although they did not take the medication before testing). The dyslexic group was also females, which is dissimilar to many other studies in which the dyslexic group is predominantly or completely males. These findings need replication in a larger and more tightly controlled study.

Using a speed discrimination task, Amitay et al. (2002) provided less clear support for the temporal processing hypothesis. They found significant between-group differences with dyslexic and control Hebrew adults ($n = 30$). However, they did not find significant correlations between speed discrimination and reading, phonological processing, or orthographic processing. However, as mentioned, this
research has been criticised methodologically and statistically (Chase & Stein, 2003). Ramus et al. (2003) did not find significant between-group differences with adults. These studies did not examine neural activation during performance on this task. To date, speed discrimination has not been used with younger samples.

More research has used coherent motion tasks than speed discrimination. Motion detection sensitivity is tested using random dot kinematograms (RDKs), in which a percentage of randomly spaced dots move in the same direction (i.e., coherently) and the remainder show random motion. The perception of global coherent motion arises because the neurons at MT sum over both time and their large receptive field. If there were smaller M cells at dLGN in dyslexia (Livingstone et al., 1991), there would be under-sampling of the moving stimuli and reduced sensitivity to coherent motion (Stein, 2003). Using fMRI, Eden et al. (1996) found normal activation in areas V1 and V2 using a stationary visual pattern (P pathway dominant), but only one of six dyslexics showed activation in area MT with low contrast randomly moving dots (M pathway dominant). All of the control participants showed activation in area MT with this stimulus.

Groups of children and adolescents (Cornelissen et al., 1995; Raymond & Sorensen, 1998; Slaghuis & Ryan, 1999; Talcott et al., 2003) and adults with dyslexia (Conlon et al., 2004; Cornelissen et al., 1995; Talcott et al., 1998; Witton et al., 1998) showed significantly poorer coherent motion detection than age-matched control groups. This consistent finding of impaired motion detection was obtained using various task parameters, samples of varying ages, and both English- and Norwegian-speaking participants. In Raymond and Sorensen's study, 70% of the dyslexic group had higher thresholds (less sensitive to motion) than the upper 99% confidence limit for thresholds in the control group. However, Kronbichler et al. (2002) found no
significant group differences between Grade 7 German boys with impaired reading fluency and poor spelling \((n = 20)\) and control group readers \((n = 20)\). Other studies with German children, who are often chosen based on spelling difficulty, have found no significant differences on both auditory and visual measures of temporal processing (Heim et al., 2001; Schulte-Körne et al., 1999).

Raymond and Sorensen (1998) found the motion coherence threshold for the group with dyslexia (mean age 9;9 years) was double that for the age-matched control group when seven-frame RDKs were used. However, with two-frame RDKs, there was no significant between-groups difference, even when the frame duration was adjusted so the total duration was the same as the seven-frame RDK. Thus, dyslexic children had difficulty in integrating motion information over time, or poor temporal recruitment, rather than a difficulty with motion detection, \textit{per se}. This was consistent with dysfunction in area MT. To test this hypothesis of poor temporal recruitment, Hill and Raymond (2002) compared performances on a similar unidirectional motion detection task and on a transparent, or bi-directional, motion detection task. In the transparent motion detection task, half of the dots move in one direction (e.g., leftward) and the other half in a perpendicular direction (e.g., downward), giving the perception of two transparent sheets of dots slipping over each other. Using adults, rather than children, and age-matched controls, they found little evidence of apparent motion deficits in the dyslexic group, compared to the control group. However, they used double the dot density of Raymond and Sorensen, which may have stimulated the motion detection system of the dyslexic group sufficiently to allow them to detect motion as well as the control group. By contrast, they found significantly lower transparent motion sensitivity in the dyslexic group than in the control group. Thus, the group with dyslexia were significantly poorer at detecting the two directions of
Six out of seven participants in the dyslexic group had transparency thresholds (the number of frames needed to achieve 75% accuracy in judging motion) above the upper 99% confidence limit calculated on the control group mean. This was consistent with a higher order deficit in integration and segmentation of motion information. This could be due to difficulty disengaging and reengaging attention from one moving sheet to the other, which would occur if attentional shifting were sluggish.

The relationship between coherent motion detection and reading skills was examined in normative samples. With the effects of IQ and reading ability removed, Talcott et al. (2000) found a significant moderate correlation between motion coherence sensitivity and orthographic processing but not phonological processing in 32 children aged 10 years. Talcott et al. (2002) used a larger sample of 7- to 11-year-olds. With age and nonverbal IQ entered first in a hierarchical regression analysis, motion coherence accounted for an additional 3% of the variance in literacy and phonological skills and an additional 7% of the variance in orthographic skill. After the effects of IQ, age, reading ability, and phonological awareness were controlled, Cornelissen, Hansen, Hutton, Evangelinou, and Stein (1998) found there was a significant positive, non-linear relationship between motion thresholds and the number of orthographically inconsistent letter errors (e.g., reading *suspect* as *sub pact*) in a sample of 58 children (aged 9 to 11 years).

Whilst most studies found coherent motion deficits in the group with dyslexia, these deficits are only subtle compared to the effects of lesions in area MT. Zeffiro and Eden (2000) related this to similar compensation that occurred in monkeys after complete destruction of the neurons in area MT. In humans, if the M pathway was damaged *in utero* (Galaburda et al., 1985), neural plasticity during development may
result in compensation and only mild deficits. Several imaging studies (Breier, Panagiotis, et al., 2003; B. A. Shaywitz et al, 2002; S. E. Shaywitz et al., 1998, 2003; Temple et al., 2001) conducted during performance on various tasks, showed activation in dyslexics in different brain areas to that of controls, indicative of neural compensation having occurred.

4.2.3.4 Relationships between Measures of Visual Temporal Processing

Few studies have incorporated multiple measures of visual temporal processing and fewer still have reported the relationships between these measures. Different visual temporal processing measures assess the M pathway at different points and involve different generic task demands, including memory and attention. If the different tasks are measuring the same construct, there should be significant correlations between performances on different measures and similar deficits in the same sample.

In a sample of adolescents, Farmer and Klein (1993) found a trend toward between-group differences on a visual TOJ and no significant difference on gap detection. Methodological flaws with their gap detection task can partially explain this difference. Talcott et al. (1998) found significantly poorer performance, relative to an age-matched control group, for an adult group with dyslexia on two measures of temporal processing of dynamic stimuli; flicker sensitivity and coherent motion detection. There was a significant moderate correlation between performances on these two tasks ($r = -.494$). Together the two measures correctly discriminated 72.2% of the dyslexic group from the control group, which was consistent with previous reports that 75% of dyslexics have M system weaknesses (Slaghuis & Lovegrove, 1985). By contrast, only 17% of control group showed these combined visual
temporal processing deficits. The combined measures accounted for 48% of the 
variance in non-word naming. This combination of visual tasks taps both subcortical M pathway function at the level of retina to LGN (flicker sensitivity) and cortical areas of the dorsal stream at area MT (coherent motion).

However, others failed to find similar deficits on different measures of sensitivity to dynamically changing stimuli. Amitay et al. (2002) found a significant deficit in a group of Hebrew-speaking adults with dyslexia on speed discrimination, but not on coherent motion detection. Ramus et al. (2003) failed to find significant deficits on either of these tasks in English-speaking adults. However, methodological issues such as the number of frames presented and the density of the dots used in different motion coherence studies may explain different results.

Conlon et al. (2004) is the only study with measures of rapid sequential processing and processing of dynamic stimuli. Around 90% of both the adult poor and good reader groups were correctly classified using combined performance on the coherent motion and temporal dot tasks. Perception of rapid sequential stimuli (temporal dot task) was a more important contributor to the discriminant function than perception of dynamically changing stimuli (coherent motion detection task). There was only a weak correlation between these measures. By contrast, Talcott et al. (1998) found a moderate correlation between two measures of dynamic temporal processing. Thus, although these tasks measure the same construct of temporal processing, they measure quite different aspects of it. Tasks that both assess the processing of dynamic stimuli may be expected to produce stronger correlations than found with a task that assesses rapid sequential processing and a task that assesses processing of dynamic stimuli. To date, no studies have included multiple measures
of visual temporal processing with young children to examine the relationships between measures.

4.2.3.5 Conclusions and Current Research Emphasis

Taken together the results of the anatomical, physiological, and psychophysical studies provide convergent evidence of temporal processing deficits associated with an impaired M system in dyslexia. However, in a review of seven studies reporting significant between-group differences Ramus (2003) found only 29% of participants with dyslexia had higher visual thresholds (poorer temporal processing) than the control group. This is one explanation for some of the contradictory findings with between-group designs. Differences in task parameters may also explain some of the inconsistent findings. However, as Stein (2003) acknowledged, these M system effects are only modest, accounting for around 20% of the variance in reading. Stein, Talcott, and Walsh (2000) argued that these modest deficits in behavioural tasks would only occur when demands on the M system were high. Therefore, greater differences may be expected with more demanding tasks. The temporal dot task is probably a more demanding measure of rapid sequential processing than the TOJ and gap detection tasks, and the transparent motion detection task is more demanding than the coherent motion detection task. In existing between-groups designs, different sample selection criteria may also bias the likelihood of finding significant differences. Temporal processing deficits may only occur in phonological subtypes of dyslexia. The use of normative samples and a regression approach can potentially overcome these issues. This approach is consistent with the view of dyslexia as part of the continuous distribution of reading abilities.
What is particularly lacking in the temporal processing literature is longitudinal evidence to determine if pre-existing temporal processing ability predicts later reading ability, and to provide information on the development of visual temporal processing during the period of early reading development. No studies with children have incorporated multiple measures of visual temporal processing to determine if performances across different tasks produce similar results in the same sample. The current study used two measures of rapid sequential processing; a visual TOJ and a temporal dot task. The temporal dot task was expected to be more demanding perceptually as it involved processing of multiple stimuli in rapid succession, compared to the visual TOJ, which involved processing of two stimuli in rapid succession. Thus, moderate M pathway impairments may be better detected by the temporal dot task. Both were measured prior to reading and used as predictors of pre-reading skills and subsequent reading skills.

There is also little knowledge regarding whether different temporal processing measures are better able to detect deficits at different points in development. Using an inappropriate measure of temporal processing for the developmental stage of the sample may explain some of the inconsistent results in the existing literature. In the phonological processing literature, results vary depending on the age at which phonological skills are measured, and the measured used. For example, rhyme detection measured after about 6 years of age may not predict reading as well as another more developmentally appropriate measure such as phoneme segmentation. These sorts of issues remain unexplored in the temporal processing literature, but constitute one of the aims of the current study.
4.2.4 Development of Visual Temporal Processing

Some aspects of visual temporal processing develop very early. Others continue to develop throughout childhood, while reading is developing. The spatial contrast sensitivity function in 4-year-olds was 0.5 log units lower (less sensitive) than in adults (Atkinson, French, & Braddick, 1981; Beazley, Illingworth, & Greer, 1980). Seven-year-olds showed adult-like sensitivity (Ellemberg, Lewis, Liu, & Maurer, 1999). Temporal contrast sensitivity at 20 and 30 Hz temporal frequencies was at adult levels at around 4 years of age, whereas sensitivity for lower temporal frequencies (5 and 10 Hz) did not show adult-like levels until around 7 years of age (Ellemberg et al., 1999). Crewther and colleagues (Barnard et al., 1998; Crewther et al., 1996) found flicker sensitivity thresholds were significantly higher (i.e., less sensitive) in the kindergarten group (6 years) than in the Grade 3 (8 years), Grade 6 (11 years), or adult groups. Only the Grade 6 group showed adult-like Visual Evoked Potentials to this task (Crewther et al).

On the visual TOJ task, May et al. (1988) found third and fourth grade good readers had significantly higher thresholds (needed longer ISIs for accurate judgement) than good adult readers, indicating development in this ability was still incomplete at 8 to 9 years. Martos and Marmolejo (1993) found developmental changes in both temporal integration-of-form and gap detection tasks, with a linear decrease in the duration of visible persistence (minimal gap needed to detect two separate stimuli) across age groups from 7- to 14-year-olds. This decrease was most marked in dyslexic and poor readers. At 12 to 14 years of age, the difference in visible persistence between dyslexic and poor readers and control readers was much less than with younger age groups. This was consistent with a developmental delay in maturation of this aspect of the visual system in dyslexia. This could explain some of
the null results obtained with older samples on this task (e.g., Farmer & Klein, 1993). Booth et al. (2000) found the accuracy of dyslexic children (aged 11 to 18 years) on the temporal dot task was 86% of that of dyslexic adults (aged 19 to 51 years). Thus, in dyslexia, development in this aspect of visual temporal processing continued into adolescence. The lack of a control sample made it unclear whether this represented a developmental delay in this population, or whether control children were also similarly less accurate than adult controls. No other studies have assessed development in performance on this task.

Braddick, Atkinson, and Wattam-Bell (2003) provided evidence of directional motion processing appearing at around 7 weeks of age, with improving global motion coherence sensitivity in children over 4 years of age. They argued that this development is vulnerable to a range of developmental disorders, including developmental dyslexia. In normal readers, motion coherence sensitivity reaches maturity between 7 and 12 years of age (Cornelissen et al., 1995; Raymond & Sorensen, 1998). Raymond and Sorensen re-tested their sample after 1.3 years and found similar development in both the dyslexic and control groups. In other words, the dyslexic group showed persistent deficits compared to the control group across time.

Raymond & Sorenson (1998) provided the only longitudinal data on development in performance on these tasks. The other studies were cross-sectional, so only informed about age or developmental differences, not how processing actually changes with age. Unfortunately, there is little knowledge about the developmental progression in M system processing and the relationship of this to early reading development, due to this lack of longitudinal studies. One of the aims of the current
study was to examine the development in both auditory and visual temporal processing over the period during which reading development began.

4.3 Is there a generalised temporal processing deficit?

This review demonstrates substantial evidence for auditory and visual temporal processing deficits in dyslexia (albeit with some contradictory findings). However, the hypothesis is often referred to as a generalised pan-sensory temporal processing deficit. Stein (1994a; Stein & Walsh, 1997) argued that common impairments in large cell or magno neurons produced impairments in temporal processing across all sensory modalities; visual, auditory, somatosensory, and motor. This was most likely a result of genetic impairment of development (there is a strong heritability coefficient for dyslexia) or immunological attack in utero (Galaburda et al., 1985; Stein, 1994a, 2003; Stein & Walsh, 1997). This generalised underlying impairment could explain the heterogeneity of dyslexia (different degrees or types of impairment depending on the degree of magno cell impairment affecting processing in different modalities), as well as the existence of phonological, auditory, visual, motor, and timing deficits.

However, there is little evidence to date to support the position of a pan-sensory deficit. Only relatively recently have studies measured both auditory and visual temporal processing abilities in the same sample. Two lines of evidence would support a generalised deficit. Taking a regression approach, significant correlations should occur between measures of auditory and visual temporal processing. Taking a between-groups approach, those who are poor at temporal processing in one sensory modality should also be poor at temporal processing in the other modality. Few studies have reported this information.

van Ingelghem et al. (2001) used very similar auditory and visual gap detection tasks with Dutch-speaking 10- to 12-year-olds. The similarity of the tasks meant
there were minimal differences in other generic task demands between them. This allowed a more direct test of the similarity of temporal processing across the two sensory modalities. There was a significant moderate correlation between auditory and visual gap detection thresholds. Seventy percent of the dyslexic group had thresholds higher than the upper 95% confidence intervals for the mean threshold of the control group on both auditory and visual tasks. This supported a generalised impairment in the majority of dyslexic children. Cacace et al. (2000) found the group of children with dyslexia exhibited deficits on both auditory and visual TOJ tasks, supporting a pan-sensory deficit. Individual data was not provided. However, in Heim et al.’s (2000) study, 10 of the 22 German children with dyslexia ($M_{age} = 13.2$ years), who scored lowest ($\leq 75\%$ correct) on the auditory same-different task, performed well on the visual TOJ task. They concluded poor auditory temporal processing was related to good visual temporal processing. As discussed in Section 4.2.3.2, their thresholds for the visual task were so low as to suggest an error in the data, which raises concerns with any conclusions drawn.

Booth et al. (2000) found strong correlations between (visual) temporal dot and auditory TOJ accuracy in children and adolescents with dyslexia, $r = .59$. This supported the pan-sensory hypothesis. However, there was no significant correlation in the sample of adults with dyslexia ($r = .23$). They concluded there was a common underlying temporal deficit in children, but adults' reading difficulties stemmed from a more specific auditory temporal processing deficit. This relates to the idea that visual temporal processing deficits are specifically related to problems in orthographic processing, which represent a developmental delay, more strongly associated with environmental factors; whereas auditory temporal processing deficits are related to
problems in phonological processing, which continue to show deficits into adulthood, even after remediation, and are more strongly heritable.

Others measured sensitivity to dynamic stimuli across the two senses. Talcott et al. (2000) found a significant moderate correlation in their small sample of 10-year-olds between 2-Hz FM detection and coherent motion detection thresholds ($r = .39$). This supported the pan-sensory hypothesis. However, with a larger unselected sample of 7- to 12-year-olds, there was no significant correlation between these tasks (Talcott et al., 2002). In adults, Witton et al. (1998) found significant correlations between detection thresholds for 2- and 40- Hz FM detection and coherent motion detection thresholds.

According to Ramus et al. (2003), 4 out of the 17 participants with dyslexia in Witton et al.’s (1998) study had visual deficits. Nine out of the 17 had auditory deficits. Further inspection indicated the four with visual deficits also had auditory deficits; that is, 23.5% of the dyslexic sample had deficits in both sensory modalities. With Ramus et al.’s own sample, the two participants from the dyslexic group ($n = 16$) who had visual deficits also had auditory processing deficits. Ten participants in the dyslexic group had auditory only or auditory and phonological processing deficits (showing the relationship between auditory temporal processing and phonological processing). The percentages from Ramus et al. and Witton et al. were lower than were those from van Ingelghem et al. (2001). There are several possible reasons for this. Ramus et al. suggested it was because van Ingelghem et al. used a less conservative criterion for classifying participants as having greater deficits than the control group and did not control for between-group differences in nonverbal IQ. Another reason why Ramus et al.’s study found lower percentages is they used a combined auditory measure based on all temporal and non-temporal tasks, despite
finding significant between-group differences on the two temporal tasks only (auditory TOJ and 2-Hz FM detection). Therefore, it is hard to compare their percentages to those obtained using temporal processing tasks only. It is also possible the greater similarity between van Ingelghem et al.’s auditory and visual tasks (compared to the tasks in the other two studies) produced greater similarity of performance across tasks, and higher percentages showing deficits on both.

Chiappe et al. (2002) reported stronger correlations between the more similar auditory and visual gap detection tasks ($r = .65$) than between the less similar auditory TOJ and visual gap detection sensitivities ($r = .32$). This indicated part of the shared variance was related to shared task demands and part to general temporal ability.

The current study included visual and auditory measures of temporal processing. There were analogous visual and auditory TOJ tasks, which allowed the most direct comparison of temporal processing across these two modalities. There was also a temporal dot task. This allowed a comparison of rapid sequential temporal processing in the visual modality using two different tasks. Based on Chiappe et al.’s (2002) results, stronger correlations were expected between auditory and visual TOJ accuracy than between auditory TOJ and temporal dot accuracy. Similarly, stronger correlations were expected intra-modally (between the two visual tasks) than cross-modally (between the auditory task and either visual task). However, a generalised underlying temporal processing deficit would predict significant cross-modal correlations.
CHAPTER 5: RATIONALE OF THE CURRENT STUDY

The study used a full-panel prospective longitudinal design. Measures of multiple predictor and control variables were obtained at three times from the end of Preschool (non-compulsory year prior to the commencement of formal education) to mid-Grade 2. Multiple measures of reading outcome were obtained at the last two phases. Three phases ensured the design was truly longitudinal and allowed analysis of individual growth curves (Rogosa, 1995). One of the difficulties with longitudinal designs is determining when to make measurements. Inappropriately timed measurement phases may result in a Type II error, due to missing the timing of real effects (Rogosa). The three times were chosen to capture important progressions in early reading development. The first data collection, in the fourth (last) term of Preschool, ensured participants were at the pre-reading stage of development. This was critical to establishing the potentially causal role of the predictor variables in reading development (this is elaborated on later). Word identification was measured at this phase and children were excluded from the analyses if they were already reading. The second phase commenced at the start of term 2 of Grade 1 (6 months later). At this point, children had completed 11 weeks of formal literacy education. This captured the early alphabetic stage in reading development (Frith, 1985). The third phase commenced in term 2 of Grade 2 (12 months later). This captured the abilities of participants once early reading was established. The test–re-test intervals were sufficiently long to allow re-testing without problems, such as practice or memory effects (Fawcett & Nicolson, 1996; Nicolson & Fawcett; 1996; Singleton, Thomas, & Leedale, 1997; Woodcock, 1997).
5.1 **Advantages of a longitudinal design**

Establishment of baseline measures for the predictor variables at the pre-reading stage controlled for the possible confounding effect of pre-existing reading ability on outcome measures. Using pre-readers also provided stronger support for a causal relationship between pre-existing ability in predictor variables and subsequent reading ability. Rack et al. (1993) argued that causal links to reading can only be established when the autoregressive effects of previous reading ability on subsequent ability are first controlled for. Failure to control for this autoregressive effect is a criticism of many existing studies. Partialling out the effects of pre-existing reading ability controls for pre-existing reading ability; so does taking initial measurements at a pre-reading phase.

The two causal hypotheses of interest propose causal relationships between either temporal processing or phonological processing and reading. There are three conditions necessary to establish causality: covariation, non-spuriousness of the association, and temporal precedence (Blalock, 1964). Previous research (detailed in Chapters 3 and 4) established covariation in support of both these causal hypotheses. This research is non-experimental, because random assignment to reading ability is not possible. Non-random assignment results in an inability to establish non-spuriousness completely. Sound methodological control of potential confounds, such as in the current study, becomes essential to rule out spurious relationships. Vellutino et al., (2004) argued that cause could also be inferred from studies that randomly assign to a treatment group, manipulate the hypothesised causal skill, and subsequently demonstrate significantly greater reading ability in that group compared to a control group. There are intervention studies demonstrating this in the phonological processing literature (e.g., Bradley & Bryant, 1983; Byrne & Fielding-
Temporal processing and early reading

Barnsley, 1991, 1993, 1995; Lundberg et al., 1988) and in the auditory temporal processing deficit literature (Habib et al., 2002; Tallal et al., 1997; Temple et al., 2003). There are no such studies in the visual temporal processing literature.

In the phonological processing literature, several longitudinal predictive studies established temporal precedence; that the cause, poor phonological processing, precedes the effect, reading difficulty (Bowey, 1994, 1995; Bradley & Bryant, 1983; Bryant et al., 1990; Ellis & Large, 1987; Lundberg et al., 1980; Muter et al., 1997; Muter & Snowling, 1998; Stanovich et al., 1984). All but two studies of the relationship between temporal processing and reading have been cross-sectional, examining the relationship between these abilities contemporaneously. Share et al. (2002) examined the relationship between auditory temporal processing at school-entry and later reading ability longitudinally. Lovegrove et al. (1986) provided the only longitudinal evidence that pre-existing visual magnocellular function significantly predicts subsequent reading ability. However, Lovegrove et al. used a contrast sensitivity function task, and these tasks have been recently criticised (Skottun, 2000). Neither do they measure temporal processing (although they assess M system function). Longitudinal designs are essential to establishing temporal precedence, and, thereby, the direction and magnitude of the causal relationship (Menard, 2002). The current study regressed Preschool temporal processing measures on Grade 1 and 2 reading measures, in order to examine temporal precedence, and, thereby, the potentially causal relationship.

Taking measures of predictor and criterion variables, and some control variables, at each phase in a full panel design allowed a wide range of questions to be addressed. The major focus of the study, the prediction of later reading from earlier temporal processing measures and the comparison of that with prediction using
Temporal processing and early reading

phonological processing measures, used the cross-lagged effects (the effect of predictors at Phase 1 on criterion measures at Phases 2 and 3; Taris, 2000). The stability of measures across time was determined from the autocorrelations of measures at an earlier phase with the same measures at later phases. There is little existing research regarding stability or development of temporal processing measures. Furthermore, measuring the criterion reading variables at both Phases 2 and 3 (and Phase 1 in the case of the Woodcock Letter-Word Identification subtest) allowed investigation of prediction of growth or change in reading over the initial years of schooling.

A major strength of the design was that it provided a measure of the covariation between these perceptual abilities and reading before any effects of reading failure or reading remediation had occurred. Successful remediation may obscure the expected relationships between reading and temporal processing in older samples with dyslexia because word reading accuracy is elevated to normal levels (e.g., Ahissar et al., 2000). Reading itself may also influence temporal processing. The relationship between phonological processing and reading is reciprocal, such that phonological skills foster reading development, but learning to read fosters further improvement in phonological skills (Wagner & Torgeson, 1987; Wagner et al., 1994). If a similar relationship exists between temporal processing and reading, the temporal processing deficits found in older children and adults with dyslexia could be a result of, rather than a cause of, the reading failure (Ramus, 2004). For example, children who experience reading difficulties, read less. This is what Stanovich (1986) called the Matthew effect (a variation of the *rich get richer and the poor get poorer* adage). If the visual experiences associated with reading actually foster functional development in the magnocellular system, poor readers would develop magnocellular impairments.
because of their reading problem. Various authors argued that longitudinal studies like the current one are essential to determine whether visual temporal processing difficulties precede and potentially cause reading difficulty or arise because of the reading difficulty (Ramus, 2004; Stein, 2001a; Wright et al., 2000). As the current participants were pre-readers when the temporal processing measures were first obtained, the effects of reading experience or reading failure could not explain any covariation found between temporal processing and reading abilities.

5.2 Advantages of a normative sample

Most of the temporal processing deficit hypothesis research has involved selected samples of dyslexic or poor readers and control readers, with very little research involving unselected or normative samples. By contrast, in the phonological processing deficit literature, there is an extensive body of research using normative samples, establishing a potentially causal relationship between phonological processing ability and a wide range of reading abilities. This is consistent with reading ability being a continuously distributed variable (S. E. Shaywitz et al., 1992).

There are several methodological issues associated with existing between-group designs, which could explain some of the inconsistent results in the temporal processing deficit literature. These designs use small samples due to the small percentage of dyslexic readers in the population and the difficulty in obtaining these samples. Small samples limit the generalisability of results, both more broadly to the population and more narrowly to a given individual (Talcott et al., 2002). For example, even with significant between-group differences, there was often much overlap between groups on the temporal processing tasks, with half or more of the participants in the dyslexic group performing as well as the control group. Some studies attribute temporal processing deficits to phonological or mixed subtypes of
dyslexia only (e.g., Borsting et al., 1996; Cestnick & Coltheart, 1999; Slaghuis & Ryan, 1999; Spinelli et al., 1997). Hogben (1996) argued that differences in the mix of subtypes in different studies explained why some studies failed to find temporal processing deficits.

Criteria for defining and selecting dyslexic or poor readers differ markedly between studies, making comparisons difficult and possibly explaining mixed findings (Breier, Gray, Fletcher, Foorman, & Klaas, 2002; Talcott et al., 2002). Using measures that involve phonological processing, such as non-word reading, to select the reading ability groups, ensures most of the dyslexic group are phonological dyslexics. Temporal processing deficits have been found more often when the samples contain phonological dyslexics. However, selection criteria based on real word reading, with many irregular words, produces a more heterogeneous sample of dyslexics, so within-group differences may overshadow between-group differences in temporal processing, producing a null result.

The other problem with selection criteria is the degree of reading deficit used as the cut-off for inclusion in the dyslexic or poor reader group varies considerably between studies. Criteria used in the studies reviewed included self-reported reading disability (Ahissar et al., 2000; Victor et al., 1993); well-documented school records of assessment that confirmed a diagnosis of dyslexia (Amitay et al, 2002; Ramus et al., 2003; Witton et al., 2002); and contemporaneous administration of various reading and phonological processing tests, often using a discrepancy between scores on those tests and age, grade level or IQ (Eden et al., 1995; Hill & Raymond, 2002; Share et al., 2002). The cut-off reading criteria for the dyslexic or poor reader group ranged from less than 5 months behind chronological age (e.g., Mody et al., 1997) to as much as 5 years behind (e.g., Lovegrove et al., 1980, 1982; Martin & Lovegrove, 1984).
Furthermore, the criterion for inclusion in the control group also varies, resulting in more or less separation in reading ability between these groups across studies.

When selected groups are used, conditions such as Specific Language Disability (SLD) and ADHD are more likely in the group with dyslexia than in the control group due to high co-morbidity (Dykman & Ackerman, 1991; Scarborough, 1990; Semrud-Clikeman et al., 1992). Thus, selection introduces potential confounds (Breier et al., 2002). Therefore, it is important to measure language ability and attentiveness, either in order to exclude children or to statistically control for the potential effects of these factors.

Approaches to these methodological issues include using homogeneous samples of dyslexic readers, looking at subtypes at a post hoc point, and/or excluding potentially confounding factors, such as SLD. The alternative approach taken by this study is to use a normative sample. Reading ability is a continuously distributed variable, with a continuum of familial risk (S. E. Shaywitz et al., 1992; Snowling et al., 2003). Gilger and Kaplan (2001) argued that faulty genes that affect neurodevelopment would affect multiple areas of the brain, not just a specific area, like the perisylvian fissure, and would affect them to varying degrees. They also argued that the heterogeneity seen in dyslexia reflects normal brain variability. Thus, M system functioning should also show a continuum of abilities, as should phonological processing. There is evidence temporal processing ability and M pathway function are continuously distributed and related to individual differences in reading measures (Cornelissen et al., 1995; Demb, Boynton, Best, & Heeger, 1998; Demb, Boynton, & Heeger, 1998; Talcott et al., 2000). It makes sense then to investigate the relationship between temporal processing and reading across the range of abilities found in a normal population. Wright et al. (2000) called for a greater
number of normative studies of the relationship between perceptual processing ability and reading ability. The current study was designed to meet this need.

5.3 Choice of measures

5.3.1 Temporal and phonological processing predictor measures

The predictor variables were derived from the phonological processing deficit and temporal processing deficit causal hypotheses of developmental dyslexia (see Table 5.1). There was one auditory temporal processing measure (an auditory TOJ task) and two visual temporal processing measures (a visual TOJ task and a temporal dot task). Neither of the visual measures has been used with a normative sample of beginner readers before. The temporal dot task produced consistent significant relationships with reading in older children (Eden et al., 1995; Booth et al., 2000) and in adults (Conlon et al., 2004). This study examined the relationship of these visual tasks with early reading. Using TOJ tasks in each sensory domain allowed a more direct comparison of the contribution of temporal processing in each modality to reading, without the confounding of differing generic task demands. The visual TOJ and temporal dot tasks both involved processing of rapid sequential stimuli but differed in other aspects. The dot task may have greater perceptual complexity, higher memory load, and greater attentional demands, which may result in better ability to detect mild M pathway impairment. Including two visual tasks allowed the relationship between them to be examined. A total accuracy score was used rather than determining thresholds on these temporal processing tasks as done in many previous studies. This was considered more appropriate with Preschool children, who typically have more limited attention spans and impulse control than the older participants used in previous studies. Short tasks maximised the motivation and attention of the participants.
### Table 5.1

*Predictor, control, and outcome variables*

<table>
<thead>
<tr>
<th>Skills</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phonological Processing</strong></td>
<td></td>
</tr>
<tr>
<td>Phonological Awareness</td>
<td>a) Phonological Segmentation subtest of the Dyslexia Screening Test (DST; Fawcett &amp; Nicolson, 1996)</td>
</tr>
<tr>
<td></td>
<td>b) Rhymes subtest of the Cognitive Profiling System (CoPS, Singleton, Thomas, &amp; Leedale, 1997)</td>
</tr>
<tr>
<td>Rapid Automatised Naming</td>
<td>Rapid Automatised Naming subtest of the Dyslexia</td>
</tr>
<tr>
<td>- Objects</td>
<td>Early Screening Test (DEST; Nicolson &amp; Fawcett, 1996)</td>
</tr>
<tr>
<td><strong>Temporal Processing</strong></td>
<td></td>
</tr>
<tr>
<td>Auditory Temporal Processing</td>
<td>Auditory Temporal Order Judgement- Sound Order subtest of the DEST</td>
</tr>
<tr>
<td>Visual Temporal Processing</td>
<td>Visual Temporal Order Judgement</td>
</tr>
<tr>
<td></td>
<td>Temporal Dot task (modified from Eden et al., 1995)</td>
</tr>
<tr>
<td><strong>Control Measures</strong></td>
<td></td>
</tr>
<tr>
<td>Auditory-verbal memory</td>
<td>Digits Forward subtest of the DEST</td>
</tr>
<tr>
<td>Attentional Vigilance</td>
<td>Guide to Assessment of Test Session Behaviour (GATSB; Glutting &amp; Oakland, 1993)</td>
</tr>
<tr>
<td></td>
<td>Catch trials on temporal processing tasks</td>
</tr>
<tr>
<td>Early home literacy</td>
<td>Parent Questionnaire (Appendix A, questions 1 – 5, 7, 20)</td>
</tr>
<tr>
<td>environment</td>
<td></td>
</tr>
<tr>
<td>Nonverbal ability</td>
<td>Raven’s Coloured Progressive Matrices (Raven, Court, &amp; Raven, 1986)</td>
</tr>
<tr>
<td>Speech/Language Problems</td>
<td>Parent Questionnaire (Appendix A, question 15)</td>
</tr>
<tr>
<td><strong>Reading Measures</strong></td>
<td></td>
</tr>
<tr>
<td>Word Identification</td>
<td>Letter-Word Identification subtest of the Woodcock Diagnostic Reading Battery (Woodcock, 1997)</td>
</tr>
<tr>
<td>Word Decoding</td>
<td>Word Attack subtest of WDRB</td>
</tr>
<tr>
<td>Reading Fluency</td>
<td>One-minute Reading Rate</td>
</tr>
<tr>
<td>Orthographic Processing</td>
<td>Pseudohomophone Decision Task</td>
</tr>
</tbody>
</table>
The phonological predictors represented each of the separate aspects of phonological processing identified by Wagner and Torgeson (1987). There were two measures of phonological awareness; rhyme detection and phonological segmentation. Inclusion of these two measures covered the development in phonological awareness from syllable and onset-rime to phoneme that was expected during the period of the study. Rhyme ability taken before school entry significantly predicted subsequent reading ability (e.g., Bowey, 2002; Bradley & Bryant, 1983); however, by around 6 years of age it was no longer a useful predictor due to ceiling effects (Muter et al., 1997; Muter & Snowling, 1998; Nation & Hulme, 1997; Stanovich et al., 1984). Phonological segmentation is a more useful predictor for older children, although more difficult for younger children (Bowey, 1994; Muter & Snowling, 1998). There was also a measure of rapid automatised naming speed for objects. Rapid naming of objects was chosen because speed at Preschool was significantly correlated with early reading ability (Wolf, 1984), and significantly differentiated dyslexic and control groups three years later (Wolf et al., 1986). Although some studies found stronger results with letter naming speed (Badian, 1993), the current sample could not name enough letters at the initial testing phase to use this. As detailed in Chapter 3, the current study included rapid naming speed with the set of phonological predictors, but did not preclude the notion that it would account for independent components of variance in reading ability. The other aspect of phonological processing identified by Wagner and Torgeson was phonological short-term memory. This was included as a potential control measure, rather than as a phonological processing predictor. It is not thought to be causally related to reading ability, but simply associated with reading ability due to the mutual relationship with poor phonological representations (Snowling, 2000).
5.3.2 Control Measures

One of the strengths of this study was that it controlled for many of the potentially confounding factors not controlled in previous studies. Wagner and Torgeson (1987) criticised many existing studies for not controlling for the effects of verbal short-term memory. Molfese et al. (2001) recommended including Preschool verbal short-term memory in predictive studies, because it significantly predicts early reading (Mann & Liberman, 1984). It also plays a role in the measurement of many other predictors, so is a potential confound. For example, McArthur and Bishop (2001) recommended that auditory memory be included to control for the memory demands of auditory temporal processing tasks.

Many previous studies did not adequately control for IQ (Wagner & Torgeson, 1987). Non-verbal ability was included as an estimate of IQ in this study. Attentional vigilance is also a potentially confounding factor in reading research, especially when measuring temporal processing. Differences in attentional vigilance may influence temporal processing accuracy (Davis, Castles, McAnally, & Gray, 2001; Stuart, McAnally, & Castles, 2001; Talcott et al., 2002). Temporal processing tasks generally involve many uninteresting trials and require sustained vigilance (McArthur & Bishop, 2001). Eden et al. (1995) found a significant correlation between scores on an Attention Deficit Disorder checklist and temporal dot performance (but did not report the relationship between reading and temporal dot counting, with these effects partialled out). Breier, Fletcher, et al. (2003) found the presence of ADHD impaired performance on an auditory temporal processing task. In order to account for any variance due to attentional vigilance on tasks and general test session attentiveness, catch trials were included in each temporal processing measure and the experimenter completed a checklist measure of test session behaviour. Parental report of any
speech and language difficulties in their child (see Appendix A, question 15) allowed
the influence of this variable on the auditory temporal processing and language-based
measures (Heath et al., 1999; Tallal, 1980; Tallal et al., 1993) to be controlled. All
other developmental, neurological, or intellectual impairments were grounds for
exclusion from the study, because these factors may provide alternative explanations
for any reading problems.

The final factor included as a control was early home literacy environment,
because it is related to subsequent reading ability. Scarborough et al. (1991)
questioned the adequacy of simply using frequency of reading to the child. Factors
such as parental listening to the child read or actively coaching the child in reading
subskills appeared to be more important (Burgess, et al., 2002; Elbro et al., 1998;
Sénéchal et al., 1998). The current parent questionnaire (Appendix A) asked about
both passive (e.g., frequency of reading to the child) and active (e.g., frequency of
teaching reading, writing, and the alphabet) literacy practices. Parents also completed
a children’s titles checklist (CTC). These measure print exposure and were shown to
predict reading ability (Cipielewski & Stanovich, 1992; Cunningham & Stanovich,
1993, 1998; McBride-Chang, Manis, Seidenberg, Custodio, & Doi, 1993; Stanovich
& West, 1989). For example, CTC scores accounted for 21% of the variance in
reading in first grade children, after the effects of phonological processing were
partialled out (Cunningham & Stanovich).

5.3.3 Reading Measures

The reading measures were single letter and word identification, reading rate
(fluency), non-word decoding, and orthographic processing. Decoding of single
words in isolation is the critical measure in reading and dyslexia research as it
separates phonological or orthographic decoding ability from the influence of the
contextual cues that are available in text (Vellutino et al., 2004). In other words, there are no other text cues to assist in working out or guessing the word. The measure of fluency was reading rate, the number of words the child correctly identified in one minute. Reading speed is often slower in children with reading problems, due to slow and laborious word recognition, although slow reading rate can occur independently of accurate identification (Fletcher et al., 2002). Significant relationships were found between reading rate and visual temporal processing (Demb, Boynton, Best, & Heeger, 1998; Demb, Boynton, & Heeger, 1998). Non-word reading assessed single word-decoding skills. Using non-words separated out phonological decoding skill (sounding out words) from orthographic skill (recognising words or spelling sequences as visual wholes). There was also a measure of orthographic skill, a pseudohomophone choice task. This task separated out orthographic processing from phonological processing, because the child must choose the correct orthography from two spelling sequences that have identical phonology.

Previous research found different relationships between the predictor measures and these different reading subskills. For example, in children, visual temporal processing was more strongly associated with orthographic processing, and auditory temporal processing with phonological processing (Booth et al., 2000; Cornelissen et al., 1998; Talcott et al., 2000). Rapid automatised naming speed was a more important predictor of word identification than decoding skills (Bowers, 1995). However, there were also developmental differences. Rapid naming speed accounted for similar amounts of variance in word identification and fluency (reading rate) in Grade 1, but by Grade 2, it was more highly predictive of fluency than of other reading sub-skills (Schatzschneider et al., 2002). Thus, the study's design allowed an
investigation of the relationships between different predictors and reading subskills and any changes that may occur developmentally.

5.4 Research Questions

There were several questions of interest:

1. Can measures of visual and auditory temporal processing taken in pre-readers predict individual differences in subsequent early reading development? Based on the existing cross-sectional findings, it was expected that temporal processing ability in pre-readers would significantly predict subsequent ability in single word reading, non-word decoding, reading rate, and orthographic skill.

2. Do visual and auditory temporal processing abilities predict different components of reading? To answer this, differences in the relationship between the different temporal processing predictors and the different reading measures were examined as well as the common and independent components of variance that they accounted for. From existing research, it was expected that visual temporal processing would be more strongly related to orthographic processing, and auditory temporal processing to phonological processing, including non-word decoding.

3. If pre-reading temporal processing ability significantly predicts subsequent reading ability, how does it compare to the ability of pre-reading measures of phonological processing to predict subsequent reading ability?

4. Do temporal and phonological processing account for independent components of variance in reading ability? Is more variance in the reading measures explained by using both temporal and phonological processing predictors together? Commonality analyses were performed to determine the common versus unique variance in the reading measures accounted for by each of these sets of predictors.
5. Does the predictive relationship change with development, as children’s reading development changes from a phonological basis to an orthographic basis? Phonological and auditory temporal processing skills may be most strongly predictive of reading in the earlier stages, followed by an increasing relationship with visual temporal processing as children increasingly utilise orthographic strategies.

6. What is the pattern of development in temporal processing ability from Preschool to Grade 2, during which time reading emerges? Based on existing cross-sectional studies, it was expected there would be significant growth in these skills over this period.

7. How stable are these measures of temporal processing over this period of development? Stability of the temporal processing measures was compared to that of the phonological processing and reading measures, about which there is much more existing knowledge.

8. Does the pattern of prediction of the reading measures change depending on whether the predictors are measured at Preschool or at Grade 1; that is, before or after school-entry? This also provides information on the stability of the relationship between temporal and phonological processing and reading over this period of early reading development.
CHAPTER 6: METHOD

6.1 Participants

One hundred and sixty children were recruited from three local Preschools in 2000 and 2001. Preschool is a non-compulsory year before school entry, during which there is a developmentally appropriate play-based curriculum and no formal literacy instruction. Each Preschool was attached to a Primary school, at which the majority of the children attended Grade 1 in the following year. Two cohorts from three schools were included to increase the representativeness of the sample and to reduce threats to internal validity. Exclusion criteria were known or reported neurological, intellectual, or developmental impairments that might constitute biological risk factors for learning problems (Fletcher et al., 2002); a non-English speaking background; and pre-existing reading ability (a score over 17 on the Letter-Word Identification subtest of the Woodcock Diagnostic Reading Battery, WDRB; Woodcock, 1997).

This resulted in an initial sample of 142 participants. Mean score on the Woodcock Letter-Word Identification subtest was 10.40 ($SD = 2.90$; range 4 – 17). On average, this meant the children knew some, but not all, of the tested letters, with a few children able to identify a couple of words. Table 6.1 gives details of gender and mean age for the sample at each phase. All children had normal non-verbal ability, based on their score on Raven’s Coloured Progressive Matrices (Raven et al., 1986; $M = 108.78, SD = 10.14$, range = 81 – 135). Visual acuity and hearing were normal (or corrected to normal for vision). From parental report, 26 children (18 males, 8 females) had speech/language problems, but only six (3 males, 3 females) had seen a
speech pathologist. Parents of 45 children (31.5%) reported that at least one member of the extended family had a history of reading and/or spelling difficulties.

Table 6.1

**Gender and Mean Age of Sample at each Phase**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Preschool</th>
<th>Grade 1</th>
<th>Grade 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>78</td>
<td>68</td>
<td>60</td>
</tr>
<tr>
<td>Females</td>
<td>64</td>
<td>55</td>
<td>45</td>
</tr>
<tr>
<td>Total N</td>
<td>142</td>
<td>123</td>
<td>105</td>
</tr>
<tr>
<td>Mean age (years, SD)</td>
<td>5.35 (.29)</td>
<td>5.95 (.30)</td>
<td>7.02 (.29)</td>
</tr>
</tbody>
</table>

6.2 Materials and Stimuli

6.2.1 Temporal Processing Tasks

6.2.1.1 Auditory Temporal Order Judgement

A simplified version of Tallal’s (1980) task, the Sound Order sub-test of the Dyslexia Early Screening Test (DEST), was used (Fawcett & Nicolson, 1995; Nicolson & Fawcett, 1996). The DEST is suitable for children aged 4;6 to 6;5 years. A normative study reported prediction rates for reading risk of over 90%, and acceptable false negative (12% – 16.7%) and false positive (around 2 %) rates (Fawcett, Singleton, & Peer, 1998). Prediction details for individual subtests were not reported. Reported one-week test-retest reliability for the Sound Order subtest was 0.64 (N = 26; Nicholson & Fawcett, 1996).
A low tone (duck quack, 166 Hz) and a high tone (mouse squeak, 1430 Hz) were presented in random order, separated by varying ISIs, on audiotape played on a Sony TCM 939 portable tape player. Stimulus duration was 155 ms. The experimental trial ISIs were 8, 15, 30, 60, 150, and 300 ms. These all constituted short ISIs. There were 2 to 3 trials at each of those ISIs. Two trials with 947 ms ISIs were used as catch trials to detect poor vigilance or random responding. There were four identification (single stimulus) and three practice trials (using 300 ms ISIs), followed by the two catch trials (947 ms ISI) and the 14 experimental trials.

Standardised administration procedures were followed. First, identification trials were completed to ensure children could correctly identify the sounds, which they could. Then practice trials were completed. Children only received feedback regarding accuracy on the identification and practice trials. The practice trials were repeated if necessary; however, few children required this. The response format was two alternate forced choice (2AFC). Participants indicated which sound (duck/quack or mouse/squeak) occurred first, and gave their best guess if they were not sure which stimulus was first on a particular trial. The dependent measure was the total number of trials, collapsed across all experimental ISIs, on which the child correctly identified the first sound (accuracy). Previous studies used this overall accuracy measure with children and adolescents in both between-groups and normative designs (Farmer & Klein, 1993; Marshall, et al., 2001; Share, et al., 2002). The maximum possible score was 14.

6.2.1.2 Visual Temporal Order Judgment

This task was based on the methodology of Reed (1989). Nonverbal stimuli were used because they constitute purer tests of visual deficits than verbal stimuli,
which involve greater phonological processing (Vellutino, 1979). The task was presented on an IBM compatible PC with a 17-inch monitor and a screen refresh rate of 18 ms. Viewing was binocular and performed under natural light conditions, with a viewing distance of 57 cm from the screen. Stimuli were presented on a grey background (space average luminance 15 cd/m²). A 500 ms high frequency auditory tone cue preceded each trial. A central white fixation cross was visible throughout each trial. Presentation of the first stimulus, randomly to either the left or right of fixation, occurred 500 ms after the onset of the fixation cross. Stimuli were white circles, subtending 1° of visual angle at a viewing distance of 57 cm. Stimulus duration was 83 ms and ISIs of 55, 75, 100, 150, and 200 ms separated presentation of the first and second stimulus circles. The second stimulus appeared on the opposite side of the fixation cross. The proximal distance of each stimulus to central fixation subtended 2° of visual angle.

Firstly, the children were trained to fixate on the central cross. The experimenter initiated each trial, after ensuring that the child was correctly seated and fixated on the cross. There were four identification trials (single stimulus only) and four practice trials (two trials each at 44 and 200 ms ISIs), followed by a total 40 experimental trials (eight trials per ISI, half with initial right presentation and half with initial left presentation). Eight catch trials, on which only a single stimulus appeared, were interspersed randomly among the experimental trials to detect poor vigilance or random responding. The experimental trials were presented in four blocks of 10 trials each, with rests in between. Only two blocks were administered on any day. As in the Auditory TOJ task, the identification trials were completed first to ensure children could correctly identify the side of the computer on which the circle stimulus occurred. Once it was clear there were no difficulties with basic
discrimination of side of presentation, the practice trials were completed. Children only received feedback regarding accuracy on the identification and practice trials. These trials were repeated if necessary; however, few children required this.

To be consistent with the auditory TOJ task, there were pictures of a duck and a mouse attached to opposite sides of the computer screen on a black surrounding mask. This identified the side of the computer on which the circle appeared. The required response was whose circle appeared first (the duck's or the mouse's), indicated verbally or by pointing to the side or to the picture. The experimenter entered the responses via the keyboard. A 2AFC response format was used. The dependent measure was the number of trials, collapsed across ISI, on which the response was correct (accuracy). This was consistent with the Auditory TOJ measure and with previous studies (Farmer & Klein, 1993). The maximum possible score was 40.

6.2.2.3 Temporal Dot Task

This was a simplified version of the Eden et al. (1995) temporal dot task. Parameters were the same as Conlon et al. (2004). Viewing conditions and distance were the same as for the Visual TOJ task. The Temporal Dot task was created using Director Version 6.5, and was presented on a Macintosh computer with a super VGA monitor. Participants fixated on a black central fixation cross, which was presented on a grey background (space average luminance 15 cd/m$^2$) for 1s. After a variable interval (666 to 750 ms) from offset of the fixation cross, the stimuli appeared. Stimuli were black squares (“dots”) with 1 cd/m$^2$ luminance. Each square subtended 0.30° of visual angle at the viewing distance of 57 cm. On any trial, a sequence of 1 to 5 dots appeared at the central fixation point. In total, there were six trials for each number of dots (30 trials), presented in randomised order. The duration of each dot
was 40ms. Single dot trials served as catch trials. ISIs between dots were randomized, and ranged from 250 to 366 ms. Pilot testing showed ISIs less than 250 ms were too short for this younger sample to process, resulting in a very high miss rate for the next dot. With ISIs over 366ms, the children assumed the sequence had finished and responded prematurely, missing subsequent dots, again leading to a high error rate. The variable intervals between stimuli ensured there was no predictable rhythmic pattern to the dots that may have assisted counting. Intervals were long enough to exceed visible persistence and to ensure backward masking did not occur.

The ability of the child count groups of up to six objects in a group was assessed first to ensure they could count accurately up to the five dots required on this task. Children were told that once the cross disappeared, they would see a number of dots flash up, one after the other, where the cross had been, and that they had to count the number of times the dots flashed and tell the experimenter as quickly as possible. Children responded verbally and the experimenter entered the response. Five practice trials (one with each number of dots, in random order) preceded the experimental trials to ensure children understood the task instructions. Feedback was only given during practice. Trials were repeated if necessary, with the experimenter modelling the required behaviour and responses. Following this, there were two blocks of 15 trials each (three trials at each number of dots), with an intervening rest period. The dependent variable was total accuracy, summed across all trials. Maximum possible total accuracy score was 24 (six trials each for 2 to 5 dots).

6.2.2 Phonological Processing variables

There were two measures of phonological awareness (a rhyme and alliteration detection task and a phonological segmentation task), and a rapid automatised naming of objects task.
6.2.2.1 Rhyme and Alliteration Detection

This was the Rhymes subtest of the Cognitive Profiling System (CoPS; Singleton et al., 1997), a computerized early screening test for children aged 4;6 years and over. Fawcett et al. (1998) reported prediction rates using the CoPS for reading risk of over 90%, and acceptable false negative (12.0% to 16.7%) and false positive (around 2%) rates. In validation studies, there was a strong correlation \(r = .52, p < .001\) between Rhymes performance at 5 years and single word recognition at 8 years (Fawcett et al., 1998).

Standardised testing procedure was followed. Participants heard four stimulus words, accompanied by pictures presented on the computer screen (to reduce memory demands), and followed by the target word and picture (see Figure 6.1). The task was to choose the stimulus word that sounded like the target for the rhyme task, or that started with the same sound for the alliteration task. At Phase 1 (Preschool), the children only completed the rhyme detection task. At Phases 2 and 3 (Grades 1 and 2), children did the alliteration detection task once they had reached 100% accuracy on the rhyme detection task. There were eight rhyme and eight alliteration trials. The task took approximately 6 minutes. The dependent measure was the total number of items correctly detected (accuracy). The maximum score at Phase 1 was 8 (rhyme detection only) and at Phases 2 and 3 was 16 (rhyme plus alliteration detection).

6.2.2.2 Phonological Segmentation

The Phonemic Segmentation subtest of the Dyslexia Screening test (DST; Fawcett & Nicolson, 1996) was based on Rosner and Simon's (1971) Auditory Analysis test. Reported one-week test-retest reliability with 34 children aged 6;6 to 12;0 years was 0.88 (Fawcett & Nicolson, 1996). Standardised testing procedure was
This is the hat
This is the plane

This is the cat *(Target word)*

This is the dog
This is the cake

Task: Rhymes subtest: Which one sounds like cat?
Alliteration subtest: Which one starts with the same sound as cat?

Figure 6.1. Example of Rhyme and Alliteration Tasks similar to the Rhymes Subtest of the CoPS

followed. The experimenter read out a word and the child repeated it once to ensure that they heard the word and could correctly articulate it. The child was then asked to repeat it again with a specified phonological segment deleted, for example, *football* without *-ball*. The task took approximately 4 minutes. The deleted segment ranged from a syllable to a single phoneme within a blend. The location of the target phonemes varied across initial, medial, and final positions within the word. The dependent measure was the number correct (accuracy). The maximum possible score was 12.
6.2.2.3 Rapid Automatised Naming (RAN)

The Rapid Naming subtest of the DEST (see Figure 6.2) was based on Denckla and Rudel’s (1976) task. It consisted of line drawings of 20 common objects (the set of pictures was presented twice). The pictures were similar to those chosen by Fawcett and Nicolson (1994a) because the names were one syllable, high frequency, and acquired early. Reported one-week test-retest reliability was 0.75 with 26 children aged 5;5 to 6;5 years and 0.85 with 34 children aged 6;6 to 12;0 years (Fawcett & Nicolson, 1996; Nicolson & Fawcett, 1996). The task took approximately 3 minutes. Standardised testing procedure was followed. The experimenter first named all of the pictures. The child then named them once to ensure they knew the names. They were then instructed to name them again as quickly as possible. The dependent variable was the time taken to name all 40 objects. There were five-second penalties for each naming error and 10-second penalties for a loss of place. A stopwatch recorded the speed in milliseconds.

Task: Say the name of each of these objects as fast as you can

Figure 6.2. Example of a Rapid Automatised Naming of Objects Task
6.2.3 Control Measures

6.2.3.1 Auditory-verbal short-term memory

The task was the Digit Span Forward subtest from the DEST. The score was the number of correct trials, with two trials presented at each list length of digits, beginning with two digits. Testing ceased when two consecutive trials at any given length were incorrect. One-week test-retest reliability with 26 children aged 5;5 to 6;5 years was 0.63 (Nicolson & Fawcett, 1996).

6.2.3.2 Early Home Reading Environment

A parent questionnaire elicited information about the number of times per week the child was read to; frequency of parental teaching of reading/writing/alphabet; frequency of library visits; the child's interest in being read to; and the number of children’s books in the home (see Appendix A; questions 1, 3 – 5, and 7). Filler questions asked about other non-literacy parental activities with the child to reduce the focus on literacy activities. Parents also completed a children’s titles checklist (CTC), which included 20 popular age-appropriate children’s book titles and 10 foils (Appendix A, question 20). The checklist was derived from Angus and Robertson’s 100 all-time favourite children’s books (1999) and previously used children’s titles checklists (Cunningham & Stanovich, 1993; Sénéchal et al., 1998). The score was the number of real titles checked minus the number of foils. This reduced the social desirability response and corrected for guessing.

Two factors emerged from a Principal Components Analysis of the early home environment items (details of this analysis are in Appendix B). The factors related to the frequency of parental literacy teaching (Parental Teaching) and frequency of parental reading to the child (Parental Reading). Composite Parental Teaching and
Parental Reading scores were constructed by summing responses on the items that loaded on that factor\(^3\). Higher scores showed a more enriched home environment.

### 6.2.3.3 Attentional Vigilance

Four separate measures were included to assess Attentional vigilance. These were the scores on the catch trials on the three temporal processing measures plus the total score on the Guide to Assessment of Test Session Behaviour (GATSB; Glutting & Oakland, 1993). The proportion of catch trials missed on psychophysical tasks used as a covariate allows the effects of inattention or lack of motivation to be partialled out (Stein, 2003). A Principal Components Analysis was used to reduce these four scores to a single composite score (details are in Appendix C). Catch trials on the Visual TOJ and Temporal Dot tasks and the score on the GATSB loaded on a single factor, related to Attentional Vigilance. A composite Attentional Vigilance score consisted of the sum of scores on these catch trials plus the GATSB score\(^4\). The maximum score was 43 (high vigilance). The auditory TOJ catch trials score did not load on this factor. A second categorical measure of auditory attentional vigilance was formed from those catch trials (Auditory TOJ Catch Trials). Children who scored 0 or 1 \((n = 12)\) were categorized as low (coded 0) and those who scored 2 \((n = 132)\) were categorized as high.

### 6.2.3.4 Nonverbal Cognitive Ability

Nonverbal ability was measured using Raven’s Coloured Progressive Matrices (Raven et al., 1986). Standardised individual administration procedure was followed.

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\(^3\) There was no substantial difference in results of analyses run with either Factor scores or this composite score formed by summing items. As the factor structure had not been confirmed, the composite score, based on sample data, was used.

\(^4\) There was also no substantial difference in results of analyses run with this Factor score or this composite score. Therefore, because this factor structure had not been confirmed, the composite score, based on sample data, was also used.
Reported internal consistency for a Queensland, Australia, sample (mean age 5.5 years) was high, Cronbach’s alpha = .80 (Raven et al.).

6.2.3.5 Auditory discrimination (WOCK)

The Wock subtest of the CoPS was used to check the auditory discrimination ability of participants who performed below chance on the Auditory TOJ task (score of less than 7). The administration followed the standardised procedure. In the task, a pair of aliens is learning English. A picture of an object (e.g., a comb) is presented on the screen and each alien character says its name; one correctly (comb) and one incorrectly (cone). The child had to indicate which alien said the word correctly. This eliminated any explanation of auditory TOJ deficits in terms of basic problems in auditory discrimination. All of the children who completed this task performed near ceiling, well above the age norm, indicating that no children were poor on the Auditory TOJ due to basic auditory discrimination problems.

6.2.4 Reading Measures

6.2.4.1 Single Word Reading Accuracy

The WDRB Letter Word Identification subtest (Woodcock, 1997) involves retrieval of letters and/or words from the mental lexicon. The item list is graded, beginning with selected letters (upper and lower case) and continuing with words of increasing difficulty. Reported internal consistency was .94 for 5- to 18-year-olds (Woodcock). Standardised administration procedures were followed for this and the Word Attack subtests (see Section 6.2.4.2). The score was the number of items correctly identified.
6.2.4.2 Word Decoding Ability

The WDRB Word Attack subtest (Woodcock, 1997) consists of a graded list of non-words (e.g., *nar*), which conform to the regular orthographic and phonological rules of English, and are, therefore, pronounceable. Reported internal consistency is 0.91 for 5- to 18-year-olds (Woodcock).

6.2.4.3 Single Word Reading Rate (Fluency)

Participants read as many words as possible by sight in one minute (timed with a stopwatch) from a list of 120 high frequency English words taken from the Dolch sight word and Kucera-Francis lists (Dolch, 1936; Kucera & Francis, 1967). These words also corresponded to the classroom sight word lists. Words were presented in three columns on one side only of A-4 pages in Berlin Sans FB font, size 20 (see Appendix D). This font produced letters most like the script children were learning. Children were instructed to read the words as quickly as possible. The experimenter demonstrated that they were to use their finger to keep their place and to read down the first column and then proceed to the top of the next column before reading down it and finally to the top of the final column. If they did not know a word, they were told not to sound it out, but to say, “pass”, and go on to the next word. The dependent measure was the number correctly identified in one minute (maximum = 120).

6.2.4.4 Orthographic Processing

This was assessed using a lexical decision task, the Pseudohomophone Choice task, based on a task used by Olson, Forsberg, Wise, and Rack (1994). Two words were presented on a computer screen. One was orthographically correct (e.g., *bird*) and the other was an orthographically incorrect, but phonologically identical,
pseudohomophone (e.g., *burd*). The task was to choose the real word. This relies on knowledge of the written form or the orthography. Appendix E details the stimuli. The words were taken from the words used by Olson et al. and the same high frequency word lists as the timed reading rate measure (although less than half of the words in this task were also in the Reading Rate task). A 2AFC response format was used.

The stimulus words were generated using E-maker Version 1.2.7 and MacDraw II and the task was programmed using V Scope Version 1.2.7. The words were presented in black lower-case letters, on a white background. Letters measured 5 mm high. Stimuli were presented in an area measuring 60 mm x 388 mm, to the left or the right of centre on a Macintosh computer with a super VGA monitor. Side of presentation for the word and pseudohomophone varied randomly. Participants were told they would see two words. One was written correctly and one was wrong. They were told the words would both sound the same if they sounded them out so they needed to choose the word that looked like it was written correctly. The five practice trials used words that were well within all of the participants' sight vocabularies. Forty experimental trials followed. The participants initiated each trial by pressing the space bar. The participants entered their choices themselves, using the "z" and "?" keys of the computer keyboard to indicate the left or right stimulus (these keys are the left- and right- most keys on the keyboard). The keys were clearly marked with differently coloured bright smiley faces so children could easily identify them. After each response was entered, feedback (+ for correct and – for incorrect) appeared on the screen. Stimuli remained visible for 45s each before timing out; however, all participants responded well before this occurred. There were four blocks of trials, with 10 trials per block and intervening rest breaks. The score was the total number
of trials, on which a correct choice was made (accuracy; maximum possible = 40). Internal consistency for the current study was high, Cronbach's alpha = .89.

6.3 Procedure

This research had Griffith University Human Research Ethics Committee clearance, which adheres to the guidelines of the National Health and Medical Research Council of Australia. At the start of Term 4 of the Preschool year, the families of approximately 360 children enrolled in the participating Preschool classes received information packages. One hundred and sixty families completed the parent consent forms and parent questionnaires. All testing was conducted individually in a quiet room at the school. Total testing time for each phase was approximately 1.5 to 2 hours, conducted over 6 to 8 sessions of between 5 and 20 minutes each. A test session terminated if the child was inattentive, tired, or uncooperative. Children were thanked with stickers and/or colouring sheets at the end of each session. Individual feedback was given to parents after each phase of the study. Table 6.2 presents the specific measures administered at each phase.

6.3.1 Preschool Phase 1

Phase 1 testing took place in Term 4 (October to December) of Preschool. Children were initially tested on the WDRB Letter-Word Identification subtest to screen out those who were already reading words (four children were excluded). Following this, eligible children were administered the remaining battery (see Table 6.2) in a quasi-random order. Factors that governed the order of test administration included the availability of a child on a particular testing day, the amount of time available with a child in a testing session, and the concentration of that child in the session.
<table>
<thead>
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<th>Table 6.2</th>
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**Schedule of Tests Administered at each Phase**

<table>
<thead>
<tr>
<th>Phase 1 (Preschool)</th>
<th>Phase 2 (Grade 1)</th>
<th>Phase 3 (Grade 2)</th>
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<td><strong>Home Environment</strong></td>
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<td>Auditory TOJ</td>
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</tr>
<tr>
<td><strong>Raven’s Coloured Matrices</strong></td>
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</table>

* Only administered to children who scored below 50% accuracy (chance level) on the Auditory TOJ task
6.3.2 Grade 1 Phase 2

Phase 2 occurred in Terms 2 and 3 (April/May to September) in Grade 1, commencing 6 months after Phase 1 commenced. The Word Attack (word decoding), Reading Rate (fluency), and Ravens Coloured Matrices (nonverbal) tasks were introduced in this phase. The Woodcock Letter-Word Identification and Word Attack subtests were administered first, followed by the remaining battery in quasi-random order (Table 6.2), governed by the conditions detailed under the Preschool Phase.

6.3.3 Grade 2 Phase 3

Phase 3 testing occurred in Terms 2 and 3 (April/May to September) in Grade 2, commencing 12 months after the start of Phase 2. The procedure was the same as Phase 2. The Pseudohomophone Choice task (orthographic processing) was introduced in this phase, because the children now had sufficient orthographic knowledge for this task.
CHAPTER 7: ANALYSIS OF ATTRITION AND GENDER, COHORT, SCHOOL, AND LANGUAGE ABILITY DIFFERENCES

This chapter presents the results of initial analyses designed to rule out potential confounds. The first section presents an attrition analysis. In the following sections, the effects of gender, cohort, school, and presence of speech and language problems on the variables of interest were analysed. The results of those analyses determined the need to control any of those factors in the main predictive regression analyses reported in later chapters.

7.1 Treatment of missing data

There were small amounts of missing data on the Temporal Dot task. Where data were missing due to children’s absences from school on the testing days, unconditional mean imputation replaced the data (Little & Rubin, 1987). Whilst unconditional mean imputation underestimates standard deviation and deflates significance (Little & Rubin), the very small number of replacements in this study posed a minimal problem in this regard. Two children could not do the task at Phase 1 (Preschool) because they could not count reliably. Their data were not replaced, and these participants were deleted from analyses involving those variables.

7.2 Data transformations

On the composite Attentional Vigilance measure, children were expected to get 100% of the catch trials correct and to score very highly on the Guide to Assessment of Test Session Behaviour scale if they were attending. Thus, as expected, there was negative skew. Reflection and square root transformation normalised the distribution of scores in order to meet the assumptions of the analyses. There was also negative
skew in the distributions of Auditory TOJ and positive skew in the Rapid Automatised Naming (RAN) scores at each phase. Reflection and square root transformation normalised the Auditory TOJ distribution at Phase 1. At Phase 2, due to greater skew, reflection plus log transformation was necessary to normalise the distribution. At Phase 3, due to a ceiling effect in Auditory TOJ scores, the distribution was unable to be normalised via any transformations, so a categorical variable was formed. Children who scored 100% correct (score = 14) were classified as High \( n = 55 \) and children who scored less than 100% correct (score < 14) were classified as Low \( n = 49 \). The scores on RAN were log transformed to normality at each phase. As described in Section 6.2.3.3, the Auditory TOJ Catch Trials measure was a categorical measure.

At Grade 1, there was positive skew in the distribution of Reading Rate scores. Square root transformation normalised this distribution. At Grade 1, there was strong positive skew (a floor effect) in Word Attack; 71% of the sample scored zero (i.e., could not decode any of the pronounceable non-words on this test). As they had only had one term of literacy instruction, they were expected to find this task difficult. The distribution could not be transformed to normality so a categorical variable was created. Children were categorised as Non-decoders if they scored zero \( n = 88 \) and as Decoders if they could decode one or more words \( n = 36 \). At Grade 2, there was also positive skew in Word Attack, but this was normalised using a square root transformation. All other measures were normally distributed.

### 7.3 Attrition Analysis

Attrition is an issue for longitudinal studies. Menard (2002) stated losses of 40 to 50% occur over time, even in studies with high annual retention rates. The longer the period of the study is, the greater the total loss rate. Attrition introduces
confounding if there are systematic differences between the participants who are lost in early phases and those who are retained into the final phases, particularly if there are disproportionate losses of participants who showed extreme scores on focal variables.

There was an overall attrition rate from Preschool to Grade 2 of 26.1%. Attrition analyses using independent groups \( t \)-tests and cross tabulations with Chi-square analysis determined whether those who dropped out of the study at each phase were different to those who continued in the study.

### 7.3.1 Analysis of Attrition from Preschool to Grade 1

Of the 142 children who completed the Preschool phase, only 123 were available for the Grade 1 phase. This represented an attrition rate of 13.4% across the initial two phases of the study. Children mainly dropped out of the study because they moved to a different school for Grade 1, although three children remained in Preschool for an additional year and one child was excluded because he was diagnosed with Autistic Spectrum Disorder. In order to determine if there were any differences between the children who dropped out of the study at the end of Preschool \((n = 19)\) and those who remained \((n = 123)\), independent groups \( t \)-tests were conducted. The dependent measures were the Preschool measures of early home reading environment (Parental Teaching and Parental Reading), Letter Word Identification, Temporal Processing (Auditory TOJ, Visual TOJ, and Temporal Dot), Phonological Processing (Rapid Automatised Naming, Phonemic Segmentation, and Rhyme), Memory (Digit Span), Attentional Vigilance, and Age. Table 7.1 presents the descriptive statistics.

The group who dropped out after the Preschool phase scored significantly lower
Table 7.1

Descriptive Statistics for Attrition Analysis from Preschool to Grades 1 and 2

<table>
<thead>
<tr>
<th>Measures</th>
<th>Mean performance</th>
<th>Standard deviation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Preschool only</td>
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<tr>
<td>Parent Teach</td>
<td>12.42</td>
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<tr>
<td>Parent Read</td>
<td>15.11</td>
<td>14.38</td>
</tr>
<tr>
<td>Letter Word Id*</td>
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</tr>
<tr>
<td>Auditory TOJ</td>
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</tr>
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<tr>
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<td>RAN (s)</td>
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<tr>
<td>Phonemic</td>
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<td>Rhyme *</td>
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</tr>
<tr>
<td>Age (years)</td>
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<td>5.37</td>
</tr>
</tbody>
</table>

*p < .05

on Preschool Letter-Word Identification, \( t (140) = -2.13, p = .035, d^5 = 0.52 \); and

\[ d = \frac{\mu_1 - \mu_2}{\sigma} \]

\( ^5 \) Cohen’s \( d \) measures effect size; \( d = \frac{\mu_1 - \mu_2}{\sigma} \)
Rhymes, \( t(140) = -2.61, p = .01, d = 0.64 \), than the group who continued to Grade 1 (see Table 7.1). These effect sizes were medium (Cohen, 1988). No other differences reached significance. Chi-square analyses showed no significant associations with gender, Preschool attended, familial history of reading and spelling problems\(^6\), and presence of speech and language problems\(^7\), \( p > .05 \).

7.3.2 Analysis of Attrition Preschool to Grade 2

Similar attrition analyses were conducted using the Preschool phase measures as dependent measures and attrition from preschool to Grade 2 as the between-groups factor. Table 7.1 presents the descriptive statistics. The group who dropped out at Preschool (\( n = 19 \)) scored significantly lower on Preschool Letter-Word Identification, \( t(122) = -2.40, p = .018, d = 0.60 \); and Rhymes, \( t(122) = -2.80, p = .006, d = 0.70 \), than the group who continued in the study to Grade 2 (\( n = 105 \)). These were medium effect sizes. No other differences were significant. Chi-square analyses revealed no significant associations between group and gender, Preschool attended, familial history, and speech problems, \( p > .05 \).

7.3.3 Analysis of Attrition from Grade 1 to Grade 2

The attrition rate from Grade 1 to Grade 2 was 14.6%. The children dropped out because they moved schools. The Grade 1 measures were the dependent measures in these analyses. Table 7.2 presents the descriptive statistics. The group who dropped out of the study after Grade 1 (\( n = 18 \)) scored significantly lower on Grade 1 Letter-Word Identification, \( t(121) = -2.06, p = .041, d = 0.53 \); and Reading Rate, \( t(121) = -2.00, p = .048, d = 0.51 \), than the group who continued in the study (\( n = 105 \)). These were both medium effect sizes. There were no other significant differences. Chi-

\(^6\) Hereafter, “familial history of reading and spelling problems” will be referred to simply as “familial history”

\(^7\) Hereafter, “speech and language problems” will be referred to simply as “speech problems”
Table 7.2

*Descriptive Statistics for Attrition Analyses from Grade 1 to Grade 2*

<table>
<thead>
<tr>
<th>Grade 1 Measures</th>
<th>Mean performance</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade 1</td>
<td>Grade 2</td>
</tr>
<tr>
<td></td>
<td>only Group (n = 18)</td>
<td>Group (n = 105)</td>
</tr>
<tr>
<td>Letter Word Id*</td>
<td>13.06</td>
<td>14.84</td>
</tr>
<tr>
<td>Word Attack</td>
<td>0.83</td>
<td>1.11</td>
</tr>
<tr>
<td>Reading Rate*</td>
<td>12.72</td>
<td>18.97</td>
</tr>
<tr>
<td>Auditory TOJ</td>
<td>12.06</td>
<td>12.21</td>
</tr>
<tr>
<td>Temporal Dot</td>
<td>9.06</td>
<td>10.06</td>
</tr>
<tr>
<td>Visual TOJ</td>
<td>28.94</td>
<td>31.46</td>
</tr>
<tr>
<td>RAN (s)</td>
<td>54.48</td>
<td>54.37</td>
</tr>
<tr>
<td>Phonemic Segmentation</td>
<td>4.06</td>
<td>4.93</td>
</tr>
<tr>
<td>Rhyme/Alliteration</td>
<td>7.50</td>
<td>9.89</td>
</tr>
<tr>
<td>Memory</td>
<td>5.50</td>
<td>5.97</td>
</tr>
<tr>
<td>Non-verbal abilitya</td>
<td>107.12</td>
<td>108.64</td>
</tr>
<tr>
<td>Age (years)</td>
<td>6.02</td>
<td>5.94</td>
</tr>
</tbody>
</table>

*a standard score

*p < .05

Square analyses indicated there were no significant associations between group and gender, school attended, familial history, and speech problems, *p > .05*.

### 7.3.4 Discussion

The overall attrition rate was similar to that reported in other longitudinal studies over this same period. For example, McBride-Chang, Wagner, and Chang
(1997) reported an attrition rate of 28% over 15 months from kindergarten, and Parrila, Kirby, and McQuarrie (2004) had 34.8% attrition from kindergarten to Grade 2. McBride-Chang et al. attributed the attrition to the fact that families are more likely to move children around schools in the early period than they would be at later periods in the child’s schooling. In the current study, some children were enrolled at that Preschool only because they had failed to obtain a place in the private school to which they had been accepted for Grade 1. Principals and teachers at the schools also reported the population as quite mobile, which contributed to the attrition.

The group who dropped out differed significantly from the group who continued on some of the reading measures. Letter-Word Identification scores at both Preschool and Grade 1 and Reading Rate at Grade 1 were significantly lower in the group who dropped out. McBride-Chang et al. (1997) also found significantly lower letter name knowledge at kindergarten in their group who dropped out. In the current study, the group who dropped out also scored significantly lower on Preschool Rhyme detection. Each of these represented a medium-sized effect. However, attrition was not a serious threat, because the reasons for dropping out were unrelated to the study. If anything, the final sample tended to represent a slightly more able group of readers than the initial sample.

### 7.4 Gender Differences

Independent groups *t*-tests and cross-tabulations with chi-square analysis determined whether there were significant gender differences on any measures at each phase.

#### 7.4.1 Preschool Phase

Table 7.3 displays the descriptive statistics for the Preschool measures for each gender. Males were significantly more accurate than females on the Auditory TOJ
Table 7.3

Mean Performance on Preschool Phase Measures of Males and Females

<table>
<thead>
<tr>
<th>Preschool Measures</th>
<th>Mean performance</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females (n = 64)</td>
<td>Males (n = 78)</td>
</tr>
<tr>
<td>Parent Teach</td>
<td>12.98</td>
<td>12.42</td>
</tr>
<tr>
<td></td>
<td>2.31</td>
<td>1.84</td>
</tr>
<tr>
<td>Parent Read</td>
<td>15.00</td>
<td>14.06</td>
</tr>
<tr>
<td></td>
<td>5.97</td>
<td>5.35</td>
</tr>
<tr>
<td>Letter Word Id</td>
<td>10.36</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>2.90</td>
<td>2.99</td>
</tr>
<tr>
<td>Auditory TOJ*</td>
<td>10.28</td>
<td>11.10</td>
</tr>
<tr>
<td></td>
<td>2.42</td>
<td>2.35</td>
</tr>
<tr>
<td>Temporal Dot*</td>
<td>6.79</td>
<td>8.23</td>
</tr>
<tr>
<td></td>
<td>3.70</td>
<td>4.08</td>
</tr>
<tr>
<td>Visual TOJ</td>
<td>26.20</td>
<td>27.24</td>
</tr>
<tr>
<td></td>
<td>6.10</td>
<td>6.07</td>
</tr>
<tr>
<td>RAN (s)</td>
<td>62.40</td>
<td>64.83</td>
</tr>
<tr>
<td></td>
<td>20.67</td>
<td>17.76</td>
</tr>
<tr>
<td>Phonemic Segmentation</td>
<td>3.00</td>
<td>3.21</td>
</tr>
<tr>
<td></td>
<td>1.36</td>
<td>1.69</td>
</tr>
<tr>
<td>Rhyme</td>
<td>4.36</td>
<td>4.45</td>
</tr>
<tr>
<td></td>
<td>3.06</td>
<td>2.71</td>
</tr>
<tr>
<td>Memory</td>
<td>5.02</td>
<td>5.33</td>
</tr>
<tr>
<td></td>
<td>1.48</td>
<td>1.42</td>
</tr>
<tr>
<td>Vigilance</td>
<td>37.25</td>
<td>35.96</td>
</tr>
<tr>
<td></td>
<td>3.75</td>
<td>4.91</td>
</tr>
<tr>
<td>Age (years)</td>
<td>5.38</td>
<td>5.33</td>
</tr>
<tr>
<td></td>
<td>0.29</td>
<td>0.29</td>
</tr>
</tbody>
</table>

* $p < .05$

...
on any of the other predictor or control measures. Chi-square analyses showed there were no significant associations between gender and Preschool attended, familial history, or the presence of speech problems, $p > .05$.

7.4.2 Grade 1 Phase

There was a small effect of gender on Non-verbal Ability (Raven's Coloured Progressive Matrices), with males ($M = 110.16; SD = 9.63$) scoring significantly higher than females ($M = 106.24; SD = 10.98$), $t (120) = -2.10$, $p = .038$, $d = .38$. There were no significant gender differences on reading measures, or on any other measures.

7.4.3 Grade 2 Phase

There were no significant effects of gender on the Grade 2 measures. There was a trend for males to score higher ($M = 7.00; SD = 1.53$) than females ($M = 6.40; SD = 1.53$) on Memory, but this difference just failed to reach significance, $t (101) = -1.97$, $p = .051$.

7.4.4 Discussion

Overall, there were few gender differences. There were small effects such that males scored higher on Preschool auditory and visual temporal processing and Grade 1 Nonverbal Ability than did females. Previous studies have reported slight male advantages in Non-verbal Ability (e.g., Maccoby & Jacklin, 1974). There have also been speculations that increased prenatal testosterone slows neuronal development in the left hemisphere and affects the immune system, which may be associated with the brain abnormalities related to temporal processing deficits (Galaburda et al., 1985). Importantly, there was no evidence of females outperforming males on the reading tests, which might have been expected given reports of female advantage on verbal
tasks from around 2 years of age (Maccoby and Jacklin). Therefore, it was not necessary to control for gender in the subsequent regression analyses.

7.5 Cohort Differences

The study included two cohorts. Cohort 1 commenced Preschool in 2000 \((n = 72)\) and Cohort 2 commenced Preschool in 2001 \((n = 71)\). The Preschool teachers were the same for both cohorts, but there were some differences in the Grade 1 and 2 teachers between cohorts. It was possible different teachers could contribute to different reading abilities between cohorts, depending on the importance the different teachers placed on reading and the methods they used to teach it. In order to determine if there were any significant differences between the cohorts, independent groups \(t\)-tests and cross tabulations were performed for each phase.

7.5.1 Preschool Phase

Cohort was the independent-groups factor and the Preschool measures were the dependent measures. Significantly greater frequency of Parental Teaching was reported for Cohort 1 \((M = 13.03, SD = 1.95)\) than for Cohort 2 \((M = 12.31, SD = 2.16)\), \(t\) (139) = 2.06, \(p = .041\), \(d = 0.35\). This was a small effect size. No other differences were significant. Chi-square analyses showed there were no significant associations between the cohorts on gender, familial history, or presence of speech problems, \(p > .05\).

7.5.2 Grade 1 Phase

By Grade 1, there were 63 children remaining from Cohort 1 and 60 from Cohort 2. There was no significant difference in attrition rate between cohorts. Similar independent groups \(t\)-tests were conducted with cohort as the independent-groups factor and the Grade 1 measures as the dependent measures. Cohort 2 \((M = 6.18, SD = 1.57)\) scored significantly higher than Cohort 1 \((M = 5.63, SD = 1.22)\) on
Memory, $t(121) = -2.17, p = .032, d = 0.39$. This was approaching a medium effect size. The cohorts did not differ significantly on reading or other measures.

7.5.3 Grade 2 Phase

By Grade 2, 55 children from Cohort 1 and 50 from Cohort 2 remained. There was no significant difference in attrition rate to Grade 2 between cohorts. There were no significant differences on the reading measures or on the phonological and memory measures. Cohort 2 scored significantly higher on Visual TOJ accuracy ($M = 35.44, SD = 3.14$) than Cohort 1 ($M = 34.00, SD = 4.13$), $t(103) = -2.00, p = .048, d = 0.39$. This also approached a medium effect size. There were no other effects of cohort on Grade 2 measures.

7.5.4 Discussion

Overall, there were few differences between the cohorts. Cohort 2 scored significantly higher on reported parental literacy teaching, Grade 1 auditory-verbal memory, and Grade 2 visual temporal processing. The effect sizes were all small, although a couple were close to medium. However, there were no differences between the cohorts on any of the criterion reading measures. Therefore, it was not necessary to control for cohort in the subsequent regression analyses.

7.6 Differences between Schools

When participants are members of a group, such as a school, correlations between scores within the group are likely. This is called clustering (Cohen, Cohen, West, & Aiken, 2003). Share et al. (1984) argued that one possible reason why batteries of early predictors failed to account for more than about half of the variance in subsequent reading was that they failed to account for the ability composition of the children’s school or class. They examined the amount of variance in first and second grade reading scores accounted for by the mean school ability. Phonemic
segmentation score at school-entry was used as the measure of mean school ability because it was the single best predictor of reading one and two years later. They found a strong significant relationship between mean school ability and individual reading at the end of first grade. Mean school ability added 9% to the variance already explained (63%) by a large battery of 39 measures. In fact, mean school ability on phonemic segmentation was as good at predicting individual reading as individual phoneme segmentation was. These results applied equally to high- and low- ability children. Results at the school level were stronger, albeit not significantly so, than results using mean class abilities. Despite these results, school ability is not taken into account in most studies.

Apart from accounting for more variance in individual reading scores, there is an important statistical reason for considering school or class group. Clustering results in artificially small standard errors for regression coefficients obtained via ordinary least squares regression. This leads to increased Type 1 error rates. The analyses reported in this section examined whether there were significant differences between schools on the measures of interest. Where there were significant differences on the reading measures, intra-class correlation (ICC) indicated the degree of clustering. ICC measures the amount of variance that the group accounted for. The general linear model assumes the ICC is zero; that is, there is no clustering. Cohen et al. pointed out that an ICC as low as .01 to .05 with small group sizes inflates the Type 1 error rate to over .10. Therefore, in cases where there was clustering (a significant school effect), the group (school) effect was partialled out at the first step in the subsequent regression analyses. Interactions between school attended and cohort were also examined, because of the differences in teachers within the schools across the cohorts.
7.6.1 Preschool Phase

Factorial ANOVA with cohort and school as independent-groups factors and the Preschool measures as the dependent variables showed there were no significant interaction effects between school attended and cohort on any of the Preschool measures. One-way ANOVAs were then conducted with Preschool attended as the independent-groups factor and the Preschool measures as dependent variables. Table 7.4 displays the descriptive statistics.

There was a significant difference between Preschools on Parental Reading, $F(2, 138) = 5.94, p = .003, \omega^2 = 0.06$. Omega squared ($\omega^2$) was used as the measure of effect size because it is considered a less biased estimate of population effect size than the more commonly reported eta-squared ($\eta^2$; Howell, 2002). This was a medium effect size, with 6% of the variance in Parental Reading accounted for by the school attended. Contrast analysis showed parents from School B reported significantly greater frequency of reading to children than did parents at School A, $F(1, 138) = 5.36, p = .022$; and at School C, $F(1, 138) = 10.74, p = .001$ (Table 7.4). There was a small significant effect of Preschool on Phonemic Segmentation, $F(2, 139) = 4.69, p = .011, \omega^2 = 0.05$. The Preschool attended accounted for 5% of the variance in Phonemic Segmentation. Children at School B scored significantly higher on Phonemic Segmentation than children at School A, $F(1, 139) = 4.67, p = .032$; and School C, $F(1, 139) = 8.23, p = .005$ (Table 7.4). The Preschools also differed significantly on Rhymes, $F(2, 139) = 9.04, p < .0001, \omega^2 = 0.10$. Thus, the Preschool attended accounted for 10% of the variance in Rhyme detection, a medium effect. Contrast analysis revealed significantly higher Rhyme scores for children at School B scored than for those at School A, $F(1, 139) = 17.89, p < .0001$; and School C, $F(1,$
### Table 7.4

*Mean Performance on Preschool Phase Measures of each School*

<table>
<thead>
<tr>
<th>Preschool measures</th>
<th>Mean performance</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preschool attended</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A $(n = 43)$</td>
<td>B $(n = 59)$</td>
</tr>
<tr>
<td>Parent Teach</td>
<td>12.91</td>
<td>12.80</td>
</tr>
<tr>
<td>Parent Read*</td>
<td>13.74</td>
<td>16.27</td>
</tr>
<tr>
<td>Letter Word Id</td>
<td>9.61</td>
<td>10.61</td>
</tr>
<tr>
<td>Auditory TOJ</td>
<td>10.67</td>
<td>10.97</td>
</tr>
<tr>
<td>Visual TOJ</td>
<td>26.40</td>
<td>27.68</td>
</tr>
<tr>
<td>Temp. Dot</td>
<td>7.98</td>
<td>7.86</td>
</tr>
<tr>
<td>RAN (s)</td>
<td>63.21</td>
<td>66.29</td>
</tr>
<tr>
<td>Phonemic Segment.*</td>
<td>2.91</td>
<td>3.56</td>
</tr>
<tr>
<td>Rhyme *</td>
<td>3.14</td>
<td>5.44</td>
</tr>
<tr>
<td>Memory</td>
<td>4.95</td>
<td>5.31</td>
</tr>
<tr>
<td>Vigilance</td>
<td>36.45</td>
<td>36.71</td>
</tr>
<tr>
<td>Age (years)</td>
<td>5.29</td>
<td>5.37</td>
</tr>
</tbody>
</table>

* $p < .05$
Chi-square analyses showed there were no significant associations between the Preschool attended and familial history of reading problems or presence of speech problems, $p > .05$.

### 7.5.2 Grade 1 Phase

Similar factorial ANOVAs were conducted with the school attended in Grade 1 and cohort as the independent-groups factors and the Grade 1 measures as dependent variables to determine if there were significant interactions between the school and cohort or differences between the schools on the Grade 1 measures. See Table 7.5 for descriptive statistics. There were no significant interactions between school and cohort on any reading measures. There was a significant main effect of school on Grade 1 Reading Rate, $F(2, 120) = 4.70, p = .011, \omega^2 = 0.04$. This was a small effect, with the school attended accounting for 4% of the variance in Reading Rate. Contrast analysis revealed children at School A scored significantly higher on Reading Rate than those at School B, $F(1, 120) = 5.72, p = .018$. Children at Schools B and C did not significantly differ, $F(1, 120) = 0.71, p = .417$ (see Table 7.5). The ICC was 0.06, enough to cause problems with Type 1 error inflation in the regression analyses. Thus, this group effect will be partialled out in subsequent regressions on Grade 1 Reading Rate. There were no significant main effects of School on any other reading measures.

There was a significant interaction between school and cohort on Rhyme and Alliteration detection, $F(2, 117) = 4.20, p = .017$. Simple effects analysis of school in each cohort revealed there were no significant differences in Rhyme and Alliteration detection between schools in the 2000 Cohort, $F(2, 117) = 0.51, p = .602$; but there was a significant difference in the 2001 Cohort, $F(2, 117) = 12.54, p < .0001$. Within the 2001 Cohort, inspection of the 95% confidence intervals revealed there was
Table 7.5

Mean Performance on Grade 1 Phase Measures of each School

<table>
<thead>
<tr>
<th></th>
<th>Mean performance</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>School</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Grade 1 measures</td>
<td>(n = 32)</td>
<td>(n = 53)</td>
</tr>
<tr>
<td>LetterWord Id</td>
<td>15.25</td>
<td>14.58</td>
</tr>
<tr>
<td>Word Attack</td>
<td>1.38</td>
<td>1.19</td>
</tr>
<tr>
<td>Read Rate*</td>
<td>23.44</td>
<td>17.26</td>
</tr>
<tr>
<td>Auditory TOJ</td>
<td>12.22</td>
<td>12.55</td>
</tr>
<tr>
<td>Visual TOJ</td>
<td>31.25</td>
<td>31.40</td>
</tr>
<tr>
<td>Temp. Dot</td>
<td>10.81</td>
<td>10.11</td>
</tr>
<tr>
<td>RAN (s)</td>
<td>54.01</td>
<td>54.71</td>
</tr>
<tr>
<td>Phonemic</td>
<td>4.88</td>
<td>5.09</td>
</tr>
<tr>
<td>Phonemic Segmentation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhyme/</td>
<td>7.63</td>
<td>11.79</td>
</tr>
<tr>
<td>Alliteration*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td>6.13</td>
<td>5.96</td>
</tr>
<tr>
<td>Nonverbal</td>
<td>109.44</td>
<td>108.77</td>
</tr>
<tr>
<td>Ability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>5.91</td>
<td>5.96</td>
</tr>
</tbody>
</table>

Note: a Significant interaction between cohort and school explains this main effect; b Standard scores reported
* p < .05
significantly better Rhyme and Alliteration detection by children in School B than by children in Schools A or C (see Figure 7.1). Children from the latter two schools did not significantly differ on Rhyme and Alliteration detection. Thus, the significant main effect of School on Rhyme and Alliteration Detection, $F (2, 120) = 8.52, p < .0001, \omega^2 = 0.11$, can be explained by this difference only in the 2001 Cohort. There were no other significant interactions between School and Cohort or significant main effects of school.

![Graph showing interaction effect of school attended by cohort on rhyme and alliteration detection in grade 1 (phase 2).](image)

Figure 7.1. Interaction Effect of School Attended by Cohort on Rhyme and Alliteration Detection in Grade 1 (Phase 2).

Note: Error bars represent the 95% confidence intervals of the mean.

7.5.3 Grade 2 Phase

See Table 7.6 for descriptive statistics. According to Levene's test, there were violations of the assumption of homogeneity of variance on Pseudohomophone
Choice and Rhyme/Alliteration. However, in each case the largest variance was less than twice the smallest variance. ANOVA is robust to such small violations so this did not present problems for the analyses (Howell, 2002).

There were no significant interaction effects of school by cohort on any Grade 2 measures. There were significant differences between the schools on all reading measures. There was a significant medium effect of school on Grade 2 Letter Word Identification, $F(2, 102) = 8.21, p < .0001, \omega^2 = 0.12$. School attended accounted for 12% of the variance in Grade 2 Letter Word Identification. The ICC was 0.17. Children at School A scored identified significantly more letters and words than did those at School B, $F(1, 102) = 11.70, p = .001$. Children at Schools B and C did not differ significantly from each other, $F(1, 102) = 0.25, p = .621$ (see Table 7.6). There was also a significant medium effect of school on Grade 2 Word Attack, $F(2, 102) = 5.39, p = .006, \omega^2 = 0.08$. The school attended accounted for 8% of the variance in Word Attack. The ICC was 0.11. Children at School A decoded significantly more non-words than those at School B, $F(1, 102) = 7.76, p = .006$. Schools B and C did not differ significantly from each other, $F(1, 102) = .029, p = .879$ (Table 7.4). School also had a significant effect on Reading Rate, $F(2, 100) = 3.35, p = .039, \omega^2 = 0.04$. This represented a small effect with 4% of the variance in Reading Rate accounted for by the school attended. The ICC was 0.06. Children at School A read significantly more words correctly in one minute than children at School B, $F(1, 100) = 6.64, p = .011$. Children at schools B and C did not differ significantly on Reading
Table 7.6

*Mean Performance on Grade 2 Phase Measures of each School*

<table>
<thead>
<tr>
<th></th>
<th>Mean performance</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>School attended</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>(n = 30)</td>
<td>(n = 42)</td>
<td>(n = 33)</td>
<td>(n = 30)</td>
<td>(n = 42)</td>
<td>(n = 33)</td>
</tr>
<tr>
<td>Letter Word Id*</td>
<td></td>
<td>31.77</td>
<td>26.26</td>
<td>25.48</td>
<td>6.79</td>
<td>7.10</td>
</tr>
<tr>
<td>Word Attack*</td>
<td></td>
<td>12.10</td>
<td>8.05</td>
<td>7.64</td>
<td>7.22</td>
<td>5.88</td>
</tr>
<tr>
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<td>56.25</td>
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<td>12.73</td>
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<td>1.30</td>
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<td>Visual TOJ</td>
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<td>34.10</td>
<td>34.30</td>
<td>3.13</td>
<td>3.64</td>
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<tr>
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<td>11.60</td>
<td>10.21</td>
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<td>5.59</td>
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<tr>
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<td>45.01</td>
<td>44.03</td>
<td>9.55</td>
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<tr>
<td>Rhym/Allit *</td>
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<td>14.36</td>
<td>11.88</td>
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<td>6.73</td>
<td>1.38</td>
<td>1.59</td>
</tr>
<tr>
<td>Age (years)</td>
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<td>7.03</td>
<td>7.03</td>
<td>0.30</td>
<td>0.29</td>
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</tbody>
</table>

*p < .05

Rate, $F(1, 100) = 0.73$, $p = .393$ (Table 7.4). This was consistent with the results at Grade 1. Schools also differed significantly on the Pseudohomophone Choice measure, $F(2, 99) = 8.08$, $p = .001$, $\omega^2 = 0.12$. The school attended accounted for
12% of the variance in this measure of orthographic processing ability, a medium effect. The ICC was 0.17. Children at School A scored significantly higher on this measure of orthographic processing than those at School B, $F(1, 67.91) = 14.99, p < .0001$. Children at Schools B and C did not differ significantly, $F(1, 63.82) = 0.16, p = .693$ (Table 7.6). These group effects will be partialled out of the subsequent regression analyses using these criterion reading measures.

There was also a significant small to medium effect of school on Grade 2 Rhyme and Alliteration detection, $F(2, 100) = 3.92, p = .023, \omega^2 = 0.05$. The school attended accounted for 5% of the variance in scores. Children at Schools A and B did not significantly differ from each other in Rhyme and Alliteration detection, $F(1, 59.95) = 0.09, p = .767$. Children at School B scored significantly higher than did those at School C, $F(1, 53.65) = 5.87, p = .019$ (Table 7.6). There were no significant main effects of School on any other measures.

7.5.4 Discussion

There were significant differences between the schools in the frequency with which parents read to children in the early home environment and in phonological processing ability at each phase of the study. At Grade 1, there was a significant difference on Reading Rate; and, by Grade 2, there were significant differences on all reading measures. The school attended accounted for between 4 and 12% of the variance in the reading measures. Differences between schools in the method of teaching literacy or the importance placed on, and, therefore, time devoted to, literacy might explain these differences. Differences between schools could also reflect differences in the families and the environments they created. However, the significant differences in reported frequency of parental reading to children and in phonological processing abilities were not consistent with the significant differences
in reading. School B scored significantly higher on parental reading and phonological processing skills, yet School A scored significantly higher on reading measures in both grades. This is consistent with the previous reports that there are no significant relationships between passive aspects of home literacy and subsequent reading ability (Elbro et al., 1998; Sénéchal et al., 1998). The results also show better onset-rime awareness (Rhyme and Alliteration detection accuracy) alone is insufficient to produce better early reading development. Differences in early teaching could either enhance or fail to utilise the pre-existing skills that children bring to school. In the Grade 1 phase only, an interaction between Cohort and School explained the significant main effect of School attended on Rhyme and Alliteration Detection. Possibly changes in Grade 1 teachers at School B between 2000 and 2001 explains this result. However, in the other two phases, there were no significant Cohort x School interactions, yet children at School B consistently scored higher on this task than those at Schools A and C. This result might reflect differences between the teachers in the different years at the different schools.

The ICCs indicated sufficient clustering effect to cause inflated Type 1 error problems in the subsequent regression analyses so this group effect needs to be controlled. The method chosen to deal with this was what Cohen et al. (2003) called disaggregated analysis with dummy-coded groups. This is the recommended approach, preferred to the newer random coefficient methods, when there are fewer than ten groups, as in the current study. Two dummy coded variables were created to encode the school attended. The reference school (coded as zero on both variables) was School A, because it had consistently scored highest on the reading measures (see Hardy, 1993). The dummy variables were entered at the initial step into the regression analyses for predicting Grade 1 Reading Rate and all Grade 2 reading
measures. Thus, the effect of school on the DV was initially partialled out, allowing focus on the relationship between other variables and the DV at subsequent steps in the regression analysis.

7.7 Differences between children with and without reported speech and language problems

There is argument over whether the temporal processing deficits occur only in children with both reading and language disabilities (Heath et al., 1999; Tallal et al., 1993), or more generally in reading disability. Language problems also affect phonological processing and verbal ability, which may be causally related to reading ability. In this study, parental report of any speech or language problems experienced by their children was used to form a categorical Speech Problems variable. Scores were coded as 0 if a problem was reported ($n = 26$ at Preschool) and 1 if no problems were reported. Independent groups $t$-tests determined whether there were significant differences between the children with and without reported Speech Problems on the variables of interest.

7.7.1 Preschool Phase

Children with Speech Problems were significantly slower at rapidly naming objects ($M = 72.49s; SD = 19.20s$) than were those without problems ($M = 61.47s; SD = 18.59s$), $t (138) = 2.88, p = .005, d = 0.62$. This was a medium effect size. There was no significant between-group difference on Auditory TOJ, nor were there significant effects of Speech Problems on any other Preschool measures.

7.7.2 Grade 1 Phase

In Grade 1, the group with Speech Problems read significantly fewer words in one minute ($M = 12.38, SD = 9.50$) than the non-problem group ($M = 19.49, SD = 14.93$), $t (119) = -2.03, p = .045, d = 0.49$. This was a medium effect. The Speech
Problem group also showed significantly poorer Memory ($M = 5.10$, $SD = 1.55$) than the non-problem group ($M = 6.08$, $SD = 1.35$), $t (119) = -2.96$, $p = .004$, $d = 0.71$. This was also a medium effect.

### 7.7.3 Grade 2 Phase

The Speech Problems group continued to show significantly slower Reading Rate ($M = 44.89$, $SD = 20.76$) than the non-problem group ($M = 59.96$, $SD = 24.62$); $t (100) = -2.42$, $p = .017$, $d = 0.63$; and significantly poorer Memory ($M = 6.06$, $SD = 1.56$) than the non-problem group ($M = 6.89$, $SD = 1.52$); $t (100) = -2.06$, $p = .042$, $d = 0.55$. On Phonemic Segmentation, the Speech Problem group successfully segmented fewer words ($M = 7.11$, $SD = 2.56$) than the non-problem group ($M = 8.36$, $SD = 2.12$), $t (101) = -2.20$, $p = .03$, $d = 0.57$. These effects were all medium. No other measures showed significant between-group differences.

### 7.7.4 Discussion

Compared to the non-problem group, the Speech Problem group showed significantly slower Reading Rate at Grades 1 and 2. However, other measures of reading (Letter-Word Identification, Word Attack, and Pseudohomophone Choice) did not differ significantly between the groups at either grade. This is consistent with a more specific effect of Speech Problems on articulation rate that affected only the timed Reading Rate measure. There were differences on two phonological processing measures; Preschool Rapid Automatised Naming (RAN) speed and Grade 2 Phonemic Segmentation. The RAN deficits would also be consistent with a slower articulation rate, although there were no significant differences in the Grade 1 and 2 phases. The Speech Problem group also showed poorer performance on digit span (Memory) at Grades 1 and 2. This involves the phonological loop for short-term retention of the digits (Wagner & Torgeson, 1987). Articulation rate is important here, because the
Temporal Processing and Early Reading

The phonological loop involves sub-vocal articulation. McDougall et al. (1994) found differences in speech rate explained verbal short-term memory differences between reading ability groups. Poor short-term phonological memory could explain the poorer performance on the Phonemic Segmentation task. Children had to hold a word in working memory while segmenting it and then deleting a specified phonological segment. Snowling (2000) argued that degraded phonological representations explain poorer phonological awareness, rapid naming speed, and verbal short-term memory. Early speech and language problems contribute to the stability and clarity of phonological representations. This could explain the pattern of results obtained here.

Importantly, the Speech Problem group did not perform more poorly on the auditory temporal processing measure, as would be expected based on some prior research (Heath et al., 1999; Tallal et al., 1993). This study used parental report of speech problem, which is a very coarse, subjective indicator. For the six participants who were receiving speech therapy, there was objective supporting evidence of a problem. However, those participants were not extreme scorers on the measures that differed. Previous studies that found significant effects of speech problems on auditory TOJ performance used objective criteria and/or tests for specific language disability. Possibly the Speech Problem group in the current study had far milder speech and language problems, explaining the lack of effect. However, the focus of the current study was on a normative sample, within which any potential effect of speech problems would be accounted for, and not on selected groups. There were also only a few children in the Speech problem group, so there may have been inadequate power to detect small effects. As there were differences on Grades 1 and 2 Reading Rate, the presence of speech problems will be included in subsequent regression analyses predicting those measures.
7.8 Summary

Overall, there were few significant differences on measures due to attrition, gender, cohort, school attended, or the presence of speech and language problems. Those who dropped out of the study had lower scores on the reading measures and Rhyme detection scores than those who remained. However, the reasons for dropping out were unrelated to the study, so attrition was not a threat. There was only a potential threat to the generalisability of the results, because the final sample represented a slightly more able group of readers than that originally sampled.

There was some male advantage in temporal processing ability at Preschool and Non-verbal Ability at Grade 1. However, there were no significant gender differences on any of the reading measures. Some studies reported a higher prevalence of reading difficulties among males than females, with a ratio of around 5:1 (Benton, 1975; Miles, Haslum, & Wheeler, 1998). However, larger epidemiological studies have reported equivalent prevalence, suggesting males are simply more likely than females to be referred for diagnosis (S. E. Shaywitz, et al., 1990). Miles et al. showed an IQ discrepancy definition (as used by S. E. Shaywitz et al.) produces approximately equivalent gender ratios. However, using specific inclusion correlates to diagnose dyslexia (drawn from the Bangor Dyslexia Test; Miles, 1993) produced a 5:1 male:female ratio. In the current study (using raw reading test scores), gender had no effect, and so was not included as a control variable in subsequent analyses.

There were some potential problems of clustering, and thereby, inflated Type 1 error rates, due to differences between schools. This affected the reading measures. In order to account for the effects of school attended, two dummy coded school variables were constructed for entry at the first step in the relevant regression analyses.
The presence of speech problems affected Reading Rate in Grades 1 and 2. Therefore, this was also included as a categorical control variable in those regression analyses. There were significant effects on the phonological processing measures, consistent with degraded phonological representations. However, there was no significant effect on auditory temporal processing.
CHAPTER 8: PREDICTION OF READING SKILLS BY
PRESCHOOL TEMPORAL AND PHONOLOGICAL
PROCESSING MEASURES

The current evidence supporting the temporal processing deficit hypothesis of
dyslexia has come from cross-sectional studies of older children, adolescents, and
adults. As detailed in Chapter 5, this provides evidence of covariation between
temporal processing skills and reading skills. However, support for a causal
relationship requires demonstration of temporal precedence. This chapter addressed
the main research question concerning the ability of Preschool temporal processing
measures to predict individual differences in reading. A series of hierarchical
multiple regression analyses using the Preschool measures of temporal processing and
phonological processing to predict pre-reading skill at Preschool (Letter Word
Identification) and reading skills at Grades 1 and 2 are presented. These analyses
provided information on whether visual and auditory temporal processing abilities
predict different components of reading, and how well their predictive abilities
compare with that of Preschool phonological processing predictors. Finally, it
addressed the extent to which temporal and phonological processing measures
account for shared versus independent variance in reading. In all analyses, the effects
of the control measures were partialled out in the initial steps of the analyses.

Commonality analysis (Pedhazur, 1997; see also Lindenberger & Pötter, 1998)
was used to determine the unique and common variance in the reading dependent
variables that was attributable to the Preschool measures of temporal processing and
phonological processing (after partiailling out the variance attributable to the control
measures). A structured series of hierarchical multiple regression analyses were
performed with the control measures always entered first in order to partial out the variance they could account for. The temporal processing measures were then entered both before and after the phonological processing variables. This partitioned the residual variance (remaining after the effects of control measures were removed) into that uniquely attributable to the temporal processing and the phonological processing variables, and that shared (or common) between these two sets of variables. The proportion of variance accounted for by the variables when entered last into the hierarchical multiple regression analysis represented their unique contribution. The residual variance when the variables' unique contribution was removed from the total variance accounted for represented the shared contribution. Separate analyses were conducted for each reading measure, and for each phase in the study.

In previous cross-sectional studies with older children and adults, temporal processing measures showed significant relationships with word identification, non-word reading, reading rate, and orthographic processing. Therefore, Preschool temporal processing ability was expected to predict a significant proportion of variance in these early reading skills. Previous research has also shown auditory temporal processing is more strongly related to phonological processing, and visual temporal processing is more strongly related to orthographic processing (Booth et al., 2000; Cornelissen et al., 1998; Talcott et al., 2000). Therefore, visual and auditory measures were expected to account for significant independent components of variance in the reading measures. Differences in the strength of the predictive relationship between specific temporal processing variables and specific reading measures were also expected. In terms of a comparison with the phonological measures, previous research found temporal and phonological processing skills are related and load on the same factor (e.g., Lovegrove et al., 1989), so it was expected
they would share some common variance in reading skills. If auditory temporal processing were causally related to phonological processing, it would be expected to show greater shared variance with these measures than would the visual temporal processing measures. For that reason, stronger relationships were expected between Auditory TOJ and Word Attack, due to the relationship of this measure to phonological decoding skills. However, all of these expectations were quite tentative because they are based on previous research with much older samples. There is little knowledge about the relationship between these measures and beginning reading skills.

8.1 Prediction of Preschool Pre-reading Skills

Table 8.1 presents the descriptive statistics for the control measures, the Preschool temporal and phonological processing measures, and the Preschool Letter Word Identification subtest. The Preschool Letter Word Identification score was mainly a measure of letter identification, because children who could identify more than the first couple of words (scored greater than 17) were excluded from the sample. As letter naming is a strong predictor of early reading development (e.g., Badian, 1993), the ability of the Preschool temporal and phonological processing measures to predict variance in this important pre-reading skill was determined. The potential control measures were Age, Parental Teaching, Parental Reading, Attentional Vigilance, Auditory TOJ catch trials, auditory-verbal short-term memory, and Non-verbal Ability. However, only control measures that showed significant zero-order correlations with Letter Word Identification were included in the subsequent hierarchical regression analyses. The Preschool temporal processing predictors were the Auditory TOJ, Visual TOJ, and Temporal Dot measures. The Preschool
phonological processing predictors were the Rapid Automatised Naming (objects), Rhyme, and Phonemic Segmentation measures.

Table 8.1

Performance on Control Measures, Preschool Temporal and Phonological Processing Predictors, and Preschool Letter Word Identification

<table>
<thead>
<tr>
<th>Measures</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
<th>Maximum Scoresa</th>
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<td>18.00</td>
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<td>25.00 – 43.00</td>
<td>43.00</td>
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<td>Memory</td>
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<td>2.00 – 9.00</td>
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</tr>
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<td>9.00 – 39.00</td>
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<td>RAN (s)</td>
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<td>2.99</td>
<td>4.00 – 17.00</td>
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</table>

a Maximum possible scores

8.1.1 Zero-order Correlations

Table 8.2 presents the Pearson zero-order correlations between the control, Preschool temporal processing, Preschool phonological processing, and Preschool
Table 8.2

**Correlations between Control Measures, Preschool Temporal Predictors, Preschool Phonological Predictors, and Preschool Letter Word Identification**

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<th>AGE</th>
<th>TEACH</th>
<th>READ</th>
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<th>ATOJcatch&lt;sup&gt;d&lt;/sup&gt;</th>
<th>MEM</th>
<th>MAT</th>
<th>ATOJ&lt;sup&gt;b&lt;/sup&gt;</th>
<th>VTOJ</th>
<th>DOT</th>
<th>RAN&lt;sup&gt;c&lt;/sup&gt;</th>
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</table>

Note: TEACH = Parental Teaching, READ = Parental Reading, VIG = Attentional Vigilance, ATOJcatch = Auditory TOJ catch trials, MEM = Memory, MAT = non-verbal ability, ATOJ = Auditory TOJ, VTOJ = Visual TOJ, DOT = Temporal Dot, RAN = Rapid Automatised Naming, PhonSeg = Phonemic Segmentation, LetWordId = Preschool WDRB Letter Word Identification.

<sup>a</sup> Reflected and log transformed; <sup>b</sup> Reflected and Square root transformed; <sup>c</sup> Log transformed; <sup>d</sup> Categorical variable

*<sup>p</sup> < .05; **<sup>p</sup> < .01
Letter Word Identification measures. Of the control measures, Age, Parental Teaching, Auditory TOJ Catch Trials, Memory, and Non-verbal Ability were significantly correlated with Letter Word Identification. Better letter identification was associated with higher frequency of early parental literacy teaching, greater attentional vigilance on the Auditory TOJ task, better auditory-verbal short-term memory, and greater non-verbal ability, and with being older. There were significant weak to moderate correlations between Preschool Letter Word Identification and the three Preschool temporal processing measures. Thus, a greater knowledge of letter names was associated with better temporal processing. The negative correlation between Letter Word Identification and Auditory TOJ was due to the reflected and square root transformed scores used for Auditory TOJ, but still indicated that better Auditory TOJ accuracy was related to better letter identification. The three Preschool phonological processing measures showed significant moderate positive correlations with Preschool Letter Word Identification.

There were some significant weak to moderate correlations between the control measures and the Preschool temporal processing measures. Attentional Vigilance, which included scores on catch trials on the two visual temporal processing measures, showed significant negative correlations with the two visual temporal processing measures, but not the Auditory TOJ task. The negative correlation was due to the reflected log transformation of the vigilance measure, but indicated that poorer vigilance, affected by less accurate detection of the visual catch trials, was associated with lower accuracy on the Visual TOJ and Temporal Dot tasks. However, as there was no significant relationship between Attentional Vigilance and Preschool Letter Word Identification, differences in Attentional Vigilance cannot explain any relationship between the Preschool temporal processing measures and Letter Word
Identification. The Auditory TOJ Catch Trials measure showed significant moderate correlations with the two TOJ tasks, such that less accurate detection of the TOJ catch trials was related to less accurate auditory and visual temporal order judgement. There were also significant moderate correlations between Age, Memory, and Non-verbal Ability and performance on the two TOJ tasks. As these control measures also showed significant correlations with Preschool Letter Word Identification, they could explain, at least partially, any relationship between the temporal processing measures and Letter Word Identification. This shared variance will be partialled out in the initial steps of the regression analyses.

There were also some significant weak correlations between the control measures and the Preschool phonological processing measures. Parental Teaching, Attentional Vigilance, Auditory TOJ Catch Trials, and Memory were significantly correlated with both Rapid Automatised Naming speed and Rhyme detection. Greater frequency of parental literacy teaching, greater vigilance, and better auditory-verbal short-term memory were associated with faster naming speed and better rhyme detection. Age was significantly positively correlated with Rhymes and Phonemic Segmentation. A significant effect of age was expected because phonological processing ability is developing between 4 to 6 years (Treiman & Zukowski, 1991). However, the variance in ages within the sample at a given phase was in the order of months, not years (see Table 8.1 for descriptive statistics), indicating that development is very rapid during this period. Phonemic Segmentation showed a significant weak positive correlation with Non-verbal Ability. There was a significant weak correlation between Parental Reading and Rhymes. Thus, differences in Age, Parental Teaching, Auditory TOJ Catch Trials, Memory, and Non-verbal Ability could explain at least part of any relationship between Preschool phonological
Temporal Processing and Early Reading

Performances on the two TOJ tasks showed significant moderate inter-correlations. The two visual temporal processing measures also showed significant moderate correlations. However, there was no significant correlation between scores on the Auditory TOJ and Temporal Dot tasks. Auditory and Visual TOJ accuracy was significantly correlated with all three phonological processing measures; better temporal order judgement was associated with better phonological processing. The Temporal Dot task was only significantly positively correlated with Rhymes.

### 8.1.2 Prediction of Preschool Letter Word Identification

Table 8.3 summarises the hierarchical multiple regression analyses. At Step 1, the control measures that showed significant zero-order correlations with Preschool Letter Word Identification were entered. These were Age, Parental Teaching, Auditory TOJ Catch Trials, Memory, and Non-verbal Ability. They accounted for 23.50% of the variance in Preschool Letter Word Identification, $F(5,113) = 6.93, p < .0001$. The squared semi-partial correlations ($s^2$) showed Parental Teaching uniquely accounted for 9.18% of that variance and Non-verbal Ability uniquely accounted for 4.37% of the variance, both of which represented significant percentages (see Table 8.3). No other control measures uniquely accounted for a significant percentage of the variance.

When the Preschool temporal processing measures were entered into the regression analysis at Step 2, they accounted for an additional 7.90% of the variance, $F(3,110) = 4.22, p = .007$. Auditory TOJ accuracy explained most of this, uniquely accounting for a significant 6.40% of the variance (Table 8.3). Neither visual temporal processing measure accounted for a significant percentage of unique
Table 8.3

Hierarchical Regression Analyses for Predicting Preschool Letter Word Identification (N = 123)

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE B)</th>
<th>( \beta )</th>
<th>sr</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Age</td>
<td>1.15 (0.86)</td>
<td>0.12</td>
<td>.11</td>
<td>.185</td>
</tr>
<tr>
<td>2. Parent Teach</td>
<td>0.44 (0.12)</td>
<td>0.31</td>
<td>.30</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>3. ATOJcatch(^c)</td>
<td>1.31 (1.01)</td>
<td>0.10</td>
<td>.09</td>
<td>.268</td>
</tr>
<tr>
<td>4. Memory</td>
<td>0.28 (0.18)</td>
<td>0.14</td>
<td>.13</td>
<td>.111</td>
</tr>
<tr>
<td>5. Non-verbal</td>
<td>0.15 (0.06)</td>
<td>0.22</td>
<td>.21</td>
<td>.012*</td>
</tr>
<tr>
<td><strong>R(^2)</strong> = .235*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Auditory TOJ(^a)</td>
<td>-1.59 (0.50)</td>
<td>-0.29</td>
<td>-.25</td>
<td>.002*</td>
</tr>
<tr>
<td>7. Visual TOJ</td>
<td>0.01 (0.05)</td>
<td>0.02</td>
<td>.01</td>
<td>.867</td>
</tr>
<tr>
<td>8. Temporal Dot</td>
<td>0.08 (0.06)</td>
<td>0.11</td>
<td>.10</td>
<td>.201</td>
</tr>
<tr>
<td>( \Delta R(^2)** = .079*</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Step 3</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>9. RAN(^b)</td>
<td>-6.42 (1.81)</td>
<td>-0.27</td>
<td>-.25</td>
<td>.001*</td>
</tr>
<tr>
<td>10. Phon. Segment.</td>
<td>0.32 (0.16)</td>
<td>0.17</td>
<td>.14</td>
<td>.042*</td>
</tr>
<tr>
<td>11. Rhyme</td>
<td>0.18 (0.09)</td>
<td>0.18</td>
<td>.15</td>
<td>.037*</td>
</tr>
<tr>
<td>( \Delta R(^2)** = .159*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. RAN(^b)</td>
<td>-6.09 (1.88)</td>
<td>-0.26</td>
<td>-.24</td>
<td>.002*</td>
</tr>
<tr>
<td>7. Phon. Segment.</td>
<td>0.36 (0.16)</td>
<td>0.19</td>
<td>.17</td>
<td>.025*</td>
</tr>
<tr>
<td>8. Rhymes</td>
<td>0.21 (0.09)</td>
<td>0.20</td>
<td>.17</td>
<td>.021*</td>
</tr>
<tr>
<td>( \Delta R(^2)** = .177*</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Auditory TOJ(^a)</td>
<td>-1.50 (0.44)</td>
<td>-0.27</td>
<td>-.24</td>
<td>.001*</td>
</tr>
<tr>
<td>10. Visual TOJ</td>
<td>0.00 (0.04)</td>
<td>0.01</td>
<td>.01</td>
<td>.927</td>
</tr>
<tr>
<td>11. Temporal Dot</td>
<td>0.04 (0.05)</td>
<td>0.06</td>
<td>.06</td>
<td>.418</td>
</tr>
<tr>
<td>( \Delta R(^2)** = .061*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* \( p < .05 \)

\(^a\) Reflected and square root transformed; \(^b\) Reflected and log transformed; \(^c\) Categorical variable
variance. When the Preschool phonological processing measures were entered at Step 2, they accounted for an additional 17.70% of the variance, $F (3,110) = 11.04, p < .0001$. All three phonological processing measures made significant unique contributions. Rapid naming speed accounted for 5.62% of the variance; Phonemic Segmentation accounted for 2.79%; and Rhymes accounted for 2.96%. Thus, over 6.00% of the variance in Preschool Letter Word Identification overlapped between these phonological processing measures. Steiger’s $z$-test (Steiger, 1980) was used to determine whether there were significant differences between the proportions of variance in Preschool Letter Word Identification accounted for by the Preschool temporal processing and phonological processing variables. This showed no significant difference in the variance accounted for in Preschool letter name knowledge by the temporal or phonological processing measures, $\bar{z} = -1.33, p > .05$

In order to separate out the unique versus common variance in Preschool Letter Word Identification explained by Preschool temporal and phonological processing predictors, both of these sets of measures were entered last into the analysis (after the control measures and the other set of predictor measures). The increment in variance accounted for at the final step represented the unique variance attributable to that set of predictor measures. When entered last, at Step 3, the Preschool temporal processing measures accounted for an additional 6.10% of the variance in Preschool Letter Word Identification, $F (3,107) = 4.11, p = .008$. This represented their unique contribution to Preschool Letter Word Identification. Auditory TOJ accuracy uniquely accounted for 5.57% of that variance (Table 8.3). When the Preschool phonological processing measures were entered at Step 3, they accounted for an additional 15.90% of the variance ($F (3,107) = 10.75, p < .0001$), which was their
unique contribution. Rapid Automatised Naming uniquely accounted for 6.20% of the variance; Phonemic Segmentation uniquely accounted for 2.07%; and Rhymes uniquely accounted for 2.22% at this final step (Table 8.3).

Together the control measures, temporal processing predictors, and phonological processing predictors accounted for 47.30% of the variance in Preschool Letter Word Identification. Commonality analysis indicated only 1.80% of that variance was shared between Preschool temporal and phonological processing predictors. With all of the measures in the regression analysis, Parental Teaching still accounted for a significant unique 2.53% of the variance. As detailed already, Auditory TOJ, Rapid Automatised Naming, Phonemic Segmentation, and Rhymes also still accounted for significant unique components of variance. Based on the $\beta$ weights, the most important predictors of Preschool Letter Word Identification were rapid naming speed and auditory temporal processing (Table 8.3).

8.1.3 Discussion

To date, there are no published findings of the relationship between temporal processing skills and pre-reading skills, such as letter naming. These results show a Preschool measure of auditory temporal processing independently accounts for a significant component of unique variance in Preschool letter identification. Thus, even before the development of word reading, there is a reliable relationship such that better auditory temporal processing skill is related to better pre-reading skills. This provides strong support for a causal role of temporal processing in reading ability as it establishes that the sort of relationships found between reading and temporal processing in older samples (Cornelissen et al., 1998; Marshall, et al., 2001; Olson & Datta, 2002; Talcott et al., 2000, 2002) are present before reading has emerged.

Despite a significant moderate correlation between Visual TOJ and Preschool Letter
Word Identification, the control measures and Auditory TOJ subsumed most of the variance it explained. This indicates that early visual temporal processing, as measured by visual temporal order judgement at Preschool, does not play an independent causal role in letter naming before school-entry. Of the temporal processing measures, only Auditory TOJ accounted for significant unique variance in Preschool Letter Word Identification, accounting for nearly all of the variance attributable to the temporal processing measures. This may reflect a common association between phonological processing and both letter name knowledge and auditory temporal processing. Adams (1995) argued that the names of letters provide a link to phonological processing because the letter sound is often contained in the letter name. If auditory temporal processing and phonological processing were causally related, Auditory TOJ and letter name knowledge would also be expected to be related, as was found.

Consistent with this, Preschool phonological processing also independently predicted a significant component of variance in Preschool Letter Word Identification. Each of the phonological processing measures accounted for unique variance, with Rapid Automatised Naming being the more important of these predictors. The relationship between Preschool letter identification and rapid naming speed for objects may reflect speed of lexical access, which is relevant to both the retrieval of letter names and the retrieval of picture names (Wolf & Bowers, 1999; Wolf et al., 2000). It may also reflect the common aspect to the letter naming and rapid object naming tasks of having to make associations between symbols and names (Manis et al., 1999). However, more variance in Preschool Letter Word Identification was explained by what the three phonological measures had in common, than was explained independently by any one of them. These findings are consistent with the
The hypothesis that phonological processing skills are essential for initial learning of letter names and sounds (Muter et al., 1997).

The variance accounted for in Preschool Letter Word Identification by the Preschool temporal and phonological processing predictors was mostly independent, with less than 2% of the variance shared between these two sets of predictors. This indicates that only a small percentage of the relationship between auditory temporal processing and letter knowledge is explained by any relationship between auditory temporal processing and phonological processing. At this point in reading development, Auditory temporal processing and these phonological processing measures are accounting for different processes in letter name knowledge. This may reflect a relationship between auditory temporal processing and other processes relevant to letter naming, such as speech perception or associative memory, that were not measured in this study.

In terms of the control measures, Parental Teaching also explained a small, but significant, component of Letter Word Identification, even after accounting for the effects of the other control measures and temporal and phonological processing. This highlights the importance of this active aspect of the early literacy environment to this important pre-reading skill. By contrast, Parental Reading, a more passive aspect of the early literacy environment, did not show even a significant zero-order correlation with Letter Word Identification. The activities that loaded most strongly on the Parental Teaching factor (see Table B.1 for loadings) were teaching children the alphabet and to write their name, both of which involved teaching letter names. This accounts for the significant relationships found here.

Another aim of the study was to examine the relationships between multiple measures of temporal processing taken in the one sample. While the hypothesis is of
a generalised temporal processing deficit, there is little evidence to show that different measures of temporal processing are related. These results showed a moderate correlation between the two TOJ tasks. This was expected because they are both hypothesised to measure the construct of temporal processing and have similar generic task demands. However, there was only around 10% shared variance between these two measures, indicating they are measuring quite different aspects of temporal processing. Part of the differences may be related to differences in temporal processing specific to either the auditory or the visual sensory modality. Also with such a young sample, a larger amount of random error was expected in these measures than would occur with older samples. This would reduce the correlation between the measures.

There was also a significant moderate correlation between the two visual temporal processing measures, as would be expected given they are both measuring rapid visual sequential processing. However, they also had only around 10% of their variance in common, indicating that they are measuring different aspects of temporal processing. Temporal Dot was most likely a more perceptually and cognitively demanding task than Visual TOJ, which would explain some of the non-shared variance. It was likely to be affected not only by temporal processing ability but also by several other factors not relevant to the Visual TOJ task. The speed and efficiency with which the children could count the dots would affect performance on the Temporal Dot task, but not be relevant to the Visual TOJ task. Counting is automatised in older samples but is a newly emerging skill in preschool-aged children. As children’s counting efficiency develops, the Temporal Dot task would increasingly become a purer measure of temporal processing. More importantly, there is a greater temporal sequencing component in the Temporal Dot task than in the Visual TOJ
task. There was also a significant moderate positive correlation between Visual TOJ and non-verbal ability, yet no significant correlation between Temporal Dot and Non-verbal Ability. Similarly, there was a significant positive correlation between Memory and Visual TOJ, yet not between Memory and Temporal Dot. This reflected the need to remember the order of stimuli in the Visual TOJ task, whereas in the Temporal Dot task it is just the cumulative number of dots that needs to be retained (i.e., what number of dots the display is up to). This issue of exactly what processes are involved in the different temporal dot tasks used in the literature has not been explored much. However, clearly the different extraneous task factors found in different temporal processing tasks may affect the relationships found between performance on those tasks and performance on measures of reading. This needs to be addressed more extensively in the literature.

There was no significant correlation between Auditory TOJ and Temporal Dot scores. This may be due to there being similar generic task demand differences between Auditory TOJ and Temporal Dot as between Visual TOJ and Temporal Dot. From Table 8.2, it can be seen that, like Visual TOJ, Auditory TOJ is also significantly related to Memory and Non-verbal Ability. The lack of a significant relationship between Auditory TOJ and Temporal Dot may also reflect the different sensory modalities engaged. Chiappe et al. (2002) reported stronger correlations between similar tasks presented in different sensory modalities (auditory and visual gap detection) than between dissimilar tasks presented in different sensory modalities (auditory TOJ and visual gap detection). The results obtained here are consistent with those findings. By contrast, Booth et al. (2000) reported a significant correlation of .59 between Auditory TOJ and Temporal Dot in an older sample of children, all of whom had dyslexia. Sample differences (older dyslexic children in Booth et al.’s
sample and younger normative sample in the current study) may explain this inconsistency with current results. The stronger correlation in Booth et al.’s sample may also reflect more shared variance between these tasks due to the children having automatised counting, and the tasks both being purer measures of temporal processing. Booth et al.’s sample was also much smaller than the current sample; smaller samples often produce stronger correlations. The non-significant relationship found in the current study may also be due to the auditory task being quite easy (on average, children were near ceiling by Grade 2) and the Temporal Dot task being quite difficult (on average, children were still achieving less than 50% accuracy by Grade 2; these effects are described more fully in Chapter 10).

Having established there were significant relationships between Preschool temporal and phonological processing skills and Preschool letter identification, the next question was whether these Preschool measures could significantly predict word identification, word decoding, and word reading fluency at Grade 1.

8.2 Prediction of Grade 1 Reading Skills

Table 8.4 displays descriptive statistics for the sample on the control measures, the Preschool temporal and phonological processing measures, and the Grade 1 reading measures. In Grade 1, three measures of reading skills were obtained: Woodcock Letter Word Identification (word reading accuracy), Woodcock Word Attack (non-word decoding skills), and Reading Rate (word reading fluency). Table 8.4 shows there was a floor effect on Word Attack and so, as described in Section 7.2, a categorical variable was formed. As children had only had around 11 weeks of school when this phase commenced, they knew few words and so the average scores on Letter Word Identification and Reading Rate were fairly low (although as Table 8.4 shows, some children already had already acquired quite a large sight word
Table 8.4

**Performance on Control Measures, Preschool Temporal and Phonological Processing Predictors, and Grade 1 Reading Measures**

<table>
<thead>
<tr>
<th>Measures</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
<th>Maximum Scores(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preschool Age (years)</td>
<td>5.37</td>
<td>0.30</td>
<td>4.83 – 6.17</td>
<td></td>
</tr>
<tr>
<td>Parental Teach</td>
<td>12.76</td>
<td>2.05</td>
<td>7.00 – 17.00</td>
<td>18.00</td>
</tr>
<tr>
<td>Parental Read</td>
<td>14.44</td>
<td>5.43</td>
<td>3.00 – 30.00</td>
<td>36.00</td>
</tr>
<tr>
<td>Vigilance</td>
<td>38.38</td>
<td>4.45</td>
<td>25.00 – 43.00</td>
<td>43.00</td>
</tr>
<tr>
<td>Memory</td>
<td>5.20</td>
<td>1.39</td>
<td>2.00 – 9.00</td>
<td></td>
</tr>
<tr>
<td>Nonverbal Ability</td>
<td>108.78</td>
<td>10.14</td>
<td>81.00 – 135.00</td>
<td></td>
</tr>
<tr>
<td>Auditory TOJ</td>
<td>10.90</td>
<td>2.37</td>
<td>4.00 – 14.00</td>
<td>14.00</td>
</tr>
<tr>
<td>Visual TOJ</td>
<td>26.86</td>
<td>5.95</td>
<td>9.00 – 39.00</td>
<td>40.00</td>
</tr>
<tr>
<td>Temporal Dot</td>
<td>7.64</td>
<td>4.15</td>
<td>0.00 – 18.00</td>
<td>24.00</td>
</tr>
<tr>
<td>RAN (s)</td>
<td>67.77</td>
<td>18.90</td>
<td>27.62 – 136.63</td>
<td></td>
</tr>
<tr>
<td>Phonemic Segmentation</td>
<td>3.22</td>
<td>1.56</td>
<td>0.00 – 8.00</td>
<td>12.00</td>
</tr>
<tr>
<td>Rhyme</td>
<td>4.76</td>
<td>2.81</td>
<td>0.00 – 8.00</td>
<td>8.00</td>
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<tr>
<td>Grade 1 Letter Word Id</td>
<td>14.61</td>
<td>3.48</td>
<td>7.00 – 28.00</td>
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</tr>
<tr>
<td>Grade 1 Word Attack</td>
<td>0.99</td>
<td>1.84</td>
<td>0.00 – 9.00</td>
<td></td>
</tr>
<tr>
<td>Gr. 1 Read Rate</td>
<td>18.29</td>
<td>14.37</td>
<td>0.00 – 78.00</td>
<td>120</td>
</tr>
</tbody>
</table>

\(^a\) Maximum possible scores

vocabulary evidenced by high scores on these two measures). The average score on the Letter Word Identification subtest was consistent with all of the letters being correctly identified.

**8.2.1 Zero-Order Correlations**

Table 8.5 presents the linear Pearson zero-order correlations between the control measures, the Preschool temporal processing and phonological processing predictors, and the Grade 1 reading measures. Of the control measures, there were significant
Table 8.5

Correlations between Control Measures, Preschool Temporal Predictors, Preschool Phonological Predictors, and Grade 1 Reading Outcomes

<table>
<thead>
<tr>
<th></th>
<th>AGE</th>
<th>TEACH</th>
<th>READ</th>
<th>VIG$^a$</th>
<th>ATOJ$^a$</th>
<th>MEM</th>
<th>MAT</th>
<th>ATOJ$^b$</th>
<th>VTOJ</th>
<th>DOT</th>
<th>RAN$^c$</th>
<th>PhonSeg</th>
<th>Rhymes</th>
<th>LetWordId</th>
<th>Attack$^c$</th>
<th>RATE$^d$</th>
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<tr>
<td>AGE</td>
<td>1.00</td>
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</tr>
<tr>
<td>TEACH</td>
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<td>1.00</td>
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<tr>
<td>READ</td>
<td>.11</td>
<td>.28**</td>
<td>1.00</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>VIG$^a$</td>
<td>-.21*</td>
<td>-.20*</td>
<td>-.26**</td>
<td>1.00</td>
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<tr>
<td>ATOJ$^a$</td>
<td>.26**</td>
<td>.12</td>
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<td>.10</td>
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<tr>
<td>MAT</td>
<td>.25**</td>
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<td>.19*</td>
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<td>-.12</td>
<td>.12</td>
<td>-.28**</td>
<td>-.29**</td>
<td>-.32**</td>
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<td>.16</td>
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<td>.19*</td>
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<td>RAN$^c$</td>
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<td>.24**</td>
<td>-.15</td>
<td>.19*</td>
<td>-.26**</td>
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<td>.18*</td>
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<td>.21*</td>
<td>-.28**</td>
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<td>Rhymes</td>
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<td>.23**</td>
<td>.17*</td>
<td>-.22**</td>
<td>.13</td>
<td>.25**</td>
<td>.17</td>
<td>-.24**</td>
<td>.20*</td>
<td>.23**</td>
<td>-.33**</td>
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<td>.28**</td>
<td>.04</td>
<td>-.24**</td>
<td>.06</td>
<td>.16</td>
<td>.18</td>
<td>-.44**</td>
<td>.24**</td>
<td>.23**</td>
<td>-.37**</td>
<td>.33**</td>
<td>.38**</td>
<td>1.00</td>
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<tr>
<td>Attack$^c$</td>
<td>.32**</td>
<td>.18*</td>
<td>.08</td>
<td>-.21*</td>
<td>.11</td>
<td>.14</td>
<td>.18*</td>
<td>-.39**</td>
<td>.30**</td>
<td>.23*</td>
<td>-.31**</td>
<td>.43**</td>
<td>.31**</td>
<td>.64**</td>
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<tr>
<td>RATE$^d$</td>
<td>.25**</td>
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<td>-.29**</td>
<td>.17</td>
<td>.11</td>
<td>.18*</td>
<td>-.37**</td>
<td>.29**</td>
<td>.32**</td>
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<td>.35**</td>
<td>.38**</td>
<td>.83**</td>
<td>.65**</td>
<td>1.00</td>
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</table>

Note: TEACH = Parental Teaching, READ = Parental Reading, VIG = Attentional Vigilance, ATOJcatch = Auditory TOJ catch trials, MEM = Memory, MAT = nonverbal ability, ATOJ = Auditory TOJ, VTOJ = Visual TOJ, DOT = Temporal Dot, RAN = Rapid Automatised Naming, PhonSeg = Phonemic Segmentation, LetWordId = WDRB Letter Word Identification, Attack = WDRB Word Attack, RATE = Reading Rate.

$^a$ Reflected and log transformed; $^b$ Reflected and square root transformed; $^c$ Log transformed; $^d$ Square root transformed; $^e$ Categorical Variable

* $p < .05$; ** $p < .01$
moderate correlations between Age, Parental Teaching, and Attentional Vigilance and all three reading measures. Greater frequency of parental literacy teaching, better attentional vigilance on tasks, and being older were related to better Grade 1 word reading accuracy (Letter Word Identification), decoding skills (Word Attack), and fluency (Reading Rate). There were significant weak correlations between Non-verbal Ability and Word Attack and Reading Rate. There were no significant correlations between the Auditory TOJ catch trials (ATOJcatch), Parental Reading, or Memory, and any reading measures. Therefore, those three control measures were not included in any of the subsequent regression analyses for the Grade 1 reading measures.

All three temporal processing measures showed significant weak to moderate correlations with all three Grade 1 reading measures. Better auditory and visual temporal processing skills were associated with better word identification and decoding and faster reading fluency. As Attentional Vigilance was significantly correlated with the reading measures as well as with the temporal processing measures, it was possible differences in Attentional Vigilance could explain the correlation between visual temporal processing and the reading measures. Similarly, because Age and Non-verbal Ability were related to the two TOJ measures as well as Word Attack and Reading Rate, they could explain the correlations between performance on the TOJ tasks and these two reading measures. By entering these control measures in the initial step in the hierarchical regression analyses, their effects can be partialled out of the relationship between the temporal processing measures and the reading measures.

There were significant weak to moderate correlations between the three phonological processing measures. These three measures showed significant
correlations with the three Grade 1 reading measures. There were significant correlations between Memory and the phonological processing measures, as would be expected given the memory task involves the phonological loop. However, Memory was not significantly related to any of the Grade 1 reading measures, so cannot explain any relationship between the phonological processing measures and reading.

The reading measures showed strong positive linear relationships with each other. The relationship between Letter Word Identification and Reading Rate was stronger than that between either of those measures and Word Attack. This was probably due to the restricted range of scores on Word Attack at Grade 1.

8.2.2 Prediction of Grade 1 Letter-Word Identification

All of the assumptions of hierarchical multiple regression analysis were met. Table 8.6 summarizes the results of the hierarchical regression analyses. The control measures that showed significant zero-order correlations with Grade 1 Letter Word Identification (Age, Parental Teaching, and Attentional Vigilance) were entered at Step 1. The squared semi-partial correlation showed these control measures accounted for 15.00% of the variance in Grade 1 Letter Word Identification; \( F(3,119) = 7.00, p < .0001 \).

Age and Parental Teaching made significant independent contributions, accounting for 3.65% and 4.45% of the variance, respectively (Table 8.6).

When the three temporal processing measures were entered at Step 2, the squared semi-partial correlation showed they accounted for an additional 13.60% of the variance in Grade 1 Letter Word Identification, \( F(3, 116) = 7.35, p < .0001 \). Only Auditory TOJ made a significant unique contribution, accounting for 11.36% of the variance (Table 8.3). When the three phonological processing measures were entered at Step 2, they accounted for an additional 13.20% of the variance in Letter Word
**Table 8.6**

*Hierarchical Regression Analyses for Preschool Variables Predicting Grade 1 Letter Word Identification (N = 123)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE B)</th>
<th>(\beta)</th>
<th>sr</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Age</td>
<td>2.44 (1.08)</td>
<td>0.20</td>
<td>.19</td>
<td>.026*</td>
</tr>
<tr>
<td>2. Parent Teach</td>
<td>0.39 (0.15)</td>
<td>0.22</td>
<td>.21</td>
<td>.014*</td>
</tr>
<tr>
<td>3. Vigilance</td>
<td>-2.01 (1.12)</td>
<td>-0.16</td>
<td>-.15</td>
<td>.077</td>
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</tbody>
</table>

\[ R^2 = .150* \]

<table>
<thead>
<tr>
<th>Variable</th>
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<th>(\beta)</th>
<th>sr</th>
<th>(p)</th>
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<tr>
<td><strong>Step 2.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Auditory TOJ</td>
<td>-2.59 (0.60)</td>
<td>-0.37</td>
<td>-.34</td>
<td>&lt; .0001*</td>
</tr>
<tr>
<td>5. Visual TOJ</td>
<td>-0.02 (0.06)</td>
<td>-0.03</td>
<td>-.03</td>
<td>.723</td>
</tr>
<tr>
<td>6. Temporal Dot</td>
<td>0.12 (0.08)</td>
<td>0.13</td>
<td>.12</td>
<td>.121</td>
</tr>
</tbody>
</table>

\[ \Delta R^2 = .136* \]

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE B)</th>
<th>(\beta)</th>
<th>sr</th>
<th>(p)</th>
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<tbody>
<tr>
<td><strong>Step 3.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. RAN</td>
<td>-6.32 (2.39)</td>
<td>-0.21</td>
<td>-.20</td>
<td>.009*</td>
</tr>
<tr>
<td>8. Phon. Segment.</td>
<td>0.30 (0.21)</td>
<td>0.13</td>
<td>.11</td>
<td>.149</td>
</tr>
<tr>
<td>9. Rhyme</td>
<td>0.14 (0.12)</td>
<td>0.11</td>
<td>.09</td>
<td>.225</td>
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</tbody>
</table>

\[ \Delta R^2 = .090* \]

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE B)</th>
<th>(\beta)</th>
<th>sr</th>
<th>(p)</th>
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<tr>
<td><strong>Step 2.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. RAN</td>
<td>-6.77 (2.52)</td>
<td>-0.23</td>
<td>-.21</td>
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</tr>
<tr>
<td>5. Phon. Segment.</td>
<td>0.37 (0.21)</td>
<td>0.15</td>
<td>.14</td>
<td>.082</td>
</tr>
<tr>
<td>6. Rhymes</td>
<td>0.20 (0.12)</td>
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<td>.13</td>
<td>.099</td>
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</table>

\[ \Delta R^2 = .132* \]

<table>
<thead>
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<th>B (SE B)</th>
<th>(\beta)</th>
<th>sr</th>
<th>(p)</th>
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<tbody>
<tr>
<td><strong>Step 3.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Auditory TOJ</td>
<td>-2.23 (0.59)</td>
<td>-0.32</td>
<td>-.29</td>
<td>&lt; .0001*</td>
</tr>
<tr>
<td>8. Visual TOJ</td>
<td>-0.03 (0.06)</td>
<td>-0.06</td>
<td>-.05</td>
<td>.534</td>
</tr>
<tr>
<td>9. Temporal Dot</td>
<td>0.10 (0.07)</td>
<td>0.11</td>
<td>.10</td>
<td>.183</td>
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</tbody>
</table>

\[ \Delta R^2 = .093* \]

* \(p < .05\)
Identification; $F (3, 116) = 7.13, p < .0001$. Only Rapid Automatised Naming made a
significant unique contribution, accounting for 4.45% of the variance. The remaining
variance overlapped between the three phonological measures (Table 8.3). Steiger's
$z$-test (Steiger, 1980) showed there was no significant difference in the amount of
variance accounted for in Grade 1 Letter Word Identification between these two sets
of predictor variables, after accounting for the variance due to the control factors,
$\bar{z}^* = -0.05, p = .96$.

To determine the unique versus shared variance in Grade 1 Letter Word
Identification accounted for by the temporal and phonological processing measures,
each was entered at the final step in the regression analysis. When the temporal
processing measures were entered at Step 3, after both the control and phonological
processing measures, they accounted for an additional 9.30% of the variance, $F (3,
113) = 5.61, p = .001$, which represented their unique contribution (Table 8.3). When
the phonological processing measures were entered at Step 3, they accounted for an
additional 9.00% of the variance, $F (3, 113) = 5.40, p = .002$ (Table 8.3). This
represented their unique contribution.

Together, the control and Preschool temporal and phonological processing
measures accounted for a total 37.50% of the variance in Grade 1 Letter Word
Identification. Commonality analysis indicated there was 4.20% common variance
accounted for by the Preschool temporal and phonological processing measures.
When all the measured had entered the regression analysis, only Auditory TOJ and
Rapid Automatised Naming accounted for significant unique components of variance,
accounting for 8.18% and 3.88%, respectively. Based on the $\beta$ weights, the most
important Preschool predictor of Grade 1 Letter Word Identification was Auditory TOJ accuracy.

8.2.3 Prediction of Grade 1 Reading Rate

There were significant effects of school attended (see Chapter 7.6.2) and the presence of Speech Problems (see Chapter 7.7.2) on Grade 1 Reading Rate, so those variables were also included in these regression analyses, in order to partial out their effects. Table 8.7 summarises the regression analyses. The school variables were included at Step 1 (SCHOOL1 and SCHOOL2) and accounted for 6.70% of the variance, $F(2, 115) = 4.15, p = .018$. Age, Parental Teaching, Attentional Vigilance, Auditory TOJ catch trials, and Non-verbal Ability showed significant zero-order correlations with Grade 1 Reading Rate, and so were entered at Step 2, along with the Speech Problems variable. Together, they accounted for an additional 20.80% of the variance in Grade 1 Reading Rate, $F(6, 109) = 5.21, p < .0001$. The squared semi-partial correlations showed Age, Parental Teaching, and Speech Problems uniquely accounted for significant variance in Grade 1 Reading Rate. Parental Teaching uniquely accounted for 4.58%. Age uniquely accounted for 2.89% of the variance, and Speech Problems uniquely accounted for 2.76% (See Table 8.7).

At Step 3, addition of the three temporal processing measures accounted for an additional 8.30% of the variance, $F(3, 106) = 4.58, p = .005$. The squared semi-partial correlations showed Auditory TOJ uniquely accounted for 5.02% of that variance and Temporal Dot uniquely accounted for 2.62%. When the three phonological processing measures were entered at Step 3, they accounted for an additional 13.30% of the variance, $F(3, 106) = 7.96, p < .0001$. Only Rhymes made a significant unique contribution, accounting for 4.93% of that variance (see Table 8.7).
Table 8.7

*Hierarchical Regression Analyses for Variables Predicting Grade 1 Reading Rate (N = 118)*

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
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<th>$\beta$</th>
<th>sr</th>
<th>$p$</th>
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<td>1. SCHOOL1</td>
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<td>2. SCHOOL2</td>
<td>-1.11 (0.40)</td>
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<td>.007*</td>
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<td>$R^2 = .067*$</td>
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<tr>
<td>Step 2</td>
<td>3. Age</td>
<td>1.06 (0.51)</td>
<td>0.19</td>
<td>.17</td>
<td>.04*</td>
</tr>
<tr>
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<td>4. Parent Teach</td>
<td>0.18 (0.07)</td>
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<td>.21</td>
<td>.01*</td>
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<tr>
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<td>5. Vigilance</td>
<td>-0.96 (0.51)</td>
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<td>.063</td>
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<td>6. ATOJcatch</td>
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<td>.523</td>
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<td>7. Nonverbal</td>
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<td>8. Speech Problem</td>
<td>0.78 (0.38)</td>
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<td>.17</td>
<td>.045*</td>
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<td>$\Delta R^2 = .208*$</td>
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<tr>
<td>Step 3</td>
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<td>-0.82 (0.28)</td>
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<td>-.22</td>
<td>.005*</td>
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<td>10. Visual TOJ</td>
<td>0.01 (0.03)</td>
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<td>.745</td>
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<td>11. Temporal Dot</td>
<td>0.07 (0.04)</td>
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<td>.16</td>
<td>.04*</td>
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<td>$\Delta R^2 = .083*$</td>
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<tr>
<td>Step 4</td>
<td>12. RAN</td>
<td>-2.17 (1.13)</td>
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<td>-.14</td>
<td>.058</td>
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<tr>
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<td>13. Phon. Segment.</td>
<td>0.12 (0.10)</td>
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<td>.201</td>
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<td>14. Rhymes</td>
<td>0.15 (0.06)</td>
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<td>.19</td>
<td>.011*</td>
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<td>$\Delta R^2 = .106*$</td>
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<td></td>
</tr>
<tr>
<td>Step 3</td>
<td>9. RAN</td>
<td>-2.09 (1.17)</td>
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<td>-.13</td>
<td>.078</td>
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<tr>
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<td>10. Phon. Segment.</td>
<td>0.14 (0.10)</td>
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<td>.14</td>
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<td></td>
<td>11. Rhymes</td>
<td>0.17 (0.06)</td>
<td>0.29</td>
<td>.22</td>
<td>.004*</td>
</tr>
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<td>$\Delta R^2 = .133*$</td>
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<td></td>
</tr>
<tr>
<td>Step 4</td>
<td>12. Auditory TOJ</td>
<td>-0.69 (0.27)</td>
<td>-0.22</td>
<td>-.19</td>
<td>.011*</td>
</tr>
<tr>
<td></td>
<td>13. Visual TOJ</td>
<td>0.01 (0.03)</td>
<td>0.04</td>
<td>.03</td>
<td>.656</td>
</tr>
<tr>
<td></td>
<td>14. Temporal Dot</td>
<td>0.06 (0.03)</td>
<td>0.14</td>
<td>.12</td>
<td>.094</td>
</tr>
<tr>
<td></td>
<td>$\Delta R^2 = .056*$</td>
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</tbody>
</table>

* $p < .05$
Steiger's $z$-test (Steiger, 1980) showed there was no significant difference between the temporal and phonological processing measures in the amount of variance they accounted for in Grade 1 Reading Rate, $z^* = -0.59, p = .555$.

When entered at Step 4, after the phonological processing predictors, the temporal processing measures accounted for an additional 5.60% of the variance, $F(3, 103) = 3.60, p = .016$. Thus, the temporal processing measures accounted for 5.60% unique variance in Grade 1 Reading Rate. Auditory TOJ accounted for 3.53% of that variance. When the phonological processing measures were entered last, at Step 4, they accounted for an additional 10.60% of the variance; $F(3, 103) = 6.81, p < .0001$, which represented their unique contribution to variance in Grade 1 Reading Rate. Rhymes uniquely accounted for 3.50% of that variance. In total, the school attended, control measures, and Preschool temporal and phonological processing predictors accounted for 46.40% of the variance in Grade 1 Reading Rate. Commonality analysis showed 2.70% of the variance in Grade 1 Reading Rate was common to the Preschool temporal and phonological processing measures. When all measures had entered the regression analysis, only School attended, Auditory TOJ, and Rhymes accounted for significant unique components of variance. The $\beta$ weights indicated school attended was the most important predictor of Grade 1 Reading Rate, followed in importance by Preschool rhyme detection and auditory temporal processing.

8.2.4 Grade 1 Word Attack

The third reading outcome measured at Grade 1 was Woodcock Word Attack (ATT), a measure of decoding skills. Using non-words separates phonological decoding skill from visual recognition or orthographic processing. Multiple
regression analysis could not be used because Grade 1 Word Attack was a categorical variable, formed because of the floor effect. Discriminant function analysis was conducted to determine if the Preschool temporal and phonological processing measures could significantly discriminate children who could decode at Grade 1 (score > 0; \( n = 36 \)) from those who could not (score = 0; \( n = 88 \)). Table 8.8 presents the descriptive statistics for the Decoder and Non-decoder groups. Decoders showed significantly better temporal and phonological processing than the Non-decoders did. Of the control measures, Decoders were significantly older than Non-decoders were, \( t(122) = -3.71, p < .0001, d = .73; \) and experienced significantly higher frequency of Parental Teaching, \( t(121) = -1.99, p = .049, d = 0.39 \). Thus, Age and Parental Teaching were also included into the discriminant function analyses. Grade 1 Word Attack group was the DV. In the first analysis, Age, Parental Teaching, and the three temporal processing measures were included. There was a significant discriminant function, \( \chi^2(5) = 30.59, p < .0001 \), with 23.14% of the variance in the Word Attack categories explained by the IVs. Only Parental Teaching did not contribute significantly to the discriminant function, \( p = .058 \). There were 92.90% of Non-decoders and 52.80% of Decoders correctly classified using Age, Parental Teaching and the three Preschool temporal processing measures. Auditory TOJ accuracy was the most important contributor to the discrimination (structure co-efficient = -.76). This negative loading is due to the reflected square root transformation of Auditory TOJ scores.

In the second analysis, the same two control measures plus the three phonological processing measures were entered into the discriminant function analysis. The discriminant function was significant, \( \chi^2(5) = 40.21, p < .0001 \), with 28.73% of the variance in the decoding categories explained by the IVs. All variables
contributed significantly to this discriminant function. There were 88.5% of the Non-Decoders and 55.6% of the Decoders correctly classified. Phonemic Segmentation was the most important contributor (structure co-efficient = .76).

Table 8.8

Descriptive Statistics for Control Measures and Preschool Temporal and Phonological Processing Measures for Decoders and Non-decoders at Grade 1

<table>
<thead>
<tr>
<th>Preschool Measures</th>
<th>Decoders ($n = 36$)</th>
<th>Non-decoders ($n = 88$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>5.51 (0.27)</td>
<td>5.30 (0.29)*</td>
</tr>
<tr>
<td>Parent Teaching</td>
<td>13.25 (2.30)</td>
<td>12.45 (1.92)*</td>
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<td>Parent Reading</td>
<td>15.00 (4.88)</td>
<td>13.99 (5.72)</td>
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<td>Vigilance</td>
<td>37.53 (4.30)</td>
<td>35.91 (4.55)</td>
</tr>
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<td>Memory</td>
<td>5.47 (1.52)</td>
<td>5.03 (1.39)</td>
</tr>
<tr>
<td>Nonverbal (std. Score)</td>
<td>110.09 (11.11)</td>
<td>107.76 (10.07)</td>
</tr>
<tr>
<td>Auditory TOJ</td>
<td>12.19 (2.23)</td>
<td>10.27 (2.20)*</td>
</tr>
<tr>
<td>Visual TOJ</td>
<td>29.47 (5.90)</td>
<td>25.55 (5.73)*</td>
</tr>
<tr>
<td>Temporal Dot</td>
<td>9.06 (4.39)</td>
<td>7.00 (3.85)*</td>
</tr>
<tr>
<td>RAN (secs)</td>
<td>54.58 (15.43)</td>
<td>67.09 (20.04)*</td>
</tr>
<tr>
<td>Phonemic Segment.</td>
<td>4.25 (1.65)</td>
<td>2.76 (1.33)*</td>
</tr>
<tr>
<td>Rhymes</td>
<td>6.00 (2.29)</td>
<td>4.05 (2.89)*</td>
</tr>
</tbody>
</table>

* $p < .05$
To determine if using both temporal and phonological processing measures produced better discrimination, all measures were included together. The discriminant function was significant, $\chi^2 (8) = 48.60$, $p < .0001$, with 34.46% of the variance in the decoding categories explained. All variables, except Parental Teaching ($p = .058$), contributed significantly to this discriminant function. These measures correctly classified 91.80% of the Non-Decoders and 61.10% of the Decoders. The two most important contributors were Phonemic Segmentation (structure co-efficient = .65) and Auditory TOJ (structure co-efficient = -.58).

**8.2.5 Discussion**

The Preschool temporal processing measures explained significant additional variance in Grade 1 reading accuracy (Letter Word Identification) and fluency (Reading Rate), after partialling out the effects of factors such as Age, early home environment, Attentional Vigilance, Nonverbal Ability, and the school attended. They also significantly discriminated children who were unable to decode non-words at Grade 1 from those who could (based on scores on Word Attack). Preschool temporal and phonological processing measures (either alone or in combination), Age, and Parental Teaching were very accurate at discriminating the Non-decoders, but less accurate at discriminating the Decoders. The Non-decoders were possibly a more homogeneous group (all scored zero on Word Attack), whereas the Decoders showed greater variability (scores ranged from 1 to 11, with a mean of 3.67). Overall, these predictor measures accounted for only around one third of the variance in the decoding variable, so these results need to be interpreted with caution.

Auditory TOJ accounted for unique variance in both Grade 1 reading accuracy and fluency, and was the most important contributor of the temporal processing measures to the discrimination of non-word decoding groups. Temporal Dot accuracy
only accounted for significant unique variance in Grade 1 fluency (Reading Rate). However, when the phonological processing measures were entered first, Temporal Dot no longer accounted for significant unique variance. This may reflect a greater role of rapid visual sequencing in reading fluency, in which rapid or automatic visual recognition of words is emphasised. Temporal Dot and Rhymes were significantly correlated, and the results show the variance that Temporal Dot accounted for in Reading Rate overlapped with that accounted for by Rhymes. Some of the variance that Auditory TOJ accounted for in Reading Rate overlapped with the phonological measures, but it still accounted for a significant independent percentage of variance. Despite having significant zero-order correlations with all three reading measures, all of the variance explained by Visual TOJ was subsumed by the control measures or other temporal processing measures. The results for the regression of these measures on Grade 1 Letter Word Identification were consistent with those obtained with Preschool Letter Word Identification. In the prediction of Letter Word Identification at both of these phases, Auditory TOJ was the only temporal measure to account for significant unique variance.

After accounting for the variance due to the various control factors, the Preschool phonological processing measures accounted for significant percentages of additional variance in each reading measure. Different phonological measures accounted for unique variance in each reading measure, but a larger percentage of the variance in the reading measures was explained by variance shared between the three phonological measures than by variance unique to any one phonological measure. Only Rapid Automatised Naming accounted for unique variance in Grade 1 Letter Word Identification. It had also been the most important of the phonological processing predictors of Preschool Letter Word Identification. As discussed in
Section 8.1.3, this likely reflects the common component of rapid lexical access and symbol-name association in these two tasks. The obtained zero-order correlations between Preschool rapid naming speed for objects and all three Grade 1 reading measures were almost identical to those reported by Wolf (1984). Rapid naming speed was less important in non-word decoding than it had been in word identification, a resultant consistent with Bowers (1995). If the rapid naming measure were simply a measure of processing speed as proposed by Kail et al. (1999), it should show a stronger relationship with Reading Rate, which also has a processing speed component. This did not occur; Rapid Automatised Naming did not account for significant unique variance in Reading Rate at Grade 1.

Only Rhymes accounted for significant unique variance in Grade 1 Reading Rate. This is consistent with Bowey’s (2002) argument that the most important phonological predictor of reading differs depending on when the predictors are measured. When measured before school or before reading, awareness of onset and rime, measured by rhyme and alliteration detection tasks, are the best predictors. Phonemic Segmentation was the most important of the Preschool phonological processing variables in discriminating the Word Attack (decoding) groups. More developed phonemic segmentation skills were associated with more developed non-word decoding skills. This reflects the need to be able to segment words phonologically in order to sound out unknown words, or in this case, non-words.

According to Steiger’s test (1980), there were no significant differences in the amounts of variance accounted for in Grade 1 Letter Word Identification and Reading Rate between the Preschool temporal processing predictors and Preschool phonological processing predictors. In Letter Word Identification in particular, the two sets of predictors accounted for a very similar percentage of variance in addition
to that explained by the control measures. This shows the temporal processing measures would be as useful as the phonological processing measures as predictors of Grade 1 reading. Given there was little common variance explained by these two sets of predictors, using both optimised prediction of Grade 1 reading ability. This supports including pre-school measures of temporal processing in early screening tests for risk for reading difficulties.

In terms of the control factors, the frequency of parental teaching of literacy skills in the early home environment was important in predicting individual differences in Grade 1 single word reading accuracy (Letter Word Identification) and fluency (Reading Rate). More developed decoding skills in Grade 1 (higher Word Attack scores) were also associated with greater frequency of parental literacy teaching prior to being tested. Similarly to the findings with Preschool Letter Word Identification, it was the active practices in the early home environment that were important to early reading development, not the passive practices of reading to children. This is consistent with previous research into parental and early classroom practices, which found passive parent or teacher reading to children was not related to the children's reading ability, whereas active teaching experiences, particularly of letter knowledge, were (Burgess et al., 2002; Elbro et al., 1998; Meyer et al., 1994; Sénéchal et al., 1998). For example, Sénéchal et al. found parental reports of frequency of teaching kindergarten ($n = 110$) and first grade ($n = 58$) children to print and read words accounted for 7% of the variance in children's literacy skills, after age, IQ, and parent reading experience were controlled. This is very similar to the results obtained in the present study, after controlling for similar factors.

The reported presence of speech and language problems accounted for a small percentage of unique variance in Grade 1 Reading Rate. However, Auditory TOJ still
accounted for significant variance, after controlling for this speech effect. This showed the presence of such problems could not explain the relationship between auditory temporal processing and reading ability in a normative sample. This is contrary to the argument of Heath et al. (1999), although they used objective measures of speech and language problems and a dyslexic sample. It is clearly important to control for the effects of speech problems with measures of reading fluency, but, as discussed in Section 7.7.4, the relationship may be more related to articulation rate than to auditory temporal processing. Further research including measures of articulation rate is needed to confirm this.

Results with prediction of Grade 1 Reading Rate confirmed Share et al.’s (1984) findings that a significant percentage of unique variance in individual reading skill in early primary school is accounted for by the school (or class). These results showed school attended was the most important single predictor of Grade 1 Reading Rate, after all of the measures had entered the regression analysis. Mean group ability has an effect on the individual’s ability. It is also possible differences in literacy teaching or other aspects of the school culture, such as the importance placed on literacy, contributed to this school effect. Information on teaching practices was not collected in this study.

These results established there are pre-existing identifiable differences among children in temporal processing that are significantly related to individual differences in reading abilities that emerge once the child is at school. This relationship is not explained by individual differences in factors such as the richness of the early home literacy environment, attentional vigilance, nonverbal ability, school attended, or the presence of speech or language difficulties. Furthermore, these temporal processing
measures continued to account for unique variance, after partialling out variance due to phonological processing skills.

The next question concerned the ability of these Preschool measures to predict reading over the longer term, through to Grade 2. Changes in the stage of reading development by Grade 2, when orthographic strategies are becoming more important, could lead to changes in the pattern of prediction.

8.3 Prediction of Grade 2 Reading Ability

This section presents similar multiple regression commonality analyses to those for the Grade 1 reading measures. The specific control variables included depended on significant zero-order correlations with the Grade 2 reading measures. The selected control measures were entered at Step 1 in the hierarchical multiple regression analyses. The Preschool temporal and phonological processing measures were included as predictors at subsequent steps. The dependent variables were the four Grade 2 reading measures. Letter Word Identification, Reading Rate, and Word Attack were re-measured at Grade 2, and Pseudohomophone Choice (orthographic processing) was measured for the first time. By this phase, children had been at school and receiving literacy instruction for one year and one term (around 52 weeks of actual school attendance). It was expected children would be moving into the final stage of reading development in which they would have well developed knowledge of letter symbols and sounds, resulting in well-developed word decoding skills, as well as some knowledge of orthographic strategies. They were expected to have developed a sight word vocabulary of words they could recognise automatically. Table 8.9 presents the descriptive statistics for the control measures, the Preschool predictor measures, and Grade 2 reading measures.
Table 8.9

*Performance on Control Measures, Preschool Temporal and Phonological Processing Predictors, and Grade 2 Reading Measures*

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<tr>
<th>Measures</th>
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<th>Standard Deviation</th>
<th>Range</th>
<th>Maximum Scores(^a)</th>
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\(^a\)Maximum possible scores

8.3.1 Zero-Order Correlations

Table 8.10 presents the zero-order correlations between the control measures, the Preschool temporal and phonological processing predictors, and the Grade 2
reading outcomes. Age was significantly positively correlated with Grade 2 Letter Word Identification and Word Attack skills, but not with Reading Rate or Pseudohomophone Choice. Parental Teaching showed significant weak positive correlations with all Grade 2 reading measures, but Parental Reading did not. This was consistent with the results in the Grade 1 phase. Both Attentional Vigilance and the Auditory TOJ Catch Trials scores showed significant weak to moderate correlations with all of the reading measures, except Pseudohomophone Choice. Better short-term memory and Non-verbal Ability were associated with better performance on identifying words (Letter Word Identification), decoding words (Word Attack), and orthographic processing (Pseudohomophone Choice). Thus, whereas Memory had shown no significant correlations with reading measures at Grade 1, it did at both Preschool and Grade 2.

Preschool Temporal Dot was the only temporal processing measure to show significant correlations with all four reading measures. Better accuracy on this rapid visual sequencing task was associated with better word identification and decoding, faster reading rate, and better orthographic processing. Visual TOJ was significantly correlated with Grade 2 Letter Word Identification and Word Attack only. Unlike the correlations at Grade 1, neither of the TOJ tasks showed significant correlations with Reading Rate by Grade 2. Auditory TOJ showed a significant weak correlation with Pseudohomophone Choice, such that better auditory temporal processing was related to better orthographic processing.

There were significant moderate positive correlations between all three Preschool phonological processing measures and Grade 2 Letter Word Identification, Word Attack, and Reading Rate, and significant weak positive correlations with Pseudohomophone Choice. There were significant strong linear relationships
Table 8.10

Correlations between Control Measures, Preschool Temporal Predictors, Preschool Phonological Predictors and Grade 2 Reading Outcomes

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<td>.26**</td>
<td>.26**</td>
<td>.75**</td>
<td>.65**</td>
<td>.65**</td>
<td>1.00</td>
</tr>
</tbody>
</table>


* Reflected and log transformed; † Reflected and square root transformed; ‡ Log transformed; § Square root transformed; ¶ Categorical Variable

* p < .05
** p < .01
between all of the reading measures. Analyses reported in Chapter 7 showed there was a significant effect of school attended on all of the Grade 2 reading measures and of the presence of Speech Problems on Grade 2 Reading Rate, so these were also included where necessary.

8.3.2 Prediction of Grade 2 Letter-Word Identification

Table 8.11 summarizes the results of the regression model. At Step 1, the school variables (SCHOOL1 and SCHOOL2) accounted for 13.5% of the variance in Grade 2 Letter Word Identification, $\text{F}(2, 100) = 7.80, p = .001$. Based on the zero-order correlations, Age, Parental Teaching, Vigilance, Auditory TOJ catch trials, Memory, and Non-verbal Ability were entered into the regression analysis at Step 2. They accounted for an additional 18.2% of the variance in Grade 2 Letter Word Identification, $\text{F}(6, 94) = 4.17, p = .001$. Vigilance uniquely accounted for a significant 3.65% of the variance. Memory also uniquely accounted for 2.86% of the variance, which was a marginal effect ($p = .05$). When the temporal processing measures were entered at Step 3, they accounted for an additional 7.60% of the variance in Letter Word Identification, $\text{F}(3, 91) = 3.80, p = .013$. Only Temporal Dot accounted for a significant unique component of variance, accounting for 4.62% (Table 8.11). When the three phonological processing measures were entered at Step 3, they accounted for an additional 12.90% of the variance in Grade 2 Letter Word Identification, $\text{F}(3, 91) = 7.04, p < .0001$. Rhymes accounted for a significant independent component of the variance, accounting for 4.00% of the variance. Phonemic Segmentation also accounted for significant independent variance, 2.86% (Table 8.11). Steiger's (1980) z-test revealed that there was no significant difference between the percentages of variance accounted for in Grade 2 Letter Word
### Table 8.11

**Hierarchical Regression Analyses for Variables Predicting Grade 2 Letter Word Identification (N = 103)**

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>B (SE B)</th>
<th>$\beta$</th>
<th>sr</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1. SCHOOL1</td>
<td>-5.28 (1.61)</td>
<td>-0.36</td>
<td>-0.30</td>
<td>.002*</td>
</tr>
<tr>
<td>2.</td>
<td>2. SCHOOL2</td>
<td>-6.24 (1.71)</td>
<td>-0.41</td>
<td>-0.34</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td></td>
<td>$R^2 = .135^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>3. Age</td>
<td>2.33 (2.30)</td>
<td>0.10</td>
<td>0.09</td>
<td>.315</td>
</tr>
<tr>
<td>4.</td>
<td>4. Parent Teach</td>
<td>0.59 (0.31)</td>
<td>0.17</td>
<td>0.16</td>
<td>.063</td>
</tr>
<tr>
<td>5.</td>
<td>5. Vigilance</td>
<td>-5.15 (2.30)</td>
<td>-0.20</td>
<td>-0.19</td>
<td>.028*</td>
</tr>
<tr>
<td>6.</td>
<td>6. ATOJcatch</td>
<td>2.14 (2.46)</td>
<td>0.08</td>
<td>0.07</td>
<td>.386</td>
</tr>
<tr>
<td>7.</td>
<td>7. Memory</td>
<td>0.92 (0.47)</td>
<td>0.18</td>
<td>0.17</td>
<td>.05*</td>
</tr>
<tr>
<td>8.</td>
<td>8. Nonverbal</td>
<td>0.12 (0.15)</td>
<td>0.08</td>
<td>0.07</td>
<td>.408</td>
</tr>
<tr>
<td></td>
<td>$\Delta R^2 = .182^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>9. Auditory TOJ</td>
<td>-2.38 (1.26)</td>
<td>-0.18</td>
<td>-0.15</td>
<td>.062</td>
</tr>
<tr>
<td>10.</td>
<td>10. Visual TOJ</td>
<td>0.02 (0.12)</td>
<td>0.02</td>
<td>0.02</td>
<td>.841</td>
</tr>
<tr>
<td>11.</td>
<td>11. Temporal Dot</td>
<td>0.39 (0.15)</td>
<td>0.24</td>
<td>0.22</td>
<td>.01*</td>
</tr>
<tr>
<td></td>
<td>$\Delta R^2 = .076^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>12. RAN</td>
<td>-7.25 (4.95)</td>
<td>-0.13</td>
<td>-0.11</td>
<td>.147</td>
</tr>
<tr>
<td>13.</td>
<td>13. Phon. Segment.</td>
<td>0.95 (0.41)</td>
<td>0.21</td>
<td>0.17</td>
<td>.022*</td>
</tr>
<tr>
<td>14.</td>
<td>14. Rhymes</td>
<td>0.52 (0.26)</td>
<td>0.20</td>
<td>0.15</td>
<td>.05*</td>
</tr>
<tr>
<td></td>
<td>$\Delta R^2 = .111^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>9. RAN</td>
<td>-6.14 (5.11)</td>
<td>-0.11</td>
<td>-0.09</td>
<td>.233</td>
</tr>
<tr>
<td>10.</td>
<td>10. Phon. Segment.</td>
<td>0.90 (0.41)</td>
<td>0.20</td>
<td>0.17</td>
<td>.033*</td>
</tr>
<tr>
<td>11.</td>
<td>11. Rhymes</td>
<td>0.68 (0.27)</td>
<td>0.27</td>
<td>0.20</td>
<td>.012*</td>
</tr>
<tr>
<td></td>
<td>$\Delta R^2 = .129^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>12. Auditory TOJ</td>
<td>-2.13 (1.17)</td>
<td>-0.16</td>
<td>-0.14</td>
<td>.071</td>
</tr>
<tr>
<td>13.</td>
<td>13. Visual TOJ</td>
<td>0.02 (0.11)</td>
<td>0.01</td>
<td>0.01</td>
<td>.893</td>
</tr>
<tr>
<td>14.</td>
<td>14. Temporal Dot</td>
<td>0.35 (0.14)</td>
<td>0.21</td>
<td>0.19</td>
<td>.014*</td>
</tr>
<tr>
<td></td>
<td>$\Delta R^2 = .058^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* $p < .05$

Identification by the Preschool temporal or phonological processing measures, $Z^* =$
-0.59, $p = .555$.

To determine how much variance each set of predictors uniquely accounted for, each set was entered last, at Step 4, and the percentage variance examined. When entered at Step 4, after all of the other measures had entered, the temporal processing measures accounted for an additional 5.80% of the variance, $F (3, 88) = 3.46, p = .02$ (Table 8.11). This represented their unique contribution to the variance in Grade 2 Letter Word Identification. When the phonological processing measures were entered at Step 4, they accounted for an additional 11.10% of the variance, $F (3, 88) = 6.57, p < .0001$, which represented their unique contribution. In total, the school, control, temporal processing, and phonological processing measures accounted for 50.40% of the variance in Grade 2 Letter Word Identification. Commonality analysis showed that only 1.80% of the variance accounted for in Grade 2 Letter Word Identification overlapped between the Preschool temporal processing and phonological processing measures. When all of the measures were entered, only school attended, Temporal Dot, and Phonemic Segmentation accounted for significant unique components of variance, with a marginal contribution for Rhymes. Temporal Dot accuracy accounted for 3.57% of the variance. Phonemic Segmentation accounted for 3.03% of the variance. Based on the $\beta$ weights, the most important predictor of Grade 2 Reading Rate was the school attended, a result consistent with the Grade 1 results (Table 8.11).

8.3.3 Prediction of Grade 2 Reading Rate

See Table 8.12 for summary of regression analysis. At Step 1, SCHOOL1 and SCHOOL2 accounted for 5.50% of the variance in Grade 2 Reading Rate, but this failed to reach significance, $F (2, 97) = 2.80, p = .066$. At Step 2, Parental Teaching, Vigilance, Auditory TOJ catch trials, and Speech Problems accounted for an
Table 8.12

_Hierarchical Regression Analyses for Variables Predicting Grade 2 Reading Rate (N = 100)_

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>B (SE B)</th>
<th>β</th>
<th>sr</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1. SCHOOL1</td>
<td>-13.60 (5.84)</td>
<td>-0.28</td>
<td>-.23</td>
<td>.022*</td>
</tr>
<tr>
<td></td>
<td>2. SCHOOL2</td>
<td>-10.12 (6.19)</td>
<td>-0.19</td>
<td>-.16</td>
<td>.105</td>
</tr>
<tr>
<td></td>
<td>R² = .055</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3. Parent Teach</td>
<td>1.83 (1.09)</td>
<td>0.16</td>
<td>.15</td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td>4. Vigilance</td>
<td>-20.91 (7.92)</td>
<td>-0.25</td>
<td>-.24</td>
<td>.01*</td>
</tr>
<tr>
<td></td>
<td>5. ATOJcatch</td>
<td>16.69 (8.31)</td>
<td>0.19</td>
<td>.18</td>
<td>.047*</td>
</tr>
<tr>
<td></td>
<td>6. Speech Prob.</td>
<td>12.10 (5.96)</td>
<td>0.19</td>
<td>.18</td>
<td>.045*</td>
</tr>
<tr>
<td></td>
<td>ΔR² = .190*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7. Temporal Dot</td>
<td>0.99 (0.54)</td>
<td>0.17</td>
<td>.16</td>
<td>.068</td>
</tr>
<tr>
<td></td>
<td>ΔR² = .027</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>8. RAN</td>
<td>-50.50 (17.90)</td>
<td>-0.26</td>
<td>-.23</td>
<td>.006*</td>
</tr>
<tr>
<td></td>
<td>9. Phon.Segment</td>
<td>-1.72 (1.39)</td>
<td>-0.12</td>
<td>.10</td>
<td>.221</td>
</tr>
<tr>
<td></td>
<td>10. Rhymes</td>
<td>2.07 (0.94)</td>
<td>0.24</td>
<td>.18</td>
<td>.03*</td>
</tr>
<tr>
<td></td>
<td>ΔR² = .155*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Step 3:  7. RAN -49.58 (18.00) -0.26 -.28 .007*  
8. Phon.Segment 1.56 (1.40) 0.10 .08 .267  
9. Rhymes 2.36 (0.92) 0.27 .10 .012*  
ΔR² = .168*  

Step 4: 10. Temp. Dot 0.73 (0.50) 0.13 .12 .143  
ΔR² = .014  

* p < .05

Additional 19.00% of the variance in Grade 2 Reading Rate, F (4, 93) = 5.85, p <
Temporal Processing and Early Reading

.0001. Vigilance uniquely accounted for 5.66% of the variance, Auditory TOJ Catch Trials accounted for 3.28%, and Speech Problems accounted for 3.35%, all of which were significant (Table 8.12).

Of the temporal processing measures, only Temporal Dot showed a significant zero-order correlation with Grade 2 Reading Rate so was the only temporal processing measure entered at Step 3. The $R^2$ change showed an additional 2.70% of the variance in Grade 2 Reading Rate was accounted for by Temporal Dot, but this failed to reach significance, $F(1, 92) = 3.40, p = .068$. When the three phonological processing measures were entered at Step 3, the $R^2$ change showed an additional 16.8% of the variance in Grade 2 Reading Rate was accounted for, $F(3, 90) = 8.58, p < .0001$. Rapid Automatised Naming uniquely accounted for 4.93% of the variance and Rhymes uniquely accounted for 4.24%, both of which were significant (Table 8.12).

Temporal Dot did not account for a significant additional component of variance when it was entered at Step 4, $F(1, 89) = 2.19, p = .143$. When the three phonological processing measures were entered at Step 4, after all other variables, they still accounted for an additional 15.50% of the variance in Grade 2 Reading Rate, $F(3, 89) = 8.03, p < .0001$, which was their unique contribution. Rapid Automatised Naming made a significant unique contribution, accounting for 5.11% of the variance in Grade 2 Reading Rate. Rhymes also uniquely accounted for 3.13% of the variance (Table 8.12). Together, all of the variables explained 42.70% of the variance in Grade 2 Reading Rate. Commonality analysis showed there was very little variance (1.30%) in Grade 2 Reading Rate shared between Preschool phonological processing skill and Preschool Temporal Dot accuracy. This is not surprising given Temporal Dot only
accounted for 1.4% of the variance when entered at Step 3. The β weights indicated rapid naming speed was the most important predictor.

8.3.4 Prediction of Grade 2 Word Attack

Despite some positive skew in the Grade 2 Word Attack scores, the distribution was normalised using a square root transformation and the assumptions of multiple regression were met. Table 8.13 summarises the regression analyses. At Step 1, school attended (SCHOOL1 and SCHOOL2) accounted for 8.80% of the variance in Grade 2 Word Attack, $F(2, 100) = 4.85, p = .01$ (Table 8.13). At Step 2, the control variables, Age, Parental Teaching, Vigilance, Auditory TOJ catch trials, Memory, and Non-verbal Ability, accounted for an additional 15.30% of the variance, $F(6, 94) = 3.15, p = .007$. However, none of the control measures explained significant unique variance in Grade 2 Word Attack (see Table 8.13).

The addition of the temporal processing measures at Step 3 resulted in a significant increase of 9.30% in the variance accounted for, $F(3, 91) = 4.23, p = .008$. The squared semi-partial correlations showed Auditory TOJ accounted for a significant unique percentage of the variance (4.41%), as did Temporal Dot (4.12%). Entering the Preschool phonological processing measures at Step 3 resulted in a significant increase of 12.40% in the variance accounted for in Grade 2 Word Attack, $F(3, 91) = 5.91, p = .001$. The squared semi-partial correlations showed Phonemic Segmentation and Rhymes both accounted for significant unique proportions of the variance, accounting for 4.67% and 3.35%, respectively (Table 8.13). There was no significant difference between the variance in Grade 2 Word Attack accounted for by either the Preschool temporal processing measures or the Preschool phonological processing measures when each was entered at Step 3, $Z^* = 0.34, p = .363$. 
### Table 8.13

*Hierarchical Regression Analyses for Variables Predicting Grade 2 Word Attack (N = 103)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE B)</th>
<th>$\beta$</th>
<th>sr</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. SCHOOL1</td>
<td>-0.63 (0.25)</td>
<td>-0.29</td>
<td>-0.25</td>
<td>.011*</td>
</tr>
<tr>
<td>2. SCHOOL2</td>
<td>-0.75 (0.26)</td>
<td>-0.33</td>
<td>-0.27</td>
<td>.005*</td>
</tr>
<tr>
<td>$R^2 = .088^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Age</td>
<td>0.33 (0.36)</td>
<td>0.09</td>
<td>0.08</td>
<td>.358</td>
</tr>
<tr>
<td>4. Parent Teach</td>
<td>0.09 (0.05)</td>
<td>0.18</td>
<td>0.17</td>
<td>.061</td>
</tr>
<tr>
<td>5. Vigilance</td>
<td>-0.52 (0.36)</td>
<td>-0.14</td>
<td>-.13</td>
<td>.152</td>
</tr>
<tr>
<td>6. ATOJcatch</td>
<td>0.33 (0.38)</td>
<td>0.08</td>
<td>0.08</td>
<td>.395</td>
</tr>
<tr>
<td>7. Memory</td>
<td>0.14 (0.07)</td>
<td>0.18</td>
<td>0.17</td>
<td>.065</td>
</tr>
<tr>
<td>8. Nonverbal</td>
<td>0.02 (0.02)</td>
<td>0.08</td>
<td>0.08</td>
<td>.397</td>
</tr>
<tr>
<td>$\Delta R^2 = .153^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Auditory TOJ</td>
<td>-0.48 (0.20)</td>
<td>-0.25</td>
<td>-0.21</td>
<td>.016*</td>
</tr>
<tr>
<td>10. Visual TOJ</td>
<td>0.00 (0.02)</td>
<td>0.02</td>
<td>0.02</td>
<td>.833</td>
</tr>
<tr>
<td>11. Temporal Dot</td>
<td>0.06 (0.02)</td>
<td>0.22</td>
<td>0.20</td>
<td>.02*</td>
</tr>
<tr>
<td>$\Delta R^2 = .093^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. RAN</td>
<td>-.45 (0.78)</td>
<td>-0.05</td>
<td>-0.05</td>
<td>.563</td>
</tr>
<tr>
<td>13. Phon. Segment</td>
<td>0.17 (0.06)</td>
<td>0.27</td>
<td>0.22</td>
<td>.007*</td>
</tr>
<tr>
<td>14. Rhymes</td>
<td>0.07 (0.04)</td>
<td>0.17</td>
<td>0.13</td>
<td>.111</td>
</tr>
<tr>
<td>$\Delta R^2 = .105^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* $p < .05$
In order to determine the unique versus shared contributions to Grade 2 Word Attack, the temporal and phonological processing predictors were each entered last in the regression analysis (at Step 4). At Step 4, the temporal processing measures accounted for an additional 7.40% in the variance accounted for, $F (3, 88) = 3.85$, $p = .012$. This was their unique contribution to the variance in Grade 2 Word Attack. The squared semi-partial correlations showed Auditory TOJ and Temporal Dot uniquely accounted for 3.50% each of the variance, which was significant. At Step 4, the Preschool phonological processing variables accounted for an additional 10.50% of the variance in Grade 2 Word Attack, $F (3, 88) = 5.46$, $p = .002$, which represented their unique contribution. The squared semi-partial correlations showed Phonemic Segmentation accounted for a significant unique component of the variance, accounting for 4.80% (Table 8.13). Together, all of the measures included in the regression analysis were able to explain 43.80% of the variance in Grade 2 Word Attack. Commonality analysis showed only 1.90% of the variance explained in Word Attack overlapped between the Preschool temporal and phonological processing measures. Based on the $\beta$ weights when all of the measures were entered in the analysis, the most important predictor was the school attended, with Auditory TOJ and Phonemic Segmentation also important predictors.

### 8.3.5 Prediction of Grade 2 Pseudohomophone Choice Accuracy

The Pseudohomophone Choice task was a measure of orthographic processing ability, the ability to recognise the correct written form of the word, without using phonological decoding. At Step 1, the school attended (SCHOOL1 and SCHOOL2) accounted for 13.30% of the variance in Grade 2 Pseudohomophone Choice accuracy, $F (2, 97) = 7.46$, $p = .001$ (see Table 8.14). Parental Teaching, Memory, and Nonverbal Ability were entered as control variables at Step 2 and accounted for
Table 8.14

_Hierarchical Regression Analyses for Variables Predicting Grade 2 Pseudohomophone Choice (N = 100)_

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE B)</th>
<th>β</th>
<th>s_threshold</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. SCHOOL1</td>
<td>-4.74 (1.44)</td>
<td>-0.37</td>
<td>-0.31</td>
<td>.001*</td>
</tr>
<tr>
<td>2. SCHOOL2</td>
<td>-5.33 (1.53)</td>
<td>-0.40</td>
<td>-0.33</td>
<td>.001*</td>
</tr>
<tr>
<td>R² = .133*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Parent Teach</td>
<td>0.79 (0.28)</td>
<td>0.26</td>
<td>0.25</td>
<td>.006*</td>
</tr>
<tr>
<td>4. Memory</td>
<td>1.03 (0.42)</td>
<td>0.23</td>
<td>0.22</td>
<td>.015*</td>
</tr>
<tr>
<td>5. Nonverbal</td>
<td>0.15 (0.13)</td>
<td>0.10</td>
<td>0.10</td>
<td>.262</td>
</tr>
<tr>
<td>ΔR² = .121*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Auditory TOJ</td>
<td>-0.76 (1.15)</td>
<td>-0.07</td>
<td>-0.06</td>
<td>.496</td>
</tr>
<tr>
<td>7. Temporal Dot</td>
<td>0.25 (0.13)</td>
<td>0.17</td>
<td>0.17</td>
<td>.058</td>
</tr>
<tr>
<td>ΔR² = .034</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Step 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. RAN</td>
<td>-1.47 (4.89)</td>
<td>-0.03</td>
<td>-0.03</td>
<td>.765</td>
</tr>
<tr>
<td>9. Phon. Segment</td>
<td>0.30 (0.41)</td>
<td>0.08</td>
<td>0.06</td>
<td>.476</td>
</tr>
<tr>
<td>10. Rhymes</td>
<td>0.39 (0.26)</td>
<td>0.17</td>
<td>0.13</td>
<td>.134</td>
</tr>
<tr>
<td>ΔR² = .036</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Step 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. RAN</td>
<td>-1.39 (4.81)</td>
<td>-0.03</td>
<td>-0.02</td>
<td>.774</td>
</tr>
<tr>
<td>7. Phon. Segment</td>
<td>0.30 (0.40)</td>
<td>0.08</td>
<td>0.06</td>
<td>.457</td>
</tr>
<tr>
<td>8. Rhymes</td>
<td>0.51 (0.25)</td>
<td>0.23</td>
<td>.17</td>
<td>.043*</td>
</tr>
<tr>
<td>ΔR² = .053</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Auditory TOJ</td>
<td>-0.47 (1.16)</td>
<td>-0.04</td>
<td>-0.04</td>
<td>.683</td>
</tr>
<tr>
<td>10. Temporal DOT</td>
<td>0.19 (0.14)</td>
<td>0.13</td>
<td>0.13</td>
<td>.154</td>
</tr>
<tr>
<td>ΔR² = .018</td>
<td></td>
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</tbody>
</table>

* p < .05

12.10% of the variance, F (3, 94) = 5.08, p = .003. Parental Teaching uniquely accounted for 6.25% of the variance and Memory uniquely accounted for 4.93%, both of which were significant.

At Step 3, the addition of Auditory TOJ and Temporal Dot (Visual TOJ did not
show a significant zero-order correlation with Grade 2 Pseudohomophone Choice) explained an additional 3.40% of the variance, but this was not a significant increase, $F(2, 92) = 2.21, p = .116$. When the three phonological processing measures were entered at Step 3, they accounted for an additional 5.30% in the variance explained, but this increase was also not significant, $F(3, 91) = 2.31, p = .082$. However, Rhymes still accounted for a significant independent component of variance, 2.89%. With all of the variables in the analysis, 32.4% of the variance was explained. Parental Teaching and school attended still accounted for significant unique percentages of variance in Pseudohomophone Choice accuracy. The $\beta$ weights indicated the school attended was the most important predictor of this measure of orthographic skill at Grade 2.

8.3.6 Discussion

These results demonstrate measures of temporal processing taken at Preschool continue to account for significant variance in word and non-word reading (Letter Word Identification and Word Attack) up until Grade 2. However, they did not account for significant additional variance in fluency (Reading Rate) or orthographic processing (Pseudohomophone Choice) at Grade 2, after variance accounted for by the control factors was removed.

There were changes in which temporal measures independently accounted for a significant percentage of variance, compared to results from the earlier phases. Preschool Temporal Dot accuracy was the only temporal measure to show significant zero-order correlations with all four Grade 2 reading measures. In the multiple regression analyses, Preschool Temporal Dot was the only temporal processing measure to account for significant independent variance in Grade 2 Letter Word Identification, after variance due to the school attended, control measures, other
temporal measures, and phonological processing measures was accounted for. Thus, there was a significant relationship between better rapid visual sequencing in Preschool and better letter and word identification skills at Grade 2, which was independent of any relationship between Temporal Dot and Rhymes and Phonemic Segmentation. Temporal Dot, along with Auditory TOJ, also accounted for significant unique variance in Grade 2 Word Attack scores. These visual and auditory temporal processing measures accounted for quite independent components of variance in Word Attack. Even after accounting for variance due to the other measures, including Preschool phonological processing skills, these two temporal processing measures still accounted for significant unique variance. Thus, by Grade 2, temporal processing was related to different components of word identification and decoding to onset-rime awareness and phonological segmentation skills.

There was only a trend toward Temporal Dot accounting for additional variance in Grade 2 Reading Rate, over that due to the control factors. Despite a significant zero-order correlation between Temporal Dot and Pseudohomophone Choice, there was also only a trend toward Temporal Dot accuracy accounting for additional unique variance, over that due to the control measures. However, it must also be noted that there were many factors controlled for in these analyses prior to the temporal or phonological processing measures being entered into the regression analysis, making this a very conservative test of the ability of these measures to predict subsequent reading. Continuing to assess this sample on these measures over time will clarify whether this relationship gains strength as children’s orthographic processing develops.

This represented a change from the prediction of Grade 1 reading measures, for which Auditory TOJ was the only temporal processing measure to account for
significant unique variance. Developmental changes in the skills utilised in reading may underlie these changes. As reading develops, particularly to the orthographic or fluent stage (Frith, 1985), it is possible the role of visual temporal processing emerges or increases in importance. There is evidence visual temporal processing is important in various processes that are important for effective reading; letter position encoding, global word form perception, binocular stability, and effective saccadic eye movements (Habib, 2000; Stein & Talcott, 1999). These results show that as children move into more advanced automatic stages of reading development, better visual temporal processing may become increasingly important because of its role in those processes, which are required for efficient mature reading skills.

Given the relationship between visual temporal processing and letter position encoding and global word form perception, visual temporal processing was expected to account for a significant percentage of variance in orthographic processing, as measured by the Pseudohomophone Choice task. This did not reach significance. Only the control measures, when entered at Step 1, accounted for a significant percentage of variance, with school attended, Parental Teaching, and Memory accounting for significant unique variance. This is not consistent with Talcott et al. (2002), who found significant relationships between temporal processing measures and orthographic processing in a normative sample, after variance due to age and IQ was removed. However, Talcott et al. used measures of dynamic changes in auditory and visual stimuli, whereas the current study used measures of rapid sequential processing. Talcott et al. also had an older sample in which orthographic skill would be more developed than in the current sample. In the current study, neither temporal nor phonological processing measures accounted for significant additional variance in Pseudohomophone Choice; although Rhymes still independently accounted for a
small significant percentage of the variance. Talcott et al.’s orthographic processing measure also differed to that used in the current study. Their measure summed scores on a Pseudohomophone Choice task and an exception word-reading task, whereas the current study only used Pseudohomophone Choice.

Preschool Rhymes was a significant predictor of all reading skills in Grade 2. This was similar to the results of Muter et al. (1997). They argued that with development, rhyme, which sensitises children to onset-rime distinctions, enhances the use of analogy in reading. Unknown words can also be read by analogy to known words or word segments. Furthermore, Muter et al. found the relationship was reciprocal. Reading in Grade 1 predicted rhyme detection in Grade 2, possibly because reading sensitised the child to onset-rime structures within words, which then enhanced subsequent rhyme skills. Thus, it is important to consider the strength of predictors within a developmental context as Snowling (2000) recommended.

Together the three Preschool phonological processing measures predicted significant additional variance, over that attributable to the control measures, in all of the reading measures, except Pseudohomophone Choice. The individual predictors that accounted for unique variance differed from the Preschool and Grade 1 results. At Preschool and Grade 1, only Rapid Automatised Naming had accounted for significant variance in Letter Word Identification, whereas by Grade 2, Rhymes and Phonemic Segmentation independently accounted for variance, but Rapid Automatised Naming did not. This would be consistent with developmental models of reading development. At the early phases, children were pre-readers or very early readers, and were most likely in the logographic phase of reading (Frith, 1985). Rapid Automatised Naming speed is related to speed of lexical access so if children were recognizing letters and words as logographs, they would be accessing them as visual
wholes from the lexicon; hence, the significant percentage of variance shared with rapid naming speed. Rapid Automatised Naming has also been related to the quality of the phonological representations (Snowling, 2000); faster speed is achieved when there are clear stable phonological representations of words. Better quality phonological representations have been related to better reading (Snowling).

By the final phase, children would have moved beyond the logographic stage and into the alphabetic stage, in which letter sequences must be analysed more fully. Letter sequences are sounded out using grapheme-phoneme conversion rules; hence, measures of phonemic awareness predicted reading skills in this final phase. Consistent with this, Rhyme and Phonemic Segmentation also accounted for unique variance in Grade 2 Word Attack, which requires phonological decoding. By Grade 2, Preschool Rapid Automatised Naming predicted significant independent variance in Reading Rate only. There are several possible explanations for this. Faster reading rate and faster naming speed are both affected by the quality of the phonological representations. Both these tasks would share variance related to basic information processing speed. Both Reading Rate and naming speed rely on the automaticity of access of the lexicon.

This increased analysis of letter sequences by Grade 2 may also explain the increased variance accounted for by the Temporal Dot task; visual sequencing skills become important. The Temporal Dot involved a greater role for visual sequencing than the Visual TOJ task, which may explain why Temporal Dot accounted for independent variance and Visual TOJ did not. This sequencing component may also underlie the variance that Auditory TOJ explained independent of the phonological processing measures. The ability to sequence the resultant phonemes after grapheme-
phoneme conversion would be important to correct identification or pronunciation of the word or non-word.

The results showed there were no significant differences between Preschool measures of temporal or phonological processing in the additional variance accounted for in any of the Grade 2 reading measures, after the variance due to the control measures was removed. Very little variance in the reading measures was common to these two sets of Preschool predictors. Thus, there was definitely an advantage in utilising both temporal and phonological measures in the prediction of Grade 2 reading measures. They account for different components of the reading process.

Compared to earlier phases, there were also developmental changes in which control measures uniquely predicted significant variance in reading at Grade 2. Parental Teaching had been important in prediction of all reading measures at Grade 1, yet by Grade 2, it uniquely accounted for significant variance in Pseudohomophone Choice only. Thus, greater frequency of parental teaching of writing and reading prior to school was related to better orthographic skill at Grade 2. Presumably, those children who experienced more exposure to words and letters early on were more familiar with the shapes of words and the sequence of letters that are permissible in English, resulting in better orthographic skill. One explanation for Parental Teaching no longer accounting for significant unique variance in the other Grade 2 reading measures is that once children enter school, differences in the pre-school home environment become increasingly less important over time. Early environmental experiences may also lead to faster acquisition of skills. In the first grade at school, when children are just acquiring grapheme-phoneme knowledge and a sight word vocabulary, better early literacy environments may result in faster acquisition of reading skills, and higher scores on measures of those skills (Letter Word...
Identification, Word Attack, and Reading Rate). However, by second grade, the experiences at school may compensate for any lack of enriched early home experiences, and the early home environment no longer accounts for significant unique variance. In second grade, acquisition of orthographic rules and strategies would be first occurring so once again faster acquisition due to a more enriched early environment may produce higher scores. If this were the correct explanation, the early home environment would again become less important over time as experiences at school facilitated development on these skills in all children.

Consistent with this explanation, differences between schools became increasingly important in reading by Grade 2. The school attended only affected Reading Rate at Grade 1. By Grade 2, the school attended was the most important predictor of variance in all Grade 2 reading measures, except Reading Rate. It accounted for significant unique variance in the reading measures, even when all variables were entered in the analysis. Share et al. (2002) argued that this group effect arises from ad hoc peer teaching and interactions between children within the group that results in the mean group ability influencing the individual ability. It is also possible that children’s skills within a school become increasingly similar over time due to the shared environmental experience of school. Very little is known about the role of the school culture or peer environment on early reading development. The non-shared environmental influence of the early home literacy teaching became increasingly less important over time in accounting for variance in reading.

Short-term auditory-verbal memory predicted significant variance in Grade 2 Letter Word Identification and Pseudohomophone Choice. These two reading measures relied on accurate representation of words in the child’s lexicon, indicating better memory was related to a larger lexicon, to better ability in retrieving
information from it, or to both of these processes. Memory did not account for variance in Word Attack, performance on which required the use of phonological decoding with little reference to stored word forms.

Attentional Vigilance explained unique variance in Grade 2 Letter Word Identification and Reading Rate. This represented a change from earlier phases, in which it had not predicted unique variance in any reading measures. Thus, as children advanced through school, the ability to attend became increasingly important in word identification and reading fluency. These measures were more reliant on the children having been previously exposed to the words and having attended to them and stored them away in the lexicon. However, that would suggest that better attention and concentration would also be related to better accuracy on the Pseudohomophone Choice task, which was not found. The relationship between Reading Rate and Attentional Vigilance may also be due to better concentration on task, resulting in more words being able to be read in the one minute time period given.

Similar to the prediction at Grade 1, reported Speech Problems accounted for significant unique variance in Grade 2 Reading Rate. However, once again, there was no relationship with Auditory TOJ. Across all phases, there was no evidence that any relationship between auditory temporal processing and reading in a normative sample is explainable by differences in speech and language abilities. However, as noted previously, parental report (a subjective, crude measure of speech and language problems) was used, and results may differ with a more objective measure that can detect more subtle differences in speech ability. The results do support the need to include a measure of speech and language ability when measures of reading fluency are used.
8.4 Summary

The results detailed in this chapter established temporal processing measured before school entry predicted significant variance in pre-reading skills, as well as in reading skills at Grade 1 and Letter Word Identification and Word Attack at Grade 2. They did not account for significant variance in Grade 2 Reading Rate (fluency), indicating that any relationship between these measures and reading is not due to shared variance in the rate of processing information. They also did not account for significant unique variance in Grade 2 Pseudohomophone Choice (orthographic processing), contrary to expectations, although this may reflect immaturity in orthographic processing at the age tested. Stein (2003) argued that orthographic measures were of maximum importance in children at an older age (around 10 to 12 years). Other measures of orthographic processing may be more suitable for this age.

There were developmental changes in which temporal processing measures accounted for unique variance in reading. At Preschool and Grade 1, auditory temporal processing was most important, whereas by Grade 2 visual temporal processing began to account for unique variance. When children are in the early logographic stage, visual sequencing skills are not important as words (and letters) are recognised as logographs and not sequentially analysed. They then progress to reliance on letter-by-letter sounding out and finally to an increasingly automatic process of recognising words as visual wholes (Frith, 1985). Thus, as expected rapid visual sequencing skills became increasingly important.

There were no significant differences between the amounts of variance accounted for in reading across the three phases by either the temporal or phonological processing predictors. Neither was there much variance in common between these two sets of predictors. This is important as it shows Preschool
temporal processing measures would be just as useful as screening measures for risk of reading problems as the Preschool phonological processing measures currently used. Furthermore, utilising both optimized prediction.

The relationships found between reading and the temporal and phonological processing measures were not fully explained by individual differences in factors such as age, early home environment, attentional vigilance, non-verbal ability, school attended, and the presence of speech or language problems. However, the early home environment, attentional vigilance, and school attended are important factors to control. The frequency with which parents engaged in literacy teaching with children before school entry accounted for variance in pre-reading skills and Grade 1 reading skills. However, this was no longer an important factor in reading by Grade 2. This was interpreted in the context of Vellutino et al.’s (2004) argument that environmental factors underlie many children who present with poor skills early in Grade 1. Experiences within the school environment result in improvement to normal levels in these skills within a short period in the majority of those children. Supporting this interpretation was the finding that the school attended was the most important predictor of reading skills by Grade 2.
CHAPTER 9: PREDICTION OF GROWTH RATE IN READING SKILLS

The analyses presented in Chapter 8 determined the ability of Preschool measures of temporal and phonological processing to predict the level of various reading skills at static points in time from Preschool to Grade 1. A further question concerns the prediction of rate of change or of growth in these skills over the period of early reading development covered by the study. One way to look at change or growth is to perform autoregression analyses in which earlier ability on a measure is partialled out at an initial step in hierarchical regression. After the autoregressive effects are removed, the variance that remains to be explained by predictors entered at subsequent steps is only that associated with unexpected change in the criterion measure; in other words, variance in Grade 1 or Grade 2 reading skills that is not expected based on earlier ability on those same measures (Menard, 2002). When there is high stability over time in the criterion measures, there is little unexpected variance left to account for and null results are common using this method, particularly if the predictor measures account for significant variance in the criterion measure at the earlier phase as well. Reading measures are known to show high stability over time (e.g., Juel, 1988; see also Chapter 10 for stability of reading measures in the current study). There is also debate over what is a suitable early measure of reading ability to use as the autoregressor. Parilla et al. (2004) argued that pre-school letter identification is not an appropriate autoregressor for Grade 1 reading, due to its reciprocal relationship to phonological processing. This study was designed to begin at a pre-reading point in order to negate the need to account for the autoregressive effects of earlier reading ability. Therefore, this approach was not
considered the best method to examine the prediction of change in reading in this study.

Another approach is to directly predict growth rate or change scores, calculated as the individual slopes of the lines formed by the scores across all phases in which measurement of the reading skill occurred. Commonality analyses were used to examine the ability of the control and Preschool temporal and phonological processing predictor measures to account for variance in the growth rate or change in the reading skills. The dependent variables were the growth or change rate scores. The least squares method of linear regression provided the slope estimates. As only two or three time points were available, the most stable estimate of growth is the linear function. A quadratic function to plateau at adolescence, around 12.5 years, best describes reading growth curves (Francis, Shaywitz, Stuebing, Shaywitz, & Fletcher, 1994). However, in this early stage of beginning reading, a linear function adequately describes the growth curves (Jacobsen, 1999). Of the reading measures, Letter Word Identification was measured in all three phases of the study and so a measure of growth rate was possible. Reading Rate and Word Attack were measured in Phases 2 and 3 (Grades 1 and 2), so with only two points the slope defined rate of change rather than of growth. However, the term “growth rate” will be used throughout this chapter to refer to both rate of growth and change. As Pseudohomophone Choice was only measured at Phase 3, neither growth nor change scores could be determined. Descriptive statistics for the slopes are presented in Table 9.1. It can be seen that there was much steeper growth in Reading Rate than in the other two reading measures, and that some children showed little growth (or in the case of Word Attack, no growth). Letter Word Identification and Reading Rate growth rate scores were normally distributed. Word Attack growth rate scores from
Phase 2 to Phase 3 were positively skewed (due to the floor effect at Phase 2) and was normalised using a square root transformation. All of the assumptions of the hierarchical multiple regressions were then met.

Table 9.1

Descriptive statistics for Slope (Growth Rate) of Letter Word Identification, Reading Rate, and Word Attack

<table>
<thead>
<tr>
<th>Measures</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Letter Word Identification(^a)</td>
<td>0.91</td>
<td>0.33</td>
<td>0.23 – 1.79</td>
</tr>
<tr>
<td>Reading Rate(^b)</td>
<td>3.18</td>
<td>1.30</td>
<td>0.58 – 8.00</td>
</tr>
<tr>
<td>Word Attack(^b)</td>
<td>0.66</td>
<td>0.43</td>
<td>0.00 – 1.92</td>
</tr>
</tbody>
</table>

\(^a\) Slope based on Preschool to Grade 2; \(^b\) Slope based on Grade 1 to Grade 2

9.1 Zero-order Correlations

Table 9.2 shows the zero-order correlations between the three reading growth rate (slope) scores, the control measures, the Preschool temporal processing measures, and the Preschool phonological processing measures. Attentional Vigilance showed significant weak to moderate correlations with the growth rates of all three reading measures. There were also significant weak correlations between Auditory TOJ Catch Trials and Reading Rate growth rate. Memory and Word Attack growth rate showed a significant weak positive correlation. There were no other significant zero-order correlations between control measures and any of the reading growth rate measures.
### Table 9.2

**Correlations between Control Measures, Preschool Temporal Predictors, Preschool Phonological Predictors, and Reading Growth Rate Scores**

<table>
<thead>
<tr>
<th></th>
<th>AGE</th>
<th>TEACH</th>
<th>READ</th>
<th>VIG&lt;sup&gt;a&lt;/sup&gt;</th>
<th>ATOJcatch&lt;sup&gt;d&lt;/sup&gt;</th>
<th>MEM</th>
<th>MAT</th>
<th>ATOJ&lt;sup&gt;b&lt;/sup&gt;</th>
<th>VTOJ</th>
<th>DOT</th>
<th>RAN&lt;sup&gt;c&lt;/sup&gt;</th>
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<th>Rhymes</th>
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</tr>
<tr>
<td>VIG&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-.21*</td>
<td>-.20*</td>
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<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATT</td>
<td>.14</td>
<td>.18</td>
<td>-.05</td>
<td>-.23**</td>
<td>.28</td>
<td>.21*</td>
<td>.18</td>
<td>-.29**</td>
<td>.20*</td>
<td>.30**</td>
<td>-.23**</td>
<td>.33**</td>
<td>.29**</td>
<td>.79**</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>RATE</td>
<td>-.03</td>
<td>.08</td>
<td>-.01</td>
<td>-.26**</td>
<td>.22*</td>
<td>.19</td>
<td>-.08</td>
<td>-.04</td>
<td>-.04</td>
<td>.10</td>
<td>-.41**</td>
<td>.23*</td>
<td>.53**</td>
<td>.46**</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

Note: TEACH = Parental Teaching, READ = Parental Reading, VIG = Attentional Vigilance, ATOJcatch = Auditory TOJ catch trials; MEM = Memory, MAT = Nonverbal Ability, ATOJ = Auditory TOJ, VTOJ = Visual TOJ, DOT = Temporal Dot, RAN = Rapid Automatised Naming, PhonSeg = Phonemic Segmentation, LetWordId = slope of WDRB Letter Word Identification scores, ATT = slope of WDRB Word Attack scores, RATE = slope of Reading Rate scores.

<sup>a</sup> Reflected and log transformed; <sup>b</sup> Reflected and square root transformed; <sup>c</sup> Log transformed; <sup>d</sup> Categorical variable

* p < .05; ** p < .01
All three Preschool temporal processing measures showed significant weak to moderate correlations with Word Attack growth rate. Thus, better temporal processing at Preschool was related to faster growth in word decoding skills. There was a significant moderate positive correlation between Temporal Dot and Letter Word Identification growth rate. There were no significant correlations between Preschool temporal processing measures and growth in Reading Rate. All three Preschool phonological processing measures showed weak to moderate correlations with growth rates in Letter Word Identification and Word Attack. Better phonological processing was associated with faster growth in those two reading skills. Only Rapid Automatised Naming speed and Rhymes showed significant correlations with growth in Reading Rate.

Growth in Letter Word Identification showed a significant strong positive correlation with growth in Word Attack. There were significant moderate correlations between growth in Reading Rate and growth in the other two reading skills.

9.2 Differences in Growth Rates between Genders, Cohorts, Schools, and Speech Groups

There were no significant differences in Letter Word Identification slopes between genders, cohorts, or the speech problems groups. Therefore, these variables were not included in subsequent regression analyses. No Cohort x School interaction was significant. However, the schools significantly differed on all three measures of reading growth rate. Therefore, the effect of school will be partialled out at Step 1 in the multiple regression analyses.

There was a significant difference between schools in Letter Word Identification growth rate from Preschool to Grade 2, $F(2, 102) = 12.30, p < .0001, \omega^2 = 0.18$. This was a large effect. Contrast analysis revealed that children at School A had
significantly steeper slopes \((M = 1.14, SD = .32)\) than children at School B \((M = 0.82, SD = .31)\), \(F(1, 102) = 20.43, p < .0001\). There was no significant difference between the slopes from children at Schools B and C \((M = 0.83, SD = .26)\), \(F(1, 102) = 0.01, p = .93\). The ICC was .25; therefore, this clustering had the potential to create substantial Type I error rate inflation.

There was also a significant effect of school on Reading Rate growth rate from Grade 1 to Grade 2, \(F(2, 100) = 3.61, p = .031, \omega^2 = 0.05\), a small effect. Contrast analysis showed that children at School A \((M = 3.52, SD = 1.22)\) did not differ significantly from children at School C \((M = 3.41, SD = 1.42)\) in their Reading Rate growth rates, \(F(1, 92) = 0.12, p = .734\), but had significantly faster growth rates than did the children at School B \((M = 2.78, SD = 1.18)\), \(F(1, 100) = 5.78, p = .018\). The ICC was .07.

The school attended had a significant medium effect on the growth rate in Word Attack from Grade 1 to Grade 2, \(F(2, 102) = 5.44, p = .006, \omega^2 = 0.08\). Contrast analysis showed that children at School A had significantly faster growth rates (steeper slopes) on Word Attack \((M = 0.90, SD = 0.27)\) than did children at School B \((M = 0.71, SD = 0.27), F(1, 102) = 9.32, p = .003\). Children at Schools B and C \((M = 0.72, SD = 0.26)\) did not differ significantly in their growth rates on Word Attack, \(F(1, 102) = 0.03, p = .856\). The ICC was .11.

9.3 Prediction of Growth Rate in Letter Word Identification Skills from Preschool to Grade 2

Table 9.3 summarises the hierarchical multiple regression analysis. At Step 1, the effect of school attended (SCHOOL 1 and SCHOOL2) accounted for 19.30% of the variance in the slope of Letter Word Identification, \(F(1, 100) = 11.93, p < .0001\). At Step 2, the addition of Vigilance, the only control measure that showed a
### Table 9.3

Hierarchical Regression Analyses for Variables Predicting Growth Rate in Letter Word Identification from Preschool to Grade 2 (N = 103)

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE B)</th>
<th>β</th>
<th>sr</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. SCHOOL1</td>
<td>-0.32 (0.07)</td>
<td>-0.47</td>
<td>-.39</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>2. SCHOOL2</td>
<td>-0.32 (0.08)</td>
<td>-0.45</td>
<td>-.38</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>R² = .193*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Vigilance</td>
<td>-0.34 (0.10)</td>
<td>-0.29</td>
<td>-.29</td>
<td>.001*</td>
</tr>
<tr>
<td>ΔR² = .083*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Temporal Dot</td>
<td>0.02 (0.01)</td>
<td>0.25</td>
<td>.23</td>
<td>.006*</td>
</tr>
<tr>
<td>ΔR² = .054*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. RAN</td>
<td>-0.08 (0.23)</td>
<td>-0.03</td>
<td>-.23</td>
<td>.733</td>
</tr>
<tr>
<td>6. Phon. Seg.</td>
<td>0.04 (0.02)</td>
<td>0.19</td>
<td>.10</td>
<td>.033*</td>
</tr>
<tr>
<td>7. Rhymes</td>
<td>0.02 (0.01)</td>
<td>0.19</td>
<td>.18</td>
<td>.072</td>
</tr>
<tr>
<td>ΔR² = .091*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. RAN</td>
<td>-0.07 (0.24)</td>
<td>-0.03</td>
<td>-.02</td>
<td>.769</td>
</tr>
<tr>
<td>5. Phon. Seg.</td>
<td>0.04 (0.02)</td>
<td>0.18</td>
<td>.16</td>
<td>.056</td>
</tr>
<tr>
<td>6. Rhymes</td>
<td>0.03 (0.01)</td>
<td>0.24</td>
<td>.18</td>
<td>.025*</td>
</tr>
<tr>
<td>ΔR² = .106*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Temporal Dot</td>
<td>0.02 (0.01)</td>
<td>0.21</td>
<td>.20</td>
<td>.014*</td>
</tr>
<tr>
<td>ΔR² = .038*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < .05

Significant zero-order correlation with Letter Word Identification growth rate, accounted for an additional 8.30% of the variance, \( F (1, 99) = 11.41, p = .001 \). Based on the zero-order correlations, only Preschool Temporal Dot was included as a temporal processing predictor. When entered at Step 3, it added 5.40% to the variance explained, \( F (1, 98) = 7.88, p = .006 \). When the three Preschool phonological processing measures were entered at Step 3, they accounted for an
additional 10.60% of the variance, $F(3, 96) = 5.51, p = .002$, over that already explained by school attended and Vigilance. Only Preschool Rhyme detection accounted for a significant unique percentage of the variance, accounting for 3.35%. Steiger’s $z$ (1980) indicated no significant difference between temporal and phonological measures in their ability to account for variance in the growth rate in Letter Word Identification, $Z^* = -0.60, p = .549$.

When Temporal Dot accuracy was entered last, after the phonological measures, at Step 4, it still accounted for an additional 3.80% of the variance, $F(1, 95) = 6.28, p = .014$. This represented its unique contribution to variance in Letter Word Identification growth rate. When the phonological processing measures were entered at Step 4, their unique contribution to the variance in Letter Word Identification growth rate was 9.10%, $F(3, 95) = 4.96, p = .003$. Only Phonemic Segmentation made a significant unique contribution, accounting for 2.86% of the variance in the growth rate in Letter Word Identification from Preschool to Grade 2. Together all of the measures explained a total 42.10% of the variance in Letter Word Identification growth rate. Commonality analysis showed that only 1.50% of that variance was shared between the Preschool temporal processing and phonological processing measures. With all measures entered, $\beta$ weights showed that the school attended was the most important predictor of this growth rate.

### 9.4 Prediction of Growth Rate in Reading Rate from Grade 1 to Grade 2

Table 9.4 summarises the regression model. The school attended (SCHOOL1 and SCHOOL2) was entered at Step 1 and accounted for 5.70% of the variance, but this was not a significant percentage of the variance, $F(2, 98) = 2.97, p = .056$. At
Step 2, the two vigilance measures, Attentional Vigilance and Auditory TOJ Catch Trials, accounted for an additional 8.20% of the variance, $F (2, 96) = 4.59, p = .013$.

**Table 9.4**

*Hierarchical Regression Analyses for Variables Predicting Growth Rate in Reading Rate from Grade 1 to Grade 2 (N = 101)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE B)</th>
<th>$\beta$</th>
<th>sr</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. SCHOOL1</td>
<td>-0.69 (0.31)</td>
<td>-0.26</td>
<td>-0.22</td>
<td>.027*</td>
</tr>
<tr>
<td>2. SCHOOL2</td>
<td>-0.14 (0.33)</td>
<td>-0.05</td>
<td>-0.04</td>
<td>.660</td>
</tr>
<tr>
<td><strong>R$^2$</strong></td>
<td></td>
<td></td>
<td>.057</td>
<td></td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Vigilance</td>
<td>-1.04 (0.43)</td>
<td>-0.23</td>
<td>-0.23</td>
<td>.018*</td>
</tr>
<tr>
<td>4. ATOJ catch</td>
<td>0.64 (0.46)</td>
<td>0.13</td>
<td>.13</td>
<td>.167</td>
</tr>
<tr>
<td><strong>$\Delta$R$^2$</strong></td>
<td></td>
<td></td>
<td>.082*</td>
<td></td>
</tr>
<tr>
<td><strong>Step 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. RAN</td>
<td>-2.61 (1.03)</td>
<td>-0.26</td>
<td>-0.23</td>
<td>.013*</td>
</tr>
<tr>
<td>6. Phon. Seg.</td>
<td>-0.00 (0.08)</td>
<td>-0.01</td>
<td>-0.00</td>
<td>.964</td>
</tr>
<tr>
<td>7. Rhymes</td>
<td>0.09 (0.05)</td>
<td>0.19</td>
<td>.15</td>
<td>.103</td>
</tr>
<tr>
<td><strong>$\Delta$R$^2$</strong></td>
<td></td>
<td></td>
<td>.113*</td>
<td></td>
</tr>
</tbody>
</table>

* $p < .05$

Only Attentional Vigilance accounted for a significant unique percentage of variance, accounting for 5.20%. The remainder overlapped between these two measures of vigilance. The Preschool temporal processing measures were not included as predictors as they did not show any significant zero-order correlations with growth rate in Reading Rate. At Step 3, the three Preschool phonological processing
measures accounted for an additional 11.30% of the variance, \( F(3, 93) = 4.70, p = .004 \). Rapid Automatised Naming speed independently accounted for 5.20% of the variance, with the remainder overlapping between the three phonological processing predictors. With all variables entered into the regression analysis, it was the most important predictor (see \( \beta \) weights in Table 9.3).

9.5 Prediction of Growth Rate in Word Attack Scores from Grade 1 to Grade 2

Table 9.5 summarises the regression model. At Step 1, the school attended (SCHOOL1 and SCHOOL2) accounted for 9.50% of the variance in the growth rate (slope) of Word Attack scores from Grade 1 to Grade 2, \( F(2, 100) = 5.25, p = .007 \). At Step 2, Attentional Vigilance and Memory increased the variance explained in Word Attack growth rate by 8.10%, \( F(2, 98) = 4.83, p = .01 \). Both accounted for a significant percentage of unique variance. Attentional Vigilance accounted for 4.16% of the variance and Memory accounted for 3.42%. Very little variance in Word Attack slope overlapped between these two control measures. When the three temporal processing measures were entered at Step 3, the \( R^2 \) change showed that another 9.10% of the variance was explained, \( F(3, 95) = 3.95, p = .011 \). Auditory TOJ uniquely accounted for 3.39% of the variance. Temporal Dot uniquely accounted for 3.35% of the variance. When the three phonological processing measures were entered at Step 3, they accounted for 11.30% more variance than that already explained by school attended, Attentional Vigilance, and Memory, \( F(3, 95) = 5.01, p = .003 \). Phonemic Segmentation and Rhymes each accounted for significant unique variance, accounting for 3.39% and 3.92%, respectively. There was no significant difference between the amount of variance in the growth rate of Word
Temporal Processing and Early Reading

Attack scores accounted for by the Preschool temporal or phonological processing measures, $Z^* = -1.04, p = .298$.

Table 9.5

*Hierarchical Regression Analyses for Variables Predicting Growth Rate in Word Attack from Grade 1 to Grade 2 ($N = 103$)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE B)</th>
<th>$\beta$</th>
<th>sr</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. SCHOOL1</td>
<td>-0.18 (0.06)</td>
<td>-0.32</td>
<td>-.27</td>
<td>.005*</td>
</tr>
<tr>
<td>2. SCHOOL2</td>
<td>-0.19 (0.07)</td>
<td>-0.32</td>
<td>-.27</td>
<td>.005*</td>
</tr>
<tr>
<td>$R^2 = .095*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Vigilance</td>
<td>-0.20 (0.09)</td>
<td>-0.21</td>
<td>-.20</td>
<td>.028*</td>
</tr>
<tr>
<td>4. Memory</td>
<td>0.04 (0.02)</td>
<td>0.19</td>
<td>.19</td>
<td>.047*</td>
</tr>
<tr>
<td>$\Delta R^2 = .081*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Auditory TOJ</td>
<td>-0.10 (0.05)</td>
<td>-0.20</td>
<td>-.19</td>
<td>.039*</td>
</tr>
<tr>
<td>6. Visual TOJ</td>
<td>0.00 (0.00)</td>
<td>0.06</td>
<td>.05</td>
<td>.579</td>
</tr>
<tr>
<td>7. Temporal Dot</td>
<td>0.01 (0.01)</td>
<td>0.20</td>
<td>.18</td>
<td>.039*</td>
</tr>
<tr>
<td>$\Delta R^2 = .091*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. RAN</td>
<td>0.02 (0.21)</td>
<td>0.01</td>
<td>.01</td>
<td>.922</td>
</tr>
<tr>
<td>9. Phon. Seg.</td>
<td>0.04 (0.02)</td>
<td>0.19</td>
<td>.15</td>
<td>.087</td>
</tr>
<tr>
<td>10. Rhymes</td>
<td>0.03 (0.02)</td>
<td>0.20</td>
<td>.17</td>
<td>.053</td>
</tr>
<tr>
<td>$\Delta R^2 = .075*$</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. RAN</td>
<td>0.05 (0.21)</td>
<td>0.02</td>
<td>.02</td>
<td>.832</td>
</tr>
<tr>
<td>6. Phon. Seg.</td>
<td>0.04 (0.02)</td>
<td>0.21</td>
<td>.18</td>
<td>.036*</td>
</tr>
<tr>
<td>7. Rhymes</td>
<td>0.03 (0.01)</td>
<td>0.26</td>
<td>.20</td>
<td>.024*</td>
</tr>
<tr>
<td>$\Delta R^2 = .113*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Auditory TOJ</td>
<td>-0.08 (0.05)</td>
<td>-0.16</td>
<td>-.14</td>
<td>.097</td>
</tr>
<tr>
<td>9. Visual TOJ</td>
<td>0.00 (0.00)</td>
<td>0.01</td>
<td>.01</td>
<td>.911</td>
</tr>
<tr>
<td>10. Temp. Dot</td>
<td>0.01 (0.02)</td>
<td>0.18</td>
<td>.16</td>
<td>.062</td>
</tr>
<tr>
<td>$\Delta R^2 = .054*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* $p < .05$
When the temporal processing measures were entered last, at Step 4, they accounted for 5.40% of the variance, but this was not a significant increase over the variance already explained by school attended, the control measures, and the Preschool phonological processing measures, $F(3, 92) = 2.52$, $p = .063$. When the phonological processing measures were entered after the temporal processing measures, at Step 4, they accounted for an additional 7.50% of the variance, $F(3, 92) = 3.51$, $p = .018$, which represented their unique contribution to growth rate in Word Attack. Together, all of the variables explained 34.30% of the variance in Word Attack growth rate. Commonality analysis showed that 3.80% of the variance was commonly explained by the Preschool temporal processing and phonological processing measures. When all measures had entered the regression analysis, none of the temporal or phonological predictors accounted for significant unique variance in Word Attack growth rate. Only the school variable still accounted for significant unique variance. It was the most important predictor of Word Attack growth rate (see $\beta$ weights in Table 9.4).

9.6 Discussion

Of the temporal processing measures, Preschool Temporal Dot accounted for significant variance in Letter Word Identification and Word Attack growth rates. This was independent of differences in school, Attentional Vigilance and Memory. Thus, better rapid visual sequencing skills at Preschool were related to faster subsequent growth in word identification and decoding skills. Temporal Dot continued to account for significant unique variance in Letter Word Identification growth rate after Preschool phonological processing skills were controlled. However, with the phonological processing skills controlled, Temporal Dot no longer accounted for significant unique variance in Word Attack growth rate. It can be concluded that
rapid visual sequencing (as measured by the Temporal Dot task) accounts for an independent component of growth in word identification to that explained by phonological processing skill. However, rapid visual sequencing and phonological processing account for overlapping variance in growth in word decoding skill (temporal and phonological processing measures showed significant zero-order correlations, so have variance in common). In word identification, both orthographic and phonological skills are likely to play separate roles. Some words may be automatically identified by visual means, whereas other words are identified after phonological decoding. In non-word decoding, there is a minimal role for visual recognition (unless non-words are decoded by analogy to known real words already stored in the lexicon), and a dominant role for phonological processing.

The results with Letter Word Identification growth rate were more consistent with those predicting variance in Letter Word Identification at Grade 2 than at earlier phases. Temporal Dot only began to account for significant variance at Grade 2, whereas Auditory TOJ had been the only significant temporal processing predictor of Letter Word Identification at Preschool and Grade 1. Thus, variance in the rate of growth in word identification is related to the accuracy of early rapid visual sequencing skills, even though auditory temporal processing ability can predict Letter Word Identification skill at static points earlier in development.

Better Preschool auditory temporal processing was related to faster growth in non-word decoding skills, after the effects of Attentional Vigilance and Memory were controlled. However, similarly to the results with Temporal Dot, the variance that Auditory TOJ explained in Word Attack growth rate was subsumed by variance explained by the Preschool phonological processing measures. None of the Preschool
temporal processing measures showed significant zero-order correlations with the growth rate in Reading Rate.

The pattern of results using the Preschool phonological processing measures was similar to that with the temporal processing measures, in that the significant predictors of growth were those that predicted Grade 2 level in these reading skills rather than that at Grade 1. The Preschool phonological processing predictors accounted for significant additional variance in all three reading growth rates, after variance explained by the control measures was partialled out. Rhymes accounted for significant independent variance in Letter Word Identification and Word Attack growth rates. Phonemic Segmentation also accounted for significant independent variance in Word Attack growth rate. Thus, better Preschool phonological awareness was related to faster growth in word identification and word decoding skills over the first two grades in primary school. Individual difference in Rapid Automatised Naming speed was the most important predictor of growth in fluency (Reading Rate).

This was consistent with previous studies. Stage et al. (2003) examined the predictors of growth in Word Identification and Word Attack measured at three times during an intervention in Grade 1 low-achieving children. They found phonological skill (syllable and phoneme segmentation) accounted for 9% of the variance in the slope of Word Identification and 14% in the slope of Word Attack in univariate analyses. In the current study, even with Vigilance and Memory controlled for, these phonological awareness measures uniquely accounted for around 4% of the variance in natural growth rates in those reading measures. However, once the temporal processing measures were entered into the regression equation, these phonological processing measures no longer accounted for significant independent variance.
Stage et al. (2003) also found Rapid Automatised Naming accounted for 12% and 30% of the variance in the slopes (growth during the intervention) of Word Identification and Word Attack, respectively. In Latvian children, Sprugevica and Høien (2003) found phonemic segmentation and deletion uniquely accounted for 15.2% of the variance in the slope (natural growth) of word reading skill from kindergarten to Grade 2, whereas rapid naming speed (objects and colours) did not account for significant unique variance. This was consistent with the current study; rapid naming speed did not account for unique variance in natural growth rates in word identification or word decoding. However, rapid naming speed was the only phonological processing measure that accounted for significant unique variance in the growth rate in Reading Rate or word reading fluency from Grade 1 to Grade 2. As discussed previously, speed of lexical access is probably the underlying link between performances on these two tasks.

Overall, the results with prediction of the rate of growth in these three reading measures were quite similar to the results in prediction of the reading measures at the final phase of the study (Grade 2). The major difference between prediction of the reading skills at Grade 2 and prediction of growth in the reading skills from either Preschool or Grade 1 to Grade 2 lay in which control measures showed significant relationships with the dependent variables. While there were significant effects of the Speech Problems variable on Reading Rate at Grades 1 and 2, there was no significant effect on growth rate in Reading Rate. This suggests that the effect of the speech problems experienced by the children in this sample (mostly mild problems not requiring speech therapy) is on the ability to rapidly articulate words, and not on the rate at which new words are acquired in the sight word vocabulary. Different results may be found with different or more severe speech and language deficits to those
experienced by this sample. Several control measures, including Age, Parental Teaching, and Non-verbal Ability, that showed significant zero-order correlations with reading measures at Grades 1 and 2 did not show significant correlations with growth rate in those reading measures. School attended, Attentional Vigilance, and Memory were important in both the prediction of reading at Grades 1 and 2 and in the rate of growth in reading over this period.

The school attended was the most important predictor of variance in Letter Word Identification and Word Attack growth rates. School attended accounted for nearly one fifth of the variance in Letter Word Identification growth rate at the initial step in the regression analysis, and continued to explain significant unique variance after all other measures had entered the analysis. While school was important in the rate of growth in word identification and word decoding skills, it did not account for significant variance in the rate of growth in Reading Rate. This result is consistent with an interpretation that the school environmental experiences become increasingly important the longer children are at school. School was only related to Reading Rate at Grade 1, but this relationship ceased to be important by Grade 2. However, by Grade 2, school accounted for significant variance in Grade 2 Letter Word Identification and Word Attack. As discussed previously, these increasing effects of the school variable probably reflect a complex combination of peer interactions as well as teaching practices that differ between schools.

Attentional Vigilance accounted for significant unique variance in all three measures of reading growth rate. In their study of growth rates in Word Identification and Word Attack during Grade 1 intervention, Stage et al. (2003) also found trainers’ ratings of the children’s attention accounted for 16% of the variance in Word Identification growth and 32% of the variance in Word Attack growth. They used a
measure more similar to the GATSB scale (Glutting & Oakland, 1993), whereas the current study used a composite of this aspect of attention plus vigilance on the visual temporal processing tasks. They also used univariate analyses (i.e., did not control for other factors), which probably explains the higher percentages of variance accounted for by attention. In the current study, Attentional Vigilance accounted for significant variance after the effects of school and other control measures were accounted for. Memory accounted for significant independent variance in Word Attack growth rate. Even though Vigilance and Memory had not accounted for significant unique variance in Word Attack at either Grade 1 or Grade 2, they accounted for significant unique variance in the growth of Word Attack over this period. The results indicated that better attention enabled faster development in word identification (or in the child’s sight word vocabulary), fluency, and decoding skills. Better memory enabled faster development of decoding skills. As previously discussed, this is possibly due to a combination of better concentration during completion of the reading measures in this study, as well as better attention during exposures to words in class and in other settings.

Generally, the results of these analyses show that prediction of growth rate provides similar results to prediction of the final phase studied. Significant predictors for earlier phases in a study may vary to those that predict both the final phase and the rate of change or growth. This is most likely a result of changes in the predictors that are important as development occurs in reading and the nature of reading undergoes change.
CHAPTER 10: GROWTH AND STABILITY OF TEMPORAL PROCESSING ABILITY

Some visual and auditory temporal processing abilities were at adult-like performance at earlier ages and some were still immature into adolescence (Atkinson et al., 1981; Barnard et al., 1998; Beazley et al., 1980; Cornelissen et al., 1995; Crewther et al., 1996; Davis & McCroskey, 1980; Ellemberg et al., 1999; Hall & Grose, 1994; Martos & Marmelejo, 1993; Raymond & Sorenson, 1998; Wightman et al., 1989). Cross-sectional studies showed rapid visual sequencing ability as measured by the Temporal Dot task (Booth et al., 2000) and auditory temporal order judgement (Marshall et al., 2001; Waber et al., 2001) was not fully developed in children. However, cross-sectional studies really only inform about differences between age groups; they do not provide evidence of developmental change. Only longitudinal research truly informs about developmental change. One of the aims of this study was to describe the development in rapid visual and auditory temporal sequencing from Preschool (5 years) to Grade 2 (7 years), using the visual and auditory TOJ tasks and the Temporal Dot task. It was expected there would be significant improvements in performance on these tasks at each phase of measurement, consistent with developmental change. The specific hypotheses were there would be significantly greater mean scores (greater accuracy) on these measures at Phase 2 than at Phase 1, and significantly greater mean scores at Phase 3 than at Phase 2. Development in phonological processing over this period was also examined. Previous longitudinal studies showed development is also occurring in these skills during this time (see Section 3.2).
One of the issues when measuring skills that are still developing and using them as predictors of later reading is whether development in those skills is stable. In other words, do children show the same relative ability in these skills from one measurement time to the next? If there is considerable instability, prediction could change dramatically, depending on the time at which the predictors were measured. Dyslexia is quite stable and even adults who have well-compensated word reading skills (within the normal range) still show difficulties when under time pressure, such as when fluency is assessed, or with more difficult tasks, such as the spoonerism task (Fawcett & Nicolson, 1994a; 1995; Gallagher et al., 1996; Miles, 1993; S. E. Shaywitz et al., 1999, 2003; Wilson & Lesaux, 2001; Yap & van der Leig, 1994).

Juel (1988) reported the probability of a child who was a poor reader in first grade still being a poor reader at the end of fourth grade as .88. Similarly, the respective probability for average readers retaining their status over the same period was .87. By contrast, the probabilities of poor first grade readers becoming average readers by fourth grade and average first grade reader becoming poor readers by fourth grade were only .13 and .12, respectively. Given this degree of stability in reading, it could be argued that the underlying causes should show similar stability across time. There is very little knowledge about the stability of temporal processing measures. If the measurements are reliable over time, the location of children within the distributions of performance on the temporal tasks may provide an additional measure to strengthen early assessment of risk for reading difficulties. However, it is possible the underlying causal factors change with development, and stability in any one of these factors is less related to the overall stability in reading. The idea of critical periods is relevant. Deficits due to delayed development in a particular causal factor at a critical point in reading development may have a long-lasting impact on reading ability, even
if there is subsequent development to normal levels in the causal factor. For example, Bishop and Snowling (2004) argued it is possible that an early auditory temporal processing deficit may affect initial formation of phonological representations and may have a lasting impact on phonological processing, and thereby on reading, but may itself subsequently resolve resulting in little evidence for an auditory temporal processing deficit in reading disability in samples of older children and adults.

Few studies have even reported short-term test-retest reliability with measures of temporal processing. The Auditory TOJ task showed test-retest reliability of .64 over only one week with a small sample (Nicolson & Fawcett, 1996). Using a larger ($N = 85$) and an older sample (7 to 11 years), Waber et al. (2001) reported a test-retest correlation of .85 over a 1- to 2-week interval for their auditory TOJ task. Lovegrove and Slaghuis (1989) established the reliability and stability of visible persistence in 35 dyslexic and 35 control children, aged 11 years. There were no significant differences for either the dyslexic or the control group in mean duration of visible persistence measured at three times, with test-retest intervals ranging from over one week to three months. Thus, duration of visible persistence was stable over this period. Test-retest reliability was .45 from first to second testing, .50 from second to third testing, and .57 from first to third testing (all $p < .01$). Thus, there was moderate reliability.

However, there were methodological problems in that not all participants were retested at the same intervals (range from "never less than a week and sometimes as much as three months" p. 545). The second aim in this chapter was to assess the stability of temporal processing across the period from Preschool to Grade 2. For comparison, the stability of phonological processing and Letter-Word Identification scores across this period were also examined.
There is currently much more knowledge about the stability or test-retest reliability of phonological processing measures and Letter Word Identification during the developmental period of the current study. Parilla et al. (2004) found correlations of .77 for auditory-verbal short-term memory, .74 for rapid naming speed (colours), and .68 for phonological awareness (sound isolation and phoneme blending) from Kindergarten (similar age to Preschool in the current study) to Grade 1. Word Identification at Grade 1 and Grade 2 showed a significant correlation of .76. Others reported similar test-retest correlations for rapid naming speed and Word Identification over the same period (Cardosa-Martins & Pennington, 2004; Manis et al., 1999). Manis et al. also reported correlations of .54 for sound deletion and .68 for Word Attack from Grade 1 to Grade 2. This was similar to correlations reported by Cardosa-Martins and Pennington between phoneme awareness and Word Attack. Thus, these measures showed moderate to strong stability over one year at the start of primary school. Muter et al. (1997) measured rhyme detection and phoneme deletion at 4, 5, and 6 years of age. For rhyme detection, they found correlations of .58 between 4 and 5 years, .38 between 5 and 6 years, and .39 between 4 and 6 years. For phoneme deletion, the correlations for those three time intervals were .29, .49, and .18, respectively. The weak correlation for phoneme deletion from 4 to 5 years was due to floor effects at 4 years of age. Thus, greater stability was found over shorter test-retest intervals, but there was less stability when measured at the youngest ages. Muter and Snowling (1998) reported stability for these measures on this same sample when the children were 9 years old. Rhyme detection at 4, 5, and 6 years showed significant correlations of .51, .59, and .53 with rhyme discrimination at 9 years. Phoneme deletion at 4, 5, and 6 years showed correlations of .16 (non-significant), .47, and .45 with phoneme deletion at 9 years (the latter two correlations were
significant). This demonstrates that even over the long term there is moderate stability in phonological processing.

Wagner et al. (1997) examined the stability of latent variables. They found correlations of .83 from kindergarten to Grade 1, .89 from Grade 1 to Grade 2, and .62 from kindergarten to Grade 2 for phonological awareness. Correlations over these periods were very similar for naming speed. Memory showed the greatest stability. The test-retest correlations were 1.00 for the one-year intervals and .93 for the two-year interval. For word reading, test-retest correlation from kindergarten to Grade 1 was .69, from Grade 1 to Grade 2 was .84, and from kindergarten to Grade 2 was .39. However, as Wagner et al. (1994) noted, stronger correlations are expected with latent variables than with observed variables, because only common variance is included in the latent variable. Despite this, the pattern is similar to that with observed variables, considerable stability over the period from kindergarten to Grade 2 with greater stability over shorter rather than longer intervals.

The final section of this chapter examines the prediction of Grade 1 and 2 reading measures when the temporal and phonological processing predictors were measured at Grade, rather than at Preschool as presented in Chapter 8. This examined the stability of the pattern of prediction with predictors measured at after school-entry as opposed to before school-entry. There is some evidence of better prediction of late Grade 1 reading ability group membership (dyslexic versus control) when the phonological processing measures are obtained at early Grade 1 rather than at Preschool, although these differences were not significant (O’Connor & Jenkins, 1999; Parilla et al., 2004). Certainly if development is still occurring in both the predictor and criterion measures, changes in the percentages of variance explained might occur. Substantial differences in the pattern of prediction would be more likely
if development in the measures was unstable, or if major changes occurred in the relationship.

10.1 Development in Temporal Processing

Repeated measures ANOVAs were conducted to determine if there were significant differences across the three phases of the study in the three measures of temporal processing. Due to violations of the assumptions of sphericity for all three temporal processing measures, the Huynh-Feldt correction was used. Other assumptions of the analysis were met. Figure 10.1 shows the development in scores on the Auditory TOJ task. The effect of phase of measurement on ATOJ performance was significant, $F(1.83, 188.20) = 51.77, p < .0001, \omega^2 = 0.23$. This was a large effect, accounting for 23% of the variance. Only the linear function was significant, $F(1, 103) = 77.12, p < .0001$. The children were significantly more accurate at judging order at Grade 1 than at Preschool, $F(1, 103) = 41.81, p < .0001$. At Grade 2, they were significantly more accurate than at Grade 1, $F(1, 103) = 19.51, p < .0001$. By Grade 2 (7 years), the average score approached ceiling (maximum score on the task was 14). Almost 53% of children were at ceiling.

There was also a significant effect of phase on Visual TOJ accuracy, $F(1.89, 196.74) = 105.51, p < .0001, \omega^2 = 0.39$. This was also a large effect, with phase accounting for 39% of the variance in VTOJ. Only the linear contrast was significant, $F(1, 104) = 170.46, p < .0001$. At Grade 1, the children were significantly more accurate than at Preschool, $F(1, 104) = 70.71, p < .0001$. At Grade 2, they were significantly more accurate than at Grade 1, $F(1, 104) = 48.99, p < .0001$. There was no ceiling effect on this task; the maximum score was 40, which children had not reached by Grade 2 (see Figure 10.2).
Figure 10.1. Development in Auditory Temporal Order Judgement (maximum score = 14) from Preschool to Grade 2.

Figure 10.2. Development in Visual Temporal Order Judgement Accuracy (maximum score = 40) from Preschool to Grade 2.
The effect of phase on Temporal Dot accuracy was significant, $F(1.90, 190.19) = 25.00, p < .0001, \omega^2 = .13$. This was a medium effect with 13% of the variance accounted for. Only the linear contrast was significant, $F(1, 100) = 38.40, p < .0001$. Grade 1 scores were significantly higher than Preschool scores, $F(1, 100) = 23.55, p < .0001$, and Grade 2 scores were significantly higher than Grade 1 scores, $F(1, 100) = 6.98, p = .001$ (Figure 10.3). The maximum score on this task was 24, so children were still, on average, achieving less than 50% accuracy at Grade 2. This confirms that this task was perceptually and cognitively much more demanding than the other two temporal processing tasks.

\[\text{Figure 10.3. Development in Temporal Dot Accuracy from Preschool to Grade 2}\]

10.1.1 Discussion

This is the first longitudinal data on development for these temporal processing measures across this early childhood period. There was significant linear
development across the three phases of the study in all three temporal processing measures. Phase of measurement had the largest effect on Visual TOJ score. This possibly explains why the Visual TOJ task measured at Preschool did not account for unique variance in the reading measures. At that age, this aspect of temporal processing may be more undeveloped in the visual domain than in the auditory domain. Children from birth are differentiating and determining the order of rapidly presented sequences of sounds (especially in speech sounds) but have less need to differentiate and order rapidly presented visual stimuli of the sort used in the Visual TOJ task. It may be that the visual experiences associated with reading foster development of visual temporal sequencing.

The present results indicated ceiling effects on the Auditory TOJ measure by 7 years of age. This was not consistent with previous studies that showed development still occurs until older ages (e.g., Marshall et al., 2001; Tallal; 1976; Waber et al., 2001). However, those studies required the entire order of the stimuli to be reported, whereas the task used in the current study only required the first stimulus to be reported. This probably made it a simpler task (necessary for the young sample used), which may explain the different findings to other studies. This task was designed for children aged 4;6 to 6;5 years, so the average age of the sample had exceeded the developmental range by the last measurement phase. However, the task was chosen based on the age of the sample at Phase 1, which was when the predictor measures were collected.

No previous studies have reported on normal development in visual TOJ or Temporal Dot tasks. Booth et al. (2000) showed dyslexic children aged 11 to 18 years were less accurate than adults were on this task. However, it is unclear whether their results apply to children with a normal range of reading abilities. The current results
show Grade 2 children, on average, performed this task with less than 50% accuracy, indicating there was considerable development yet to occur. The older sample in Eden et al. (1995) was still not performing this task near ceiling with the higher sequences of dots.

Given there was significant development in visual and auditory temporal processing across the period of the study, the next question was the extent to which there was stability in individual performance on these measures. Specifically, was the relative position of an individual within the distribution similar across time, regardless of the absolute improvement?

10.2 Stability of Measures

This was looked at initially by examining normative stability, the correlation between scores at different testing times (Taris, 2000). Participants’ scores on each measure were rank ordered. If there was stability across time in the scores, there should be a strong positive correlation between participants' ranks across phases. In other words, a participant's rank at Phase 1 should be very similar to the rank at Phases 2 and 3. Spearman rho correlations were conducted between ranks (see Table 10.1).

10.2.1 Stability of Temporal Processing Measures

There was a strong positive correlation between the ranks for Auditory TOJ from Phase 1 to 2 (Table 10.1). However, there were only weak correlations between the ranks at Phases 1 and 3 and between Phases 2 and 3. Fisher's $z$-test indicated that the relationship between Phases 1 and 2 was significantly stronger than that between Phases 1 and 3, $z = 2.56$, $p = .005$, and between Phases 2 and 3, $z = 2.10$, $p = .018$.

There were strong correlations between the ranks for Visual TOJ in Phases 1 and 2 and between Phases 2 and 3 (Table 10.1). There was a weak correlation
between Phases 1 and 3. There were significant differences between the strengths of the correlations between Phases 1 and 3 and Phases 1 and 2 \( (z = 2.10, p = .018) \) and Phases 2 and 3 \( (z = 2.10, p = .018) \).

Ranks on the Temporal Dot task showed a significant moderate positive correlation between Phases 1 and 2 (Table 10.1). There was a significant strong correlation between Phases 2 and 3. However, the correlations between these two phases did not differ significantly in strength, \( z = 1.43, p = .08 \). The correlation between Phase 1 and 3 was significantly weaker than that between Phases 2 and 3, \( z = 2.10, p = .018 \).

10.2.2 Stability of Phonological Processing and Reading Measures

Table 10.1 shows the correlations between participant rank on the phonological processing and Letter Word Identification measures from Preschool to Grade 1 and Grade 2, and from Grade 1 to Grade 2. Phonological memory was also included here with the phonological processing measures. There were moderate to strong correlations between ranks at all phases. As occurred with the temporal processing measures, the weakest correlations occurred between ranks at Preschool and Grade 2.

10.2.3 Discussion

These results provide the most extensive information on stability in temporal processing measures currently available. There was moderate stability of temporal processing ability over the 6-month interval from Preschool to Grade 1. In other words, there was moderate consistency in the children’s relative positions in the distributions from Preschool to Grade 1. Preschool ranks on the Auditory and Visual TOJ tasks explained over one quarter of the variance in ranks at Grade 1. The stability of performance on the Auditory TOJ task over 6 months compared well to
the reported one-week test-retest reliability for this task (Nicolson & Fawcett, 1996).

Table 10.1

Correlations between Rank Order on the Temporal and Phonological Processing measures, Short-term Memory, and Woodcock Letter-Word Identification at each Phase

<table>
<thead>
<tr>
<th>Measure</th>
<th>Preschool – Grade 1 (6 months)</th>
<th>Grade 1 – Grade 2 (12 months)</th>
<th>Preschool – Grade 2 (18 months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory TOJ</td>
<td>.50***</td>
<td>.26*</td>
<td>.20*</td>
</tr>
<tr>
<td>Visual TOJ</td>
<td>.53***</td>
<td>.51***</td>
<td>.29**</td>
</tr>
<tr>
<td>Temporal Dot</td>
<td>.34***</td>
<td>.50***</td>
<td>.26**</td>
</tr>
<tr>
<td>RAN</td>
<td>.63***</td>
<td>.65***</td>
<td>.49**</td>
</tr>
<tr>
<td>PhonSeg</td>
<td>.52***</td>
<td>.52***</td>
<td>.41***</td>
</tr>
<tr>
<td>Rhymes</td>
<td>.67***</td>
<td>.49***</td>
<td>.39***</td>
</tr>
<tr>
<td>Memory</td>
<td>.73***</td>
<td>.73***</td>
<td>.57***</td>
</tr>
<tr>
<td>LetWordId</td>
<td>.63***</td>
<td>.55***</td>
<td>.45***</td>
</tr>
</tbody>
</table>

Note: RAN = Rapid Automatised Naming; PhonSeg = Phonemic Segmentation;
LetWordId = WDRB Letter Word Identification

* p < .05; ** p < .01; ***p < .001

Stability was lower over the longer time intervals of 12 months from Grade 1 to Grade 2 and 18 months from Preschool to Grade 2 for the Auditory TOJ ranks. This decreasing stability is most likely due to increasing approach to ceiling over time on this task. By Grade 2, there were only eight different ranks assigned. This restricted range impacted on the strength of the correlations with previous stages.
There was less stability in rank order on Temporal Dot over this period. Part of this may be because this task relied also on the efficiency or automaticity with which the children could count. While all children were tested to ensure they could count to six, using the principles of one-to-one correspondence, stable order, and cardinality, the efficiency with which they could process this sequence of dots may have varied considerably. Development in this aspect from Preschool through to Grade 2, particularly after children enter school, may have contributed to the lower stability seen on this task. With development in counting efficiency, this task was likely to become a purer measure of temporal processing. The greater perceptual and cognitive difficulty of this task for children at Preschool may also have contributed to the lower stability observed in this measure over time. As children’s ability to perform this task began to develop, the spread in the distribution increased and relative positions within the distribution became less stable. Figure 10.3 illustrates increasing variance in the distribution with each successive phase.

Rhymes showed a similar pattern of ceiling effects by Grade 2 to Auditory TOJ. This was consistent with previous reports that rhyme detection reached ceiling after 6 years (Nation & Hulme, 1997; Stanovich et al., 1984). Almost half of the variation in Rhymes rank at Grade 1 was explained by Rhymes rank at Preschool, but this stability decreased from Grade 1 to Grade 2, due to increasing percentages of children reaching ceiling. The strength of the correlation obtained for Rhymes from Preschool (5 years) to Grade 1 (6 years) was consistent with that reported for phonological awareness over the same period by Parilla et al. (2004), but greater than the correlations reported by Muter et al. (1997). The obtained correlation from Grade 1 to Grade 2 was identical to that reported for Muter et al. for 5- to 6-year-olds. The correlation obtained from Preschool to Grade 1 for Phonemic Segmentation was very
similar to that reported by Manis et al. (1999). Stability for Rapid Automatised naming was also consistent with previous studies (Parilla et al.). Similarly, Memory showed strong stability consistent with previous studies (Parilla et al.; Wagner et al., 1997). Letter Word Identification showed strong stability across the three phases. The results were very similar to those reported by Wagner et al. The current correlations for phonological processing and memory were lower than were those obtained by Wagner et al., but this was due to the use of observed variables in the current study and latent variables by Wagner et al.

Individual variation in development in these temporal and phonological processing skills would result in instability of rank order over phases. Children who were developing at an average rate would remain around the same relative position. If children were developing at a faster than average rate they would move up in the relative ranking within the distribution and if they were developing more slowly than average they would move relatively lower in the ranking. This movement in ranks would reduce the correlations between phases.

The next section examined the stability of the children who showed the lowest versus highest performance on the various measures. The stability in position within the distribution across time of those participants whose scores on the temporal processing, phonological processing, phonological memory, and Letter-Word Identification measures fell in the bottom and top quartiles was examined. The lowest performing participants are of most interest for diagnosis and intervention. If these children show stability in their relative positions in the population on these measures, then they could be identified before school-entry and given targeted remediation. However, if there were considerable instability (i.e., if a substantial percentage of children naturally improve and move up the distribution over time) early identification
would target many children who did not require early intervention. The stability of those children in the top quartile was examined for comparison. If some of those children initially perform the tasks well and then effectively move back in the distribution, early identification would miss them and they may be at risk of reading difficulties.

10.3 Stability of the Bottom versus Top Quartiles across Time

Table 10.2 shows the percentage of children in the bottom quartile at Preschool who fell into particular quartiles at Grade 1 on the temporal processing, phonological processing, memory, and Letter Word Identification tasks. On each of the measures, the majority of participants who performed in the bottom quartile at Preschool performed in the bottom quartile at Grade 1. The increasing ceiling effects on the Auditory TOJ and Rhymes/Alliteration measures are apparent by the inability to divide the distribution into four quartiles at Grade 1. However, it is still clear the majority of children who performed poorly on these measures at Preschool were still performing poorly on them at Grade 1. There was less stability on Temporal Dot, Rapid Automatised Naming, and Phonemic Segmentation, although over three quarters of the participants who were in the lowest Preschool quartile on these measures remained in the bottom 50\(^{th}\) percentile at Grade 1. On Letter Word Identification, 83.3\% of those in the bottom quartile at Preschool were still in the bottom quartile in Grade 1. At Preschool, this task was measuring letter name knowledge, whereas by Grade 1, it measured letter name knowledge and word identification. This demonstrated the stability on this measure, even when used from a pre-reading to a reading point. High stability was also seen on the Memory task (digit span); over 70\% remained in the bottom quartile at both phases.
Table 10.2

Performance across Preschool to Grade 1 Phases of Participants in Lowest Quartile

at Preschool

<table>
<thead>
<tr>
<th>ATOJ (n=36)</th>
<th>VTOJ (n=38)</th>
<th>DOT (n=34)</th>
<th>RAN (n=30)</th>
<th>PhonSeg (n=44)</th>
<th>Rhymes (n=39)</th>
<th>MEM (n=40)</th>
<th>LetWordId (n=36)</th>
</tr>
</thead>
</table>

Quartile range at Grade 1

1st (bottom) 61.1 55.3 41.2 48.1 40.9 66.7 72.5 83.3
2nd 27.8 18.4 35.3 33.3 50.0 17.9 25 2.8
3rd 11.1 15.8 8.8 7.4 9.1 15.4 2.5 11.1
4th (top) -- 10.5 14.7 11.1 0.0 -- 0.0 2.8

Note: Cell entries are the percentage of participants from the bottom quartile at the Preschool phase that fell into a particular quartile at the Grade 1 phase. Dashes indicate that a particular quartile was not represented.

Note: ATOJ = Auditory TOJ; VTOJ = Visual TOJ; DOT = Temporal Dot; RAN = Rapid Automatised Naming; PhonSeg = Phonemic Segmentation; MEM = Memory; LetWordId = WDRB Letter Word Identification subtest. At Grade 1, the Rhymes task involved Rhyme and Alliteration detection (only Rhyme detection at Preschool).

Table 10.3 shows the position in Grade 1 for the children who fell in the highest quartile at Preschool. Similar stability to that observed in Table 10.2 for the lowest Preschool quartile is seen in Table 10.3 for the highest Preschool quartile. For each measure, the majority of children who performed in the top quartile at Preschool performed in the top quartile in Grade 1. There was less stability among the higher Preschool performers on Temporal Dot than on the other measures. Only just over a third of those who were in the top quartile at Preschool remained there at Grade 1. There was also less stability among the highest performers on Memory and Letter Word Identification than there had been among the lowest performers on those two
tasks. Rhymes detection showed the greatest stability with 100% of those in the highest quartile at Preschool remaining in the top category at Grade 1.

Table 10.3

*Performance across Preschool to Grade 1 Phases of Participants in Highest Quartile at Preschool*

<table>
<thead>
<tr>
<th></th>
<th>ATOJ (n =18)</th>
<th>VTOJ (n =23)</th>
<th>DOT (n =22)</th>
<th>RAN (n =27)</th>
<th>PhonSeg (n =18)</th>
<th>Rhymes (n =28)</th>
<th>MEM (n =22)</th>
<th>LetWordId (n =14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartile range at Grade 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st (bottom)</td>
<td>11.1</td>
<td>0</td>
<td>4.5</td>
<td>6.7</td>
<td>5.6</td>
<td>0.0</td>
<td>4.5</td>
<td>0</td>
</tr>
<tr>
<td>2nd</td>
<td>38.9</td>
<td>17.4</td>
<td>27.3</td>
<td>6.7</td>
<td>33.3</td>
<td>0.0</td>
<td>27.3</td>
<td>7.1</td>
</tr>
<tr>
<td>3rd</td>
<td>50.0</td>
<td>21.7</td>
<td>31.8</td>
<td>23.3</td>
<td>0.0</td>
<td>100.0</td>
<td>27.3</td>
<td>35.7</td>
</tr>
<tr>
<td>4th (top)</td>
<td>--</td>
<td>60.9</td>
<td>36.4</td>
<td>63.3</td>
<td>61.1</td>
<td>--</td>
<td>40.9</td>
<td>57.1</td>
</tr>
</tbody>
</table>

*Note:* Cell entries are the percentage of participants from the bottom quartile at the Preschool phase that fell into a particular quartile at the Grade 1 phase. Dashes indicate that a particular quartile was not represented.

*Note:* ATOJ = Auditory TOJ; VTOJ = Visual TOJ; DOT = Temporal Dot; RAN = Rapid Automatised Naming; PhonSeg = Phonemic Segmentation; MEM = Memory; LetWordId = WDRB Letter Word Identification subtest. At Grade 1, the Rhymes task involved Rhyme and Alliteration detection (only Rhyme detection at Preschool).

Table 10.4 shows the position at Grade 2 of participants scoring in the bottom quartile at Grade 1. Results are similar to those from Preschool to Grade 1. Around half of the participants falling in the bottom quartile on a particular measure in Grade 1 remained in the bottom quartile at Grade 2. Very few participants from the bottom quartile at Grade 1 scored above the 50th percentile in Grade 2. There was less stability in Letter Word Identification from Grade 1 to Grade 2, than from Preschool to Grade 1 (compare Table 10.2 and Table 10.4). The strong ceiling effect by Grade 2 is observable in Auditory TOJ and Rhyme and Alliteration detection. Only two
categories could be formed based on the distribution of scores on these two measures at Grade 2. This restricted range made it difficult to demonstrate the stability accurately.

Table 10.4

Performance across Grade 1 to Grade 2 Phases of Participants in Lowest Quartile at Grade 1

<table>
<thead>
<tr>
<th></th>
<th>ATOJ (n=30)</th>
<th>VTOJ (n=25)</th>
<th>DOT (n=25)</th>
<th>RAN (n=26)</th>
<th>PhonSeg (n=25)</th>
<th>Rhym/All (n=28)</th>
<th>MEM (n=42)</th>
<th>LetWordId (n=37)</th>
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</thead>
<tbody>
<tr>
<td>Quartile range at Grade 1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st (bottom)</td>
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<td>56.0</td>
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<td>48.0</td>
<td>55.6</td>
<td>61.9</td>
<td>48.6</td>
</tr>
<tr>
<td>2nd</td>
<td>36.7</td>
<td>20.0</td>
<td>28.0</td>
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<td>44.4</td>
<td>21.4</td>
<td>40.5</td>
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<tr>
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<td>8.0</td>
<td>8.0</td>
<td>0.0</td>
<td>--</td>
<td>11.9</td>
<td>10.8</td>
</tr>
<tr>
<td>4th (top)</td>
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<td>0.0</td>
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<td>--</td>
<td>4.8</td>
<td>0</td>
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</tbody>
</table>

*Note:* Cell entries are the percentage of participants from the bottom quartile at the Grade 1 phase that fell into a particular quartile at the Grade 2 phase. Dashes indicate that a particular quartile was not represented.

*Note:* ATOJ = Auditory TOJ; VTOJ = Visual TOJ; DOT = Temporal Dot; RAN = Rapid Automatised Naming; PhonSeg = Phonemic Segmentation; Rhym/All = Rhyme and Alliteration detection; MEM = Memory; LetWordId = WDRB Letter Word Identification subtest.

Table 10.5 shows the stability in position from Grade 1 to Grade 2 for those participants in the highest quartile at Grade 1. Around one-half or more of those participants who performed in the highest quartile at Grade 1 performed in the highest quartile in Grade 2 on all measures, except Visual TOJ. However, even on Visual TOJ, the majority of those who performed in the top quartile at Grade 1, performed above the 50th percentile in Grade 2. On Letter Word Identification, all of the
participants in the top quartile at Grade 1 remained above the 50th percentile in Grade 2, again demonstrating the high stability of performance on this reading measure.

Table 10.5

*Performance across Grade 1 to Grade 2 Phases of Participants in Highest Quartile at Grade 1*

<table>
<thead>
<tr>
<th></th>
<th>ATOJ (n = 30)</th>
<th>VTOJ (n = 28)</th>
<th>DOT (n = 24)</th>
<th>RAN (n = 25)</th>
<th>PhonSeg (n = 22)</th>
<th>Rhym/All (n = 52)</th>
<th>MEM (n = 18)</th>
<th>LetWordId (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartile range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>at Grade 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st (bottom)</td>
<td>36.7</td>
<td>7.1</td>
<td>12.5</td>
<td>3.8</td>
<td>9.1</td>
<td>9.6</td>
<td>11.1</td>
<td>0</td>
</tr>
<tr>
<td>2nd</td>
<td>63.3</td>
<td>25.0</td>
<td>20.8</td>
<td>7.7</td>
<td>18.2</td>
<td>90.4</td>
<td>16.7</td>
<td>0</td>
</tr>
<tr>
<td>3rd</td>
<td>--</td>
<td>50.0</td>
<td>20.8</td>
<td>15.4</td>
<td>27.3</td>
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<td>45.5</td>
<td>--</td>
<td>50.0</td>
<td>55.0</td>
</tr>
</tbody>
</table>

*Note:* Cell entries are the percentage of participants from the bottom quartile at the Preschool phase that fell into a particular quartile at the Grade 2 phase. Dashes indicate that a particular quartile was not represented.

*Note:* ATOJ = Auditory TOJ; VTOJ = Visual TOJ; DOT = Temporal Dot; RAN = Rapid Automatised Naming; PhonSeg = Phonemic Segmentation; Rhym/All = Rhyme and Alliteration detection; MEM = Memory; LetWordId = WDRB Letter Word Identification subtest.

Table 10.6 shows the stability from Preschool to Grade 2. Over this longer period, less stability is evident on most measures. Memory showed strongest stability, with over 70% of those in the bottom quartile at Preschool performing in the bottom quartile at Grade 2. On Letter Word Identification, less than 20% of the participants in the bottom Preschool quartile performed above the 50th percentile by Grade 2. Visual TOJ showed the least stability, with around 40% of those who performed in the bottom quartile at Preschool performing above the 50th percentile by Grade 2.
Table 10.6

Performance across Preschool to Grade 2 Phases of Participants in Lowest Quartile

At Preschool

<table>
<thead>
<tr>
<th>ATOJ (n = 31)</th>
<th>VTOJ (n = 32)</th>
<th>DOT (n = 27)</th>
<th>RAN (n = 27)</th>
<th>PhonSeg (n = 44)</th>
<th>Rhym/All (n = 30)</th>
<th>MEM (n = 32)</th>
<th>LetWordId (n = 26)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartile range at Grade 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st (bottom)</td>
<td>51.6</td>
<td>37.5</td>
<td>37.0</td>
<td>41.7</td>
<td>40.9</td>
<td>46.7</td>
<td>71.9</td>
</tr>
<tr>
<td>2nd</td>
<td>48.4</td>
<td>21.9</td>
<td>40.7</td>
<td>33.3</td>
<td>50.0</td>
<td>53.3</td>
<td>15.6</td>
</tr>
<tr>
<td>3rd</td>
<td>--</td>
<td>37.5</td>
<td>11.1</td>
<td>12.5</td>
<td>9.1</td>
<td>--</td>
<td>6.3</td>
</tr>
<tr>
<td>4th (top)</td>
<td>--</td>
<td>3.1</td>
<td>11.1</td>
<td>12.5</td>
<td>0.0</td>
<td>--</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Note: Cell entries are the percentage of participants from the bottom quartile at the Preschool phase that fell into a particular quartile at the Grade 2 phase. Dashes indicate that a particular quartile was not represented.

Note: ATOJ = Auditory TOJ; VTOJ = Visual TOJ; DOT = Temporal Dot; RAN = Rapid Automatised Naming; PhonSeg = Phonemic Segmentation; Rhym/All = Rhyme and Alliteration detection; MEM = Memory; LetWordId = WDRB Letter Word Identification subtest.

Table 10.7 shows the stability of the top quartile at Preschool through to Grade 2. As was seen in Table 10.3 with the highest Preschool quartile at Grade 1, there was less stability in this quartile than in the bottom Preschool quartile. However, the majority of participants remained above the 50th percentile by Grade 2. All of the participants who performed in the top quartile on Letter Word Identification at Preschool remained above the 50th percentile at Grade 2. Although the ceiling effect produces problems for the Auditory TOJ and Rhyme and Alliteration tasks by Grade 2, it is clear that over 80% of those participants who performed in the top quartile at Preschool remained in the top scoring group at Grade 2.
Table 10.7

Performance across Preschool to Grade 2 Phases of Participants in Highest Quartile at Preschool

<table>
<thead>
<tr>
<th></th>
<th>ATOJ (n = 15)</th>
<th>VTOJ (n = 22)</th>
<th>DOT (n = 21)</th>
<th>RAN (n = 24)</th>
<th>PhonSeg (n = 18)</th>
<th>Rhym/All (n = 25)</th>
<th>MEM (n = 19)</th>
<th>LetWordId (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartile range at Grade 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; (bottom)</td>
<td>13.3</td>
<td>4.5</td>
<td>19.0</td>
<td>11.1</td>
<td>5.6</td>
<td>12.0</td>
<td>10.5</td>
<td>0</td>
</tr>
<tr>
<td>2nd</td>
<td>86.7</td>
<td>31.8</td>
<td>28.6</td>
<td>18.5</td>
<td>33.3</td>
<td>88.0</td>
<td>15.8</td>
<td>0</td>
</tr>
<tr>
<td>3rd</td>
<td>--</td>
<td>36.4</td>
<td>0.0</td>
<td>22.2</td>
<td>0.0</td>
<td>--</td>
<td>36.8</td>
<td>50.0</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; (top)</td>
<td>--</td>
<td>27.3</td>
<td>52.4</td>
<td>48.1</td>
<td>61.1</td>
<td>--</td>
<td>36.8</td>
<td>50.0</td>
</tr>
</tbody>
</table>

*Note:* Cell entries are the percentage of participants from the bottom quartile at the Grade 1 phase that fell into a particular quartile at the Grade 2 phase. Dashes indicate that a particular quartile was not represented.

*Note:* ATOJ = Auditory TOJ; VTOJ = Visual TOJ; DOT = Temporal Dot; RAN = Rapid Automatised Naming; PhonSeg = Phonemic Segmentation; Rhym/All = Rhyme and Alliteration detection; MEM = Memory; LetWordId = WDRB Letter Word Identification subtest.

10.3.1 Discussion

The poorest performing children showed considerable stability from Preschool to Grade 1 and from Grade 1 to Grade 2 on most measures. They showed less stability over the longer period from Preschool to Grade 2. Performance on Letter Word Identification was very stable from Preschool to Grade 1. This supports the strong relationship between pre-school letter knowledge and early reading ability (e.g., Badian, 1993). By Grade 2, nearly half of the children who performed in the lowest quartile on this task at Preschool (i.e., knew fewest letters) were still in the lowest quartile (i.e., knew fewest words). This is consistent with Juel’s (1988) finding that children who are the poorest performers in reading at Grade 1 are very likely to remain the poorest readers in later grades. The current results extend this to an earlier
point in development, showing that those children who are the poorest performers in
reading in Grade 1 were likely to have been the poorest performers in Preschool at
letter naming. There was also considerable stability in auditory short-term memory.
This is consistent with previous findings that there was greatest stability in this
individual characteristic (Parilla et al., 2004; Wagner et al., 1997).

There was a similar degree of stability between the temporal processing and
phonological processing measures. Around half of the participants who were in the
lowest quartile at Preschool on these measures remained in the lowest quartile at
Grade 1 and over one third remained in the lowest quartile on these tasks at Grade 2.
Unfortunately, interpretation of the stability of Auditory TOJ and Rhyme and
Alliteration detection was affected by the ceiling effect, which increased from Grade 1
to Grade 2. However, there was still evidence of stability. Half of the children whose
performance was in the bottom quartile in Grade 2 on these two measures had
performances in the bottom half of the distribution in Grade 2.

These results are consistent with a subgroup of children who show consistently
poor temporal and phonological processing over time, and another subgroup who
have poor skills initially but who develop adequate or even good levels of these skills
after school entry. There are several possible explanations. One reason for the
instability seen in the top and bottom quartiles could be a result of regression to the
mean, which results in some children’s scores falling in a higher or lower
(respectively) quartile at the second testing phase.

Other likely reasons are developmental. Some children may be naturally
developing more slowly initially but more rapidly later, and so their relative position
in the distribution improves. On the Temporal Dot task, some instability may arise
from the immaturity or inexperience in the sequencing and counting required for this
task. Initially less accurate performance on this task may be due to poorer temporal processing, poorer automaticity of sequencing, or a combination of both. As ability to sequence improves via natural development and as children gain experience with reciting the alphabet, sounding out letters in words, and counting, those children who were initially less accurate because of counting inefficiency would become more accurate. Children who were initially less accurate due to a combination of inefficient counting and poor temporal processing would improve to some extent but still experience difficulties on this task due to the ongoing difficulties with temporal processing. Those whose inaccuracy on this task arose mainly from poor temporal processing would be likely to remain in the lowest quartile on this task.

On the phonological processing tasks, some children may perform poorly at Preschool due to a less enriched early literacy environment. However, once exposed to the more enriched school environment make fast gains on these skills. Vellutino et al. (2004) argued that the majority of children who enter school with poor skills represent those with environmentally based deficits, with only a small percentage having genuine underlying cognitive and perceptual deficits. However, if this were entirely the case less stability from Preschool to Grade 1 would be expected on Letter Word Identification as well. The children who remain in the lowest quartile on the temporal and phonological processing measures may represent those with biologically based difficulties, who may be at most risk for long-term reading difficulties. They may have also had genetic (familial history) risk factors. The children who do not improve may represent the children who will meet the criteria for dyslexia, while the remainder may constitute garden-variety poor readers.

The fact that a percentage of the children with the poorest temporal and phonological processing skills at Preschool improve during the first years of school...
indicates using any of these measures to target at-risk children prior to school-entry would be inefficient to some extent. Future research needs to identify the characteristics that differentiate those who improve to average or above average levels from those who do not, and whether those who do not improve are those who are most at risk for long-term reading problems.

A similar pattern of stability was seen at the other end of the distribution. Of those children who were in the highest quartile at Preschool, around half had scores in the top quartile in Grade 1 and Grade 2. With Rhyme and Alliteration detection, all of the children who scored in the top quartile at Preschool remained in the top group at Grade 1 and around 90% scored above the 50th percentile at Grade 2. Thus, once children acquire awareness of onset and rime, there is high stability; they are unlikely to perform poorly in the future. There was less stability among this top quartile on the other phonological processing measures.

There was less stability in performance on Letter Word Identification among the top quartile from Preschool to Grade 1 (around 60% remained in the top quartile) than seen in the bottom quartile (over 80% remained in the bottom quartile). Lower Preschool letter naming scores are more likely to be predictive of lower scores on Grade 1 letter and word identification than higher Preschool letter naming scores are of higher Grade 1 word identification. One possible reason for this was a restricted range of scores in the highest quartile at Preschool, which made that group less homogenous in their ability. Children in the bottom quartile tended to be still mastering letter names at both Preschool and the Grade 1 phase, hence the greater stability in performance. The top quartile in Preschool represented those who knew most of the letters at Preschool, and so were performing at ceiling at the time. However, some of that top quartile may have been more ready to acquire a sight word
vocabulary with relative ease once at school than others were. The performance of those top performers at Preschool who made less rapid progress in word identification after school-entry fell within a lower quartile at Grade 1.

These results show there is moderate stability in these skills from Preschool to Grade 2, despite significant development occurring over that period. There were stronger correlations and greater stability between scores on the same measure over the shorter period from Preschool to Grade 1, than from Grade 1 to Grade 2 or from Preschool to Grade 2. Given there are developmental changes and some instability in both the predictor measures over the period of the study, the final question for this chapter was whether the pattern of prediction of variance in reading at Grades 1 and 2 changed depending on when the predictors were measured. Section 10.4 presents the results of analyses that examined prediction of Grade 1 and Grade 2 reading skills using the temporal and phonological processing predictors measured at Grade 1. The results will be discussed in relation to the results in Chapter 8 with Preschool predictors and in the context of developmental models of reading.

10.4 Prediction of Grade 1 and 2 Reading Skills Using Grade 1 and 2 Temporal and Phonological Processing Predictors

Analyses presented in this section were similar to those presented in Chapter 8, except that Grade 1 measures of temporal and phonological processing were used as predictors, instead of Preschool measures. The control measures entered at the first steps remained the same as described previously. The purpose of these analyses was to determine whether aspects of the prediction remained stable across time, in terms of the amount of variance accounted for, which predictors accounted for significant variance, and how prediction using temporal processing measures compared to prediction using phonological processing measures.
10.4.1 Prediction of Grade 1 Reading Measures using Grade 1 Predictor Variables

10.4.1.1 Zero-order Correlations

Table 10.8 shows the zero-order correlations between the control measures, the Grade 1 temporal and phonological processing measures, and the Grade 1 reading measures. The correlations between the control measures and the Grade 1 reading measures, and correlations between the Grade 1 reading measures were described in Section 8.1.1. This section only describes the details of the correlations between the Grade 1 predictor measures and other measures. There were significant weak to moderate correlations between Grade 1 Letter Word Identification, Reading Rate, and Word Attack and all of the Grade 1 temporal processing and phonological processing measures.

The three Grade 1 temporal processing measures showed weak to moderate significant correlations with each other, with between 6 to 12% of variance overlapped between these measures. This was similar to the overlap in variance between these measures when obtained at Preschool. There were only weak correlations between Rapid Automatised Naming and the two phonological awareness measures, with only the correlation between rapid naming and Phonemic Segmentation reaching significance (6.25% variance in common). There was a significant moderate positive correlation between the two phonological awareness measures, Phonemic Segmentation and Rhyme and Alliteration detection (16.8% of the variance in common). When these phonological processing measures were obtained at Preschool, there were significant weak to moderate correlations between all three measures (see Table 8.2).
Table 10.8

Correlations between Control Measures, Grade 1 Temporal Processing Predictors, Grade 1 Phonological Processing Predictors, and Grade 1 Reading Skills

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<th>TEACH</th>
<th>READ</th>
<th>VIG(^a)</th>
<th>ATOJcatch(^c)</th>
<th>MEM</th>
<th>MAT</th>
<th>ATOJ(^b)</th>
<th>VTOJ</th>
<th>DOT</th>
<th>RAN(^d)</th>
<th>PhonSeg</th>
<th>RhyAll</th>
<th>LetWordId</th>
<th>Attack(^c)</th>
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</tr>
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<td>VIG(^a)</td>
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<td>-.20*</td>
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<td>.13</td>
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<td>.26**</td>
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<tr>
<td>RAN(^d)</td>
<td>-.12</td>
<td>-.07</td>
<td>-.03</td>
<td>.26**</td>
<td>-.12</td>
<td>-.14</td>
<td>-.14</td>
<td>.17</td>
<td>-.24**</td>
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<td>1.00</td>
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<tr>
<td>PhonSeg</td>
<td>.20*</td>
<td>.19*</td>
<td>.07</td>
<td>-.20*</td>
<td>.17</td>
<td>.27**</td>
<td>.19*</td>
<td>-.42**</td>
<td>.31**</td>
<td>.23*</td>
<td>-.25**</td>
<td>1.00</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>RhyAll</td>
<td>.10</td>
<td>.19*</td>
<td>.09</td>
<td>-.17</td>
<td>.16</td>
<td>.20*</td>
<td>.15</td>
<td>-.33**</td>
<td>.16</td>
<td>.07</td>
<td>-.17</td>
<td>.41**</td>
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<tr>
<td>LetWordId</td>
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<td>.28**</td>
<td>.04</td>
<td>-.24**</td>
<td>.06</td>
<td>.16</td>
<td>.18</td>
<td>-.30**</td>
<td>.34**</td>
<td>.22*</td>
<td>-.38**</td>
<td>.50**</td>
<td>.42**</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attack(^c)</td>
<td>.32**</td>
<td>.18*</td>
<td>.08</td>
<td>-.21*</td>
<td>.11</td>
<td>.14</td>
<td>.18*</td>
<td>-.34**</td>
<td>.32**</td>
<td>.25*</td>
<td>-.33**</td>
<td>.52**</td>
<td>.34**</td>
<td>.64**</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Rate(^b)</td>
<td>.25**</td>
<td>.31*</td>
<td>.10</td>
<td>-.29**</td>
<td>.17</td>
<td>.11</td>
<td>.18*</td>
<td>-.34**</td>
<td>.29**</td>
<td>.20*</td>
<td>-.45**</td>
<td>.49**</td>
<td>.36**</td>
<td>.83**</td>
<td>.65**</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Note: TEACH = Parental Teaching, READ = Parental Reading, VIG = Attentional Vigilance, ATOJcatch = Auditory TOJ Catch Trials, MEM = Memory, MAT = Non-verbal Ability, ATOJ = Auditory TOJ, VTOJ = Visual TOJ, DOT = Temporal Dot, RAN = Rapid Automatised Naming, PhonSeg = Phonemic Segmentation, RhyAll = Rhyme and Alliteration detection, LetWordId = WDRB Letter Word Identification, Attack = WDRB Word Attack, Rate = Reading Rate.

\(^a\) Reflected and log transformed; \(^b\) Square root transformed; \(^c\) Categorical variable; \(^d\) Log transformed

\(^*\) p < .05; \(^**\) p < .01
The zero-order correlations between the Grade 1 temporal and phonological processing measures were similar to those between the Preschool temporal and phonological processing measures (see Tables 8.2 and 10.8). At both phases, Rhyme and Alliteration detection showed a significant correlation with Auditory TOJ only, not with either of the visual temporal processing measures. Phonemic Segmentation showed significant correlations with all three temporal processing measures. Rapid Automatised Naming showed a significant correlation with Visual TOJ only. Both of those tasks involved rapid visual processing of stimuli presented on a horizontal plane, which may explain this overlap. Thus, better auditory and visual temporal processing abilities were associated with better ability to segment words into phonological units. Greater accuracy in judging auditory temporal order was associated with better detection of onsets and rimes. Greater accuracy in judging visual temporal order was associated with faster naming speed for objects.

Grade 1 Auditory TOJ showed weak to moderate correlations with Age, Auditory TOJ catch trials, Memory, and Non-verbal Ability. As there were significant correlations between Age and all three Grade 1 reading measures, and between Non-verbal Ability and Reading Rate and Word Attack, these could potentially explain any variance in those reading measures accounted for by Auditory TOJ. Visual TOJ also showed a significant correlation with Non-verbal Ability. There were significant correlations between Grade 1 Visual TOJ and Temporal Dot and Attentional Vigilance. As Attentional Vigilance was significantly related to all three reading measures, this could explain any variance in the reading measures accounted for by either visual temporal processing measure. Grade 1 Phonemic Segmentation and Rhyme and Alliteration Detection also showed significant correlations with Attentional Vigilance, so the effects of Attentional Vigilance also
need to be partialled out of the regression of these temporal and phonological processing measures on the Grade 1 reading measures. The phonological processing measures were also significantly related to Parental Teaching, which was related to all three reading measures. Grade 1 Phonemic Segmentation also showed significant correlations with Age and Non-verbal Ability. The hierarchical multiple regression analyses in the following sections allowed the variance due to these control measures to be removed at the initial step, so the variance in the reading measures that was uniquely accounted for by the Grade 1 temporal and phonological processing predictors could be determined. The results for the initial steps with control measures were essentially the same as presented in Chapter 8\(^9\) so are not described here. However, the R\(^2\), β weights, and semi-partial correlations for those steps can be seen in the tables presented in the following sections for each set of regression analyses.

10.4.1.2 Prediction of Grade 1 Letter Word Identification

Table 10.9 summarises these regression analyses. When the three Grade 1 temporal processing measures entered at Step 2 (after the control measures), they accounted for an additional 10.90% of the variance, \(F (3, 110) = 5.24, \ p = .002\). Visual TOJ uniquely accounted for 4.16% of that variance. Neither of the other two temporal processing measures accounted for significant unique variance, although there was a marginal trend toward Auditory TOJ accounting for additional independent variance (\(p = .068\)). When the phonological processing measures were entered at Step 2, they accounted for 26.20% additional variance, \(F (3, 110) = 15.37, \ p < .0001\). All three Grade 1 phonological measures accounted for significant unique components of that variance. Rapid Automatised Naming speed accounted for 5.81%

\(^9\) Minor differences in the percentages of variance accounted for were due to the slight differences in sample sizes between the analyses with Preschool predictors and those presented here.
of the variance in Grade 1 Letter Word Identification. Rhyme and Alliteration
detection accounted for 4.16% of the variance. Phonemic Segmentation skill

Table 10.9

Hierarchical Regression Analyses for Grade 1 Predictor Variables Predicting Grade 1 Letter Word Identification (N = 117)

<table>
<thead>
<tr>
<th>Variable</th>
<th>B (SE B)</th>
<th>β</th>
<th>sr</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Age</td>
<td>2.38 (0.96)</td>
<td>0.22</td>
<td>.22</td>
<td>.015*</td>
</tr>
<tr>
<td>2. Parent Teach</td>
<td>0.34 (0.14)</td>
<td>0.21</td>
<td>.21</td>
<td>.018*</td>
</tr>
<tr>
<td>3. Vigilance</td>
<td>-1.21 (1.01)</td>
<td>-0.11</td>
<td>-.11</td>
<td>.234</td>
</tr>
<tr>
<td><strong>R² = .127</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 2.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Auditory TOJ</td>
<td>-2.89 (1.57)</td>
<td>-0.17</td>
<td>-.15</td>
<td>.068</td>
</tr>
<tr>
<td>5. Visual TOJ</td>
<td>0.13 (0.05)</td>
<td>0.22</td>
<td>.20</td>
<td>.016*</td>
</tr>
<tr>
<td>6. Temporal Dot</td>
<td>0.04 (0.07)</td>
<td>0.03</td>
<td>.05</td>
<td>.527</td>
</tr>
<tr>
<td><strong>ΔR² = .109</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 3.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. RAN</td>
<td>-7.01 (2.25)</td>
<td>-0.25</td>
<td>-.23</td>
<td>.002*</td>
</tr>
<tr>
<td>8. Phon. Segment.</td>
<td>0.41 (0.15)</td>
<td>0.24</td>
<td>.20</td>
<td>.008*</td>
</tr>
<tr>
<td>9. Rhyme</td>
<td>0.13 (0.05)</td>
<td>0.22</td>
<td>.20</td>
<td>.009*</td>
</tr>
<tr>
<td><strong>ΔR² = .184</strong></td>
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</tr>
<tr>
<td><strong>Step 2.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. RAN</td>
<td>-7.18 (2.22)</td>
<td>-0.26</td>
<td>-.21</td>
<td>.002*</td>
</tr>
<tr>
<td>5. Phon. Segment.</td>
<td>0.48 (0.15)</td>
<td>0.28</td>
<td>.14</td>
<td>.001*</td>
</tr>
<tr>
<td>6. Rhymes</td>
<td>0.13 (0.05)</td>
<td>0.23</td>
<td>.13</td>
<td>.007*</td>
</tr>
<tr>
<td><strong>ΔR² = .262</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 3.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Auditory TOJ</td>
<td>-0.02 (1.49)</td>
<td>-0.00</td>
<td>-.00</td>
<td>.99</td>
</tr>
<tr>
<td>8. Visual TOJ</td>
<td>0.08 (0.05)</td>
<td>0.14</td>
<td>.12</td>
<td>.10</td>
</tr>
<tr>
<td>9. Temporal Dot</td>
<td>0.08 (0.06)</td>
<td>0.10</td>
<td>.10</td>
<td>.201</td>
</tr>
<tr>
<td><strong>ΔR² = .031</strong></td>
<td></td>
<td></td>
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</tbody>
</table>

* p < .05
accounted for 3.92% of the variance. Steiger’s test (1980) revealed no significant
difference between the percentage of variance in Grade 1 Letter Word Identification
accounted for by the Grade 1 temporal and phonological processing measures, $Z^* = -1.05, p = .294$.

In order to perform a commonality analysis, each set of Grade 1 predictors was
entered into the regression equation after the other set, at the last step. When the
Grade 1 temporal processing measures were entered last at Step 3, they accounted for
3.10% of the variance, but this was not a significant increase over the variance already
accounted for by the control and Grade 1 phonological processing measures, $F(3, 107) = 1.89, p = .135$. Thus, the Grade 1 temporal processing measures did not
account for a significant percentage of unique variance in Grade 1 Letter Word
Identification. When the Grade 1 phonological processing measures were entered
last, at Step 3, they accounted for an additional 18.40% of the variance in Grade 1
Letter Word Identification, $F(3, 107) = 11.29, p < .0001$, which represented their
unique contribution.

When all of the variables were entered, they accounted for 42.00% of the
variance in Grade 1 Letter Word Identification. Commonality analysis showed 7.80%
of the variance in Grade 1 Letter Word Identification overlapped between the Grade 1
temporal and phonological processing measures. Age and the three Grade 1
phonological measures still accounted for significant unique components of the
variance (see Table 10.9). Based on the $\beta$ weights, the most important predictors
were the three Grade 1 phonological processing measures, especially Phonemic
Segmentation.
10.4.1.3 Prediction of Grade 1 Reading Rate

Table 10.10 presents these results. When the Grade 1 temporal processing measures were entered at Step 3 (after the school attended and control measures), they increased the amount of variance explained by 8.60%, $F(3, 104) = 4.25, p = .007$. Only Auditory TOJ accounted for a significant unique percentage of the variance, accounting for 4.88%. When the Grade 1 phonological processing measures were entered at Step 3, they added another 24.60% to the variance explained in Grade 1 Reading Rate, $F(3, 104) = 16.59, p < .0001$. Rapid Automatised Naming speed uniquely accounted for 6.00% of the variance. Rhyme and Alliteration detection uniquely accounted for 5.38%. Phonemic Segmentation uniquely accounted for 3.53%. Each of these was significant. The variance accounted for in Grade 1 Reading Rate by the Grade 1 phonological processing measures was not significantly greater than that accounted for by the Grade 1 temporal processing measures, $z^* = -1.66, p = .097$.

When the temporal processing measures were entered last at Step 4, they did not account for a significant increase in variance, $R^2$ change = .015, $F(3, 101) = 1.00, p = .396$. Therefore, the Grade 1 temporal processing measures did not account for a significant unique percentage of variance in Grade 1 Reading Rate, beyond that already explained by the control measures and Grade 1 phonological processing measures. When the phonological processing measures were entered at Step 4, they increased the variance explained by 17.80%, $F(3, 101) = 12.00, p < .0001$. Together all of the measures accounted for 48.30% of the variance in Grade 1 Reading Rate. There was 7.10% of the variance shared between the Grade 1 temporal and phonological processing measures. After all of the measures were entered into the regression analysis, the school attended and all three Grade 1 phonological processing
Table 10.10

Hierarchical Regression Analyses for Grade 1 Predictor Variables Predicting Grade 1 Reading Rate (N = 118)

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
<th>sr</th>
<th>p</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>SCHOOL1</td>
<td>-0.89</td>
<td>0.37</td>
<td>-0.27</td>
<td>-.20</td>
<td>.017*</td>
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<td></td>
<td>SCHOOL2</td>
<td>-1.10</td>
<td>0.39</td>
<td>-0.31</td>
<td>-.26</td>
<td>.006*</td>
</tr>
<tr>
<td></td>
<td>R²</td>
<td>.074*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Age</td>
<td>1.13</td>
<td>0.49</td>
<td>0.20</td>
<td>.19</td>
<td>.024*</td>
</tr>
<tr>
<td></td>
<td>Parent Teach</td>
<td>0.15</td>
<td>0.07</td>
<td>0.19</td>
<td>.18</td>
<td>.033*</td>
</tr>
<tr>
<td></td>
<td>Vigilance</td>
<td>-0.81</td>
<td>0.51</td>
<td>-0.14</td>
<td>-.13</td>
<td>.116</td>
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<tr>
<td></td>
<td>Nonverbal</td>
<td>0.03</td>
<td>0.03</td>
<td>0.09</td>
<td>.09</td>
<td>.315</td>
</tr>
<tr>
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<td>Speech Problem</td>
<td>0.75</td>
<td>0.37</td>
<td>0.17</td>
<td>.17</td>
<td>.047*</td>
</tr>
<tr>
<td></td>
<td>ΔR²</td>
<td>.167*</td>
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</tr>
<tr>
<td>3</td>
<td>Auditory TOJ</td>
<td>-2.35</td>
<td>0.83</td>
<td>-0.27</td>
<td>-.23</td>
<td>.005*</td>
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<tr>
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<td>Visual TOJ</td>
<td>0.04</td>
<td>0.03</td>
<td>0.14</td>
<td>-.01</td>
<td>.135</td>
</tr>
<tr>
<td></td>
<td>Temporal Dot</td>
<td>-0.00</td>
<td>0.03</td>
<td>-0.01</td>
<td>.12</td>
<td>.932</td>
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<tr>
<td></td>
<td>ΔR²</td>
<td>.083*</td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>RAN</td>
<td>-3.79</td>
<td>0.89</td>
<td>-0.26</td>
<td>-.24</td>
<td>.001*</td>
</tr>
<tr>
<td></td>
<td>Phon. Segment.</td>
<td>0.15</td>
<td>0.07</td>
<td>0.17</td>
<td>.14</td>
<td>.045*</td>
</tr>
<tr>
<td></td>
<td>Rhymes</td>
<td>0.08</td>
<td>0.03</td>
<td>0.27</td>
<td>.21</td>
<td>.003*</td>
</tr>
<tr>
<td></td>
<td>ΔR²</td>
<td>.178*</td>
<td></td>
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</tr>
<tr>
<td>3</td>
<td>RAN</td>
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<td>1.09</td>
<td>-0.26</td>
<td>-.25</td>
<td>.001*</td>
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<tr>
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<td>Phon. Segment.</td>
<td>0.19</td>
<td>0.07</td>
<td>0.21</td>
<td>.19</td>
<td>.009*</td>
</tr>
<tr>
<td></td>
<td>Rhymes</td>
<td>0.08</td>
<td>0.03</td>
<td>0.28</td>
<td>.23</td>
<td>.001*</td>
</tr>
<tr>
<td></td>
<td>ΔR²</td>
<td>.246*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Auditory TOJ</td>
<td>-0.88</td>
<td>0.78</td>
<td>-0.10</td>
<td>-.08</td>
<td>.26</td>
</tr>
<tr>
<td></td>
<td>Visual TOJ</td>
<td>0.02</td>
<td>0.03</td>
<td>0.05</td>
<td>.04</td>
<td>.537</td>
</tr>
<tr>
<td></td>
<td>Temporal Dot</td>
<td>0.02</td>
<td>0.03</td>
<td>0.05</td>
<td>.05</td>
<td>.504</td>
</tr>
<tr>
<td></td>
<td>ΔR²</td>
<td>.015</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < .05
measures still accounted for significant unique variance in Grade 1 Reading Rate. The $\beta$ weights showed the most important predictors were the school attended, rapid naming speed, and Rhyme and Alliteration detection.

10.4.1.4 Prediction of Grade 1 Word Attack

Discriminant function analysis was used with this categorical Word Attack variable. Table 10.11 presents the descriptive statistics for the Decoder and Non-decoder groups on the control measures and Grade 1 temporal and phonological processing measures. The Decoders showed significantly better temporal and phonological processing than the Non-decoders did. Decoders were significantly older than Non-decoders were and experienced significantly higher frequency of Parental Teaching (details of $t$ statistics and effect sizes were previously presented in Section 8.14). In the first analysis, Age, Parental Teaching, and the three Grade 1 temporal processing measures were included as predictors and Word Attack group was the DV. There was a significant discriminant function, $\chi^2(5) = 35.47, p < .0001$. Only Parental Teaching did not contribute significantly to the discriminant function, $p = .06$. These measures correctly classified 91.90% of the Non-decoders and 61.10% of the Decoders. Grade 1 Auditory TOJ accuracy was the most important contributor to the discrimination (structure co-efficient = -.616), although Visual TOJ (structure co-efficient = .576) and Age were important (structure co-efficient = .571). The negative co-efficient with Auditory TOJ is due to the reflection and log transformation applied.

In the second analysis, the same two control measures plus the three Grade 1 phonological processing measures were used to discriminate group membership on the Grade 1 Word Attack measure. The discriminant function was significant, $\chi^2(5) =$
### Table 10.11

*Descriptive statistics for control measures and Grade 1 temporal and phonological processing measures for Decoders and Non-decoders at Grade 1*

<table>
<thead>
<tr>
<th>Preschool Measures</th>
<th>Decoders (n = 36)</th>
<th>Non-decoders (n = 88)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>5.51 (0.27)</td>
<td>5.30 (0.29)*</td>
</tr>
<tr>
<td>Parent Teaching</td>
<td>13.25 (2.30)</td>
<td>12.45 (1.92)*</td>
</tr>
<tr>
<td>Parent Reading</td>
<td>15.00 (4.88)</td>
<td>13.99 (5.72)</td>
</tr>
<tr>
<td>Vigilance</td>
<td>37.53 (4.30)</td>
<td>35.91 (4.55)</td>
</tr>
<tr>
<td>Memory</td>
<td>5.47 (1.52)</td>
<td>5.03 (1.39)</td>
</tr>
<tr>
<td>Nonverbal (std. Score)</td>
<td>110.09 (11.11)</td>
<td>107.76 (10.07)</td>
</tr>
<tr>
<td>Auditory TOJ</td>
<td>13.03 (1.30)</td>
<td>11.84 (1.70)*</td>
</tr>
<tr>
<td>Visual TOJ</td>
<td>33.81 (3.88)</td>
<td>29.97 (5.60)*</td>
</tr>
<tr>
<td>Temporal Dot</td>
<td>11.64 (5.09)</td>
<td>9.18 (3.93)*</td>
</tr>
<tr>
<td>RAN (secs)</td>
<td>46.73 (10.44)</td>
<td>57.30 (17.67)*</td>
</tr>
<tr>
<td>Phonemic Segment.</td>
<td>12.47 (1.62)</td>
<td>4.16 (1.63)*</td>
</tr>
<tr>
<td>Rhymes</td>
<td>6.00 (4.95)</td>
<td>8.32 (5.43)*</td>
</tr>
</tbody>
</table>

* *p < .05

49.13, *p < .0001*. All variables, except Parental Teaching (*p = .161*), contributed significantly to this discriminant function. There were 90.60% of the Non-Decoders and 52.90% of the Decoders correctly classified. Phonemic Segmentation was the most important contributor (structure co-efficient = .808).
The two control measures and both the Grade 1 temporal and phonological processing predictors were included in a final discriminant function analysis to determine if the combination of measures would better discriminate decoding status. The discriminant function was significant, $\chi^2(8) = 55.66, p < .0001$. All variables, except Parental Teaching, $p = .161$, contributed significantly to this discriminant function. The combined measures correctly classified 89.40% of the Non-Decoders and 64.70% of the Decoders. The most important contributor was Phonemic Segmentation (structure co-efficient = .741).

10.4.1.5 Discussion

Temporal processing measured at Grade 1 accounted for significant variance in Grade 1 Letter Word Identification and Reading Rate and was significantly able to discriminate Decoders from Nondecoders. The decoding groups significantly differed on all of the temporal processing measures. If reading ability were being classified using non-word reading, this would be consistent with previous reports of significant between-group differences on these temporal processing tasks. Auditory TOJ accounted for significant unique variance in Reading Rate (before the phonological processing measures were entered into the regression analysis), and was an important discriminator of the Word Attack decoding groups. Visual TOJ accounted for significant unique variance in Letter Word Identification (before the phonological processing measures were entered) and was important in discriminating the Word Attack groups.

This represented a change from the results when Preschool temporal processing predictors were used. Preschool Auditory TOJ was the only important temporal processing predictor for all reading measures. However, when the temporal
processing measures were obtained at Grade 1, and were used to predict Grade 1 reading skills, Visual TOJ emerged as an important predictor for letter and word identification and word decoding skills. This may partly reflect the significant growth in performance on Visual TOJ from Preschool to Grade 1. This is consistent with the hypothesis that auditory temporal processing would be more closely related to reading in the earlier stage, via its association with phonological processing. At the earlier stage, reading is reliant on letter-by-letter phonological decoding. However, with development and the emergence of orthographic skills, visual temporal processing would become increasingly important. It is possible the emerging ceiling effect in Auditory TOJ accuracy by Grade 1 resulted in it no longer accounting for significant unique variance in Grade 1 Letter Word Identification. Temporal Dot, which when measured at Preschool had accounted for unique variance in Grade 1 Reading Rate, no longer did when measured at Grade 1. Possibly this failure to account for significant independent variance arose because there was now more overlap in the variance between Temporal Dot and Auditory TOJ; all of the variance in Reading Rate shared with Temporal Dot may have overlapped with that accounted for by Auditory TOJ.

There were also changes in the pattern of prediction when the phonological processing measures were obtained at Grade 1, and were used to predict Grade 1 reading skills. All three measures accounted for unique variance in Grade 1 Letter Word Identification and Reading Rate. With all measures in the regression analysis, Phonemic Segmentation was the most important predictor of Letter Word Identification. When the predictors were obtained at Preschool, Rapid Automatised Naming was the only phonological processing measure to account for significant unique variance in Letter Word Identification. This was interpreted as reflecting the
logographic nature of reading at that point. With the Grade 1 predictors, phonological awareness skills also accounted for unique variance, reflecting development in those skills, especially in Phonological Segmentation, and the closer relationship they now had to word identification skills. Grade 1 Rapid Automatised Naming Speed and Rhyme and Alliteration detection were the most important phonological processing predictors of Reading Rate. Grade 1 Phonemic Segmentation was also the most important discriminator of the Word Attack decoding groups. This was consistent with the results obtained with the Preschool predictors.

A higher percentage of the variance accounted for in Grade 1 reading was common to the Grade 1 temporal and phonological processing measures, than was found when the Preschool predictors were used. With development, there was less independence in these predictor skills. This highlights the importance in this study of examining the predictive ability of these factors prior to school-entry before the experience of reading may affect these skills and lead to interactions between the skills that results in less independence. Most of the variance explained by the temporal processing measures could be explained by the phonological processing measures. Previous studies showed temporal processing skills were related to phonological processing skills (there is evidence of these loading on the same factor in factor analysis; Lovegrove et al., 1989), which would lead to substantial overlap in the variance in reading explained by these two sets of skills. At Grade 1, there were significant moderate zero-order correlations between auditory temporal processing and Phonemic Segmentation and Rhyme and Alliteration detection, and significant weak to moderate correlations between Temporal Dot accuracy and rapid naming speed and Phonemic Segmentation. This represented a change from Preschool, when the zero-order correlations between Auditory TOJ and all three phonological
processing measures were weaker. If auditory temporal processing were causally related to both phonological processing and to reading skills, it would be likely that variance in reading accounted for by both auditory temporal processing and phonological processing skills would overlap. The greater distinction in the variance accounted for by these two types of skills when measured at Preschool may reflect less development in each at that earlier phase, and the lack of ‘contamination’ of either by reading. As much development in phoneme awareness only occurs around school-entry, the relationship between auditory temporal processing ability and phonological processing would be expected to increase at that time compared to earlier points in development at which phonological skills are quite undeveloped.

Based on Steiger’s $z$-test, there was no significant difference between the variance accounted for in the Grade 1 reading measures by either the Grade 1 temporal or phonological processing predictors. However, this is a very conservative test, requiring a several-fold difference in the variance explained in order to achieve significance. There was a change in the percentage of variance accounted for by the Grade 1 phonological processing measures compared to the Preschool phonological processing predictors. The Grade 1 phonological predictors accounted for almost twice as much variance in Grade 1 reading as the Preschool phonological predictors had. Scarborough (1998a) argued that phonological processing skills (especially phoneme awareness that was more critical to the development of reading skills) were still immature around school entry and so relationships to later reading were modest. Similarly, the relationship to auditory temporal processing may be more modest for the same reasons and the extent to which they account for overlapping variance in reading much less when each is measured at a Preschool point. He concluded it may be better to use phonemic awareness in early Grade 1 to predict reading difficulties,
rather than using pre-school measures of rhyme awareness. The current results would support that. This highlights the importance of considering the prediction of reading within a developmental context, as recommended by Bowey (2002) and Snowling (2000).

There were significant weak to moderate correlations between all three temporal processing measures at Grade 1. Auditory TOJ and Temporal Dot did not show significant correlations when measured at Preschool. The role of other factors, like difficulty in the Temporal Dot task at Preschool, may partially explain this. By Grade 1, Rapid Automatised Naming speed was no longer significantly related to Phonemic Segmentation ability. Parilla et al. (2004) also found rapid naming speed and phonological awareness shared less common variance when measured at Grade 1 compared to kindergarten. They also found these two measures predicted later reading in more distinct ways than they predicted earlier reading. Parilla et al. interpreted this as being consistent with developmental changes in reading from a reliance on alphabetic strategies to increased use of orthographic strategies.

10.4.2 Prediction of Grade 2 Reading Skills Using Grade 1 Predictors

This group of analyses examined the ability of Grade 1 measures of temporal and phonological processing to predict variance in Grade 2 reading skills, one year later, after partialling out the effects of the control measures. There are separate analyses for each of the four Grade 2 reading measures. Again, details regarding variance accounted for by the control measures in the regression analyses are not described here because they are essentially the same as in Chapter 8, but details of those steps are presented in the relevant tables in this section.
10.4.2.1 Zero-Order Correlations

Table 10.12 presents the zero-order correlations between the control measures, the Grade 1 temporal and phonological processing predictors, and the Grade 2 reading outcomes. Significant correlations between the control measures and the Grade 2 reading measures and between the Grade 2 reading measures were described in Section 8.2.1. Significant correlations between the control measures and the Grade 1 temporal and phonological processing measures were described in Section 10.4.1.1.

Grade 2 Letter Word Identification and Word Attack showed significant weak to moderate correlations with all three Grade 1 temporal processing measures, a similar result to the relationship with Preschool temporal processing measures. The Grade 1 TOJ tasks were the only temporal processing measures that showed significant correlations with Reading Rate and Pseudohomophone Choice. At Preschool, Temporal Dot accuracy had shown significant weak correlations with those two Grade 2 reading measures. There were significant weak to moderate correlations between the three Grade 1 phonological processing measures and the four Grade 2 reading measures, consistent with the results with Preschool phonological processing measures. As there was a significant effect of school attended on all of the Grade 2 reading measures and of Speech Problems on Grade 2 Reading Rate, these were also included in those analyses (see Sections 7.6 and 7.7).

10.4.2.2 Prediction of Grade 2 Letter-Word Identification

Table 10.13 summarizes the results of the regression models. When the Grade 1 temporal processing measures were entered at Step 3, they accounted for an additional 5.10% of the variance in Letter Word Identification, but this did not represent a significant increase, $F(3, 89) = 2.29, p = .084$. When the three Grade 1 phonological
### Table 10.12

Correlations between Control Measures, Grade 1 Temporal Predictors, Grade 1 Phonological Predictors and Grade 2 Reading Outcomes

<table>
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<th></th>
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<th>ATOJcatch(^d)</th>
<th>MEM</th>
<th>MAT</th>
<th>ATOJ(^b)</th>
<th>VTOJ</th>
<th>DOT</th>
<th>RAN(^c)</th>
<th>PhonSeg</th>
<th>RhyAll</th>
<th>LetWordId</th>
<th>Attack(^d)</th>
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Note: TEACH = Parental Teaching, READ = Parental Reading, VIG = Vigilance, ATOJcatch = Auditory TOJ catch trials, MEM = Memory, MAT = Non-verbal Ability, ATOJ = Auditory TOJ, VTOJ = Visual TOJ, DOT = Temporal Dot, RAN = Rapid Automatised Naming, PhonSeg = Phonemic Segmentation, RhyAll = Rhyme and Alliteration detection, LetWordId = WDRB Letter Word Identification, Attack = WDRB Word Attack, RATE = Reading Rate, Pseudo = Pseudohomophone Choice.

\(^a\) Reflected and log transformed; \(^b\) Square root transformed; \(^c\) Log transformed; \(^d\) Categorical variable

\(* p < .05\)

\(** p < .01\)
**Table 10.13**

*Hierarchical Regression Analyses for Grade 1 Variables Predicting Grade 2 Letter Word Identification (N = 101)*

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
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<th>sr</th>
<th>p</th>
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* p < .05
processing measures were entered at Step 3, they accounted for an additional 21.70% of the variance in Grade 2 Letter Word Identification, $F(3, 89) = 13.15, p < .0001$. The squared semi-partial correlations revealed all three phonological processing measures accounted for significant independent percentages of the variance. Rhymes uniquely accounted for 8.88% of the variance. Rapid Automatised Naming uniquely accounted for 3.31%. Phonemic Segmentation uniquely accounted for 2.62% of the variance (Table 10.13). Steiger's (1980) $z$-test showed there was a trend toward the Grade 1 phonological processing predictors accounting for a greater percentage of variance in Grade 2 Letter Word Identification than the Grade 1 temporal processing predictors, but this did not reach significance, $Z^* = -1.88, p = .06$.

When entered at Step 4 (after the school, control, and Grade 1 phonological processing measures), the Grade 1 temporal processing measures accounted for a non-significant increase of less than 1.00% in the variance explained, $F(3, 86) = 0.50, p = .686$ (Table 10.13). When the Grade 1 phonological processing measures were entered last at Step 4, they accounted for an additional 17.50% of the variance, $F(3, 86) = 10.40, p < .0001$, which represented their unique contribution to the variance in Grade 2 Letter Word Identification. Rhyme and Alliteration detection uniquely accounted for 8.41% of the variance. Rapid naming speed accounted for 2.79%. These both represented significant percentages of the variance. In total, the school, control, Grade 1 temporal processing, and Grade 1 phonological processing measures accounted for 51.90% of the variance in Grade 2 Letter Word Identification. There was 4.20% of the variance accounted for in Grade 2 Letter Word Identification common to the Grade 1 temporal and phonological processing measures. When all of the measures were entered, only school attended, Rapid Automatised Naming, and
Rhyme and Alliteration detection accounted for significant unique components of variance. Based on the \( \beta \) weights, the most important predictors of Grade 2 Reading Rate were the school attended and Grade 1 Rhyme and Alliteration detection (Table 10.13).

10.4.2.3 Prediction of Grade 2 Reading Rate

See Table 10.14 for a summary of these regression analyses. Grade 1 Temporal Dot did not show a significant zero-order correlation with Grade 2 Reading Rate so was not included in these analyses. At Step 3, the \( R^2 \) change showed an additional 5.10% of the variance in Grade 2 Reading Rate was accounted for by the addition of Grade 1 Auditory and Visual TOJ, \( F(2, 89) = 3.16, p = .047 \). Only Auditory TOJ accounted for a significant unique component of that variance, accounting for 3.35%. When the three Grade 1 phonological processing measures were entered at Step 3, the \( R^2 \) change showed that an additional 27.90% of the variance in Grade 2 Reading Rate was accounted for, \( F(3, 88) = 16.75, p < .0001 \). Rapid Automatised Naming speed uniquely accounted for 9.92% of the variance and Rhyme and Alliteration detection uniquely accounted for 7.95%. Both of these were significant (Table 10.14). Around 10.00% of the variance in Grade 2 Reading Rate overlapped between the three phonological processing predictors. Significantly more variance in Grade 2 Reading Rate was accounted for at Step 3 by the Grade 1 phonological processing measures (27.90%) than by the Grade 1 temporal processing measures (5.10%), \( z^* = -2.43, p = .015 \).

When the Grade 1 Auditory and Visual TOJ measures were entered last at Step 4, they did not account for a significant additional component of variance, \( F(2, 86) = 0.33, p = .719 \). When the three Grade 1 phonological processing measures were
Table 10.14

Hierarchical Regression Analyses for Grade 1 Variables Predicting Grade 2 Reading Rate (N = 98)

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>B (SE B)</th>
<th>β</th>
<th>sr</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SCHOOL1</td>
<td>-15.80 (5.74)</td>
<td>-0.31</td>
<td>-0.26</td>
<td>.01*</td>
</tr>
<tr>
<td></td>
<td>SCHOOL2</td>
<td>-9.88 (6.04)</td>
<td>-0.20</td>
<td>-0.16</td>
<td>.105</td>
</tr>
<tr>
<td>R²</td>
<td></td>
<td></td>
<td></td>
<td>.068*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Parent Teach</td>
<td>1.39 (1.09)</td>
<td>0.12</td>
<td>0.12</td>
<td>.205</td>
</tr>
<tr>
<td></td>
<td>Vigilance</td>
<td>-18.86 (7.85)</td>
<td>-0.23</td>
<td>-0.22</td>
<td>.018*</td>
</tr>
<tr>
<td></td>
<td>ATOJcatch</td>
<td>16.76 (8.16)</td>
<td>0.19</td>
<td>0.19</td>
<td>.043*</td>
</tr>
<tr>
<td></td>
<td>Speech Prob</td>
<td>11.74 (5.86)</td>
<td>0.19</td>
<td>0.18</td>
<td>.048*</td>
</tr>
<tr>
<td>ΔR²</td>
<td></td>
<td></td>
<td></td>
<td>.164*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Auditory TOJ</td>
<td>-26.54 (12.98)</td>
<td>-0.21</td>
<td>-0.18</td>
<td>.044*</td>
</tr>
<tr>
<td></td>
<td>Visual TOJ</td>
<td>0.35 (0.44)</td>
<td>0.08</td>
<td>0.07</td>
<td>.423</td>
</tr>
<tr>
<td>ΔR²</td>
<td></td>
<td></td>
<td></td>
<td>.051*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RAN -69.65 (16.73)</td>
<td>-0.34</td>
<td>-0.33</td>
<td>&lt;.0001*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phon. Seg.</td>
<td>1.49 (1.15)</td>
<td>0.12</td>
<td>0.10</td>
<td>.198</td>
</tr>
<tr>
<td></td>
<td>Rhym/Allit</td>
<td>1.40 (0.39)</td>
<td>0.33</td>
<td>0.27</td>
<td>.001*</td>
</tr>
<tr>
<td>ΔR²</td>
<td></td>
<td></td>
<td></td>
<td>.232*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RAN -68.41 (16.17)</td>
<td>-0.34</td>
<td>-0.32</td>
<td>&lt;.0001*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phon. Seg.</td>
<td>1.74 (1.10)</td>
<td>0.13</td>
<td>0.12</td>
<td>.111</td>
</tr>
<tr>
<td></td>
<td>Rhym/Allit</td>
<td>1.46 (0.39)</td>
<td>0.34</td>
<td>0.28</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>ΔR²</td>
<td></td>
<td></td>
<td></td>
<td>.279*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Auditory TOJ</td>
<td>-9.46 (11.79)</td>
<td>-0.08</td>
<td>-0.06</td>
<td>.425</td>
</tr>
<tr>
<td></td>
<td>Visual TOJ</td>
<td>-0.12 (0.38)</td>
<td>-0.03</td>
<td>-0.02</td>
<td>.750</td>
</tr>
<tr>
<td>ΔR²</td>
<td></td>
<td></td>
<td></td>
<td>.004</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

entered last at Step 4, they accounted for an additional 23.20% of the variance in Grade 2 Reading Rate, F (3, 86) = 13.71, p < .0001. This represented their unique
contribution. Rapid naming speed made a significant unique contribution, accounting for 9.80% of the Variance in Grade 2 Reading Rate. Rhyme and Alliteration detection also uniquely accounted for 7.02% of the variance (Table 10.14). Together, all of the variables explained 51.50% of the variance in Grade 2 Reading Rate. Commonality analysis showed there was 4.70% of the variance in Grade 2 Reading Rate common to Grade 1 temporal order judgement accuracy and phonological processing skills. The $\beta$ weights indicated that the most important predictors were the school attended, Rapid Automatised Naming, and Rhyme and Alliteration detection.

10.4.2.4 Prediction of Grade 2 Word Attack

Table 10.15 summarises the regression analyses. The addition of the Grade 1 temporal processing measures at Step 3 resulted in a significant increase of 8.00% in the variance explained, $F(3, 89) = 3.38, p = .022$. The squared semi-partial correlations showed Auditory TOJ accounted for a significant independent proportion of the variance, accounting for 5.57%. Addition of the Grade 1 phonological processing measures at Step 3 resulted in a significant increase of 18.40% in the variance explained in Grade 2 Word Attack, $F(3, 89) = 9.10, p < .0001$. The squared semi-partial correlations showed Phonemic Segmentation and Rhyme and Alliteration detection accounted for significant unique proportions of the variance, accounting for 6.00% and 5.57%, respectively (Table 10.15). There was no significant difference between the variance in Grade 2 Word Attack accounted for by the Grade 1 temporal or phonological processing measures when each was entered at Step 3, $Z^* = -1.28, p = .20$.

When the Grade 1 temporal processing measures were added last at Step 4, they did not account for a significant increase in the variance explained, $R^2 = 0.02, F(3,$
Table 10.15

Hierarchical Regression Analyses for Grade 1 Variables Predicting Grade 2 Word Attack ($N = 103$)

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>B (SE B)</th>
<th>$\beta$</th>
<th>sr</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 1</td>
<td>1. SCHOOL1</td>
<td>-0.65 (0.25)</td>
<td>-0.31</td>
<td>-.26</td>
<td>.009*</td>
</tr>
<tr>
<td></td>
<td>2. SCHOOL2</td>
<td>-0.71 (0.26)</td>
<td>-0.32</td>
<td>-.27</td>
<td>.007*</td>
</tr>
<tr>
<td></td>
<td>$R^2 = .088^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td>3. Age</td>
<td>0.26 (0.36)</td>
<td>0.07</td>
<td>.07</td>
<td>.48</td>
</tr>
<tr>
<td></td>
<td>4. Parent Teach</td>
<td>0.08 (0.05)</td>
<td>0.15</td>
<td>.15</td>
<td>.116</td>
</tr>
<tr>
<td></td>
<td>5. Vigilance</td>
<td>-0.47 (0.36)</td>
<td>-0.13</td>
<td>-.12</td>
<td>.199</td>
</tr>
<tr>
<td></td>
<td>6. ATOJcatch</td>
<td>0.36 (0.38)</td>
<td>0.09</td>
<td>.09</td>
<td>.356</td>
</tr>
<tr>
<td></td>
<td>7. Memory</td>
<td>0.14 (0.07)</td>
<td>0.18</td>
<td>.17</td>
<td>.066</td>
</tr>
<tr>
<td></td>
<td>8. Nonverbal</td>
<td>0.02 (0.02)</td>
<td>0.08</td>
<td>.07</td>
<td>.426</td>
</tr>
<tr>
<td></td>
<td>$\Delta R^2 = .129^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3</td>
<td>9. Auditory TOJ</td>
<td>-1.65 (0.62)</td>
<td>-0.30</td>
<td>-.24</td>
<td>.01*</td>
</tr>
<tr>
<td></td>
<td>10. Visual TOJ</td>
<td>0.23 (0.02)</td>
<td>0.12</td>
<td>.10</td>
<td>.257</td>
</tr>
<tr>
<td></td>
<td>11. Temporal Dot</td>
<td>-0.00 (0.02)</td>
<td>-0.01</td>
<td>-.01</td>
<td>.886</td>
</tr>
<tr>
<td></td>
<td>$\Delta R^2 = .080^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 4</td>
<td>12. RAN</td>
<td>-0.78 (0.82)</td>
<td>-0.09</td>
<td>-.08</td>
<td>.345</td>
</tr>
<tr>
<td></td>
<td>13. Phon. Segment</td>
<td>0.13 (0.06)</td>
<td>0.23</td>
<td>.19</td>
<td>.023*</td>
</tr>
<tr>
<td></td>
<td>14. Rhym/Allit</td>
<td>0.05 (0.02)</td>
<td>0.27</td>
<td>.22</td>
<td>.01*</td>
</tr>
<tr>
<td></td>
<td>$\Delta R^2 = .122^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3.</td>
<td>9. RAN</td>
<td>-0.86 (0.79)</td>
<td>-0.10</td>
<td>-.09</td>
<td>.279</td>
</tr>
<tr>
<td></td>
<td>10. Phon. Segment</td>
<td>0.16 (0.05)</td>
<td>0.28</td>
<td>.25</td>
<td>.004*</td>
</tr>
<tr>
<td></td>
<td>11. Rhym/Allit</td>
<td>0.06 (0.02)</td>
<td>0.29</td>
<td>.24</td>
<td>.005*</td>
</tr>
<tr>
<td></td>
<td>$\Delta R^2 = .184^*$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 4</td>
<td>12. Auditory TOJ</td>
<td>-0.81 (0.62)</td>
<td>-0.15</td>
<td>-.11</td>
<td>.192</td>
</tr>
<tr>
<td></td>
<td>13. Visual TOJ</td>
<td>0.01 (0.02)</td>
<td>0.07</td>
<td>.06</td>
<td>.481</td>
</tr>
<tr>
<td></td>
<td>14. Temporal Dot</td>
<td>0.00 (0.02)</td>
<td>0.01</td>
<td>.01</td>
<td>.935</td>
</tr>
<tr>
<td></td>
<td>$\Delta R^2 = .019$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < .05
When the Grade 1 phonological processing variables were entered at Step 4, they accounted for an additional 12.20% of the variance in Grade 2 Word Attack, $F(3, 86) = 6.05, p = .001$. This represented their unique contribution. The squared semi-partial correlations showed Phonemic Segmentation uniquely accounted for 3.65% of the variance and Rhyme and Alliteration detection uniquely accounted for 4.67% of the variance (Table 10.15). Together, all of the measures included in the regression analysis were able to explain 42.00% of the variance in Grade 2 Word Attack. Commonality analysis revealed 6.20% of the variance explained in Grade 2 Word Attack overlapped between the Grade 1 temporal and phonological processing measures. Based on the $\beta$ weights, the most important predictors were the school attended, Rhyme and Alliteration detection, and Phonemic Segmentation.

10.4.2.5 Prediction of Grade 2 Pseudohomophone Choice Accuracy

These results are presented in Table 10.16. At Step 3, the addition of Grade 1 Auditory TOJ and Visual TOJ (Temporal Dot did not show a significant zero-order correlation with Grade 2 Pseudohomophone Choice) resulted in an additional 2.40% of the variance accounted for, but this was not a significant increase, $F(2, 92) = 1.55, p = .219$. When the three Grade 1 phonological processing measures were entered at Step 3, they accounted for an additional 10.00% in the variance explained, $F(3, 91) = 4.87, p = .003$. Only Rhyme and Alliteration detection accounted for a significant unique percentage of the variance, accounting for 6.35%. This difference in variance accounted for between the Grade 1 temporal and phonological processing predictors was not significant, $Z^* = -0.79, p = .430$. 
Table 10.16

**Hierarchical Regression Analyses for Grade 1 Variables Predicting Grade 2 Pseudohomophone Choice (N = 100)**

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>B (SE B)</th>
<th>β</th>
<th>sr</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SCHOOL1</td>
<td>-5.08 (1.48)</td>
<td>-0.39</td>
<td>-0.32</td>
<td>.001*</td>
</tr>
<tr>
<td></td>
<td>SCHOOL2</td>
<td>-5.50 (1.55)</td>
<td>-0.40</td>
<td>-0.33</td>
<td>.001*</td>
</tr>
<tr>
<td></td>
<td>R² = .139*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Parent Teach</td>
<td>0.77 (0.29)</td>
<td>0.24</td>
<td>0.24</td>
<td>.008*</td>
</tr>
<tr>
<td></td>
<td>Memory</td>
<td>1.12 (0.41)</td>
<td>0.23</td>
<td>0.24</td>
<td>.007*</td>
</tr>
<tr>
<td></td>
<td>Nonverbal</td>
<td>0.17 (0.13)</td>
<td>0.12</td>
<td>0.12</td>
<td>.177</td>
</tr>
<tr>
<td></td>
<td>ΔR² = .136*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Auditory TOJ</td>
<td>-4.24 (3.65)</td>
<td>-0.13</td>
<td>-0.10</td>
<td>.248</td>
</tr>
<tr>
<td></td>
<td>Visual TOJ</td>
<td>0.13 (0.12)</td>
<td>0.11</td>
<td>0.09</td>
<td>.289</td>
</tr>
<tr>
<td></td>
<td>ΔR² = .024</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>RAN</td>
<td>-5.14 (5.03)</td>
<td>-0.09</td>
<td>-0.09</td>
<td>.310</td>
</tr>
<tr>
<td></td>
<td>Phon. Segment.</td>
<td>0.09 (0.34)</td>
<td>0.03</td>
<td>0.02</td>
<td>.796</td>
</tr>
<tr>
<td></td>
<td>Rhym/Allit</td>
<td>0.34 (0.12)</td>
<td>0.29</td>
<td>0.24</td>
<td>.005*</td>
</tr>
<tr>
<td></td>
<td>ΔR² = .100*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>RAN</td>
<td>-5.82 (4.86)</td>
<td>-0.11</td>
<td>-0.10</td>
<td>.234</td>
</tr>
<tr>
<td></td>
<td>Phon. Segment.</td>
<td>0.14 (0.33)</td>
<td>0.04</td>
<td>0.04</td>
<td>.659</td>
</tr>
<tr>
<td></td>
<td>Rhym/Allit</td>
<td>0.35 (0.11)</td>
<td>0.30</td>
<td>0.25</td>
<td>.003*</td>
</tr>
<tr>
<td></td>
<td>ΔR² = .100*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Auditory TOJ</td>
<td>-1.18 (3.74)</td>
<td>-0.04</td>
<td>-0.03</td>
<td>.754</td>
</tr>
<tr>
<td></td>
<td>Visual TOJ</td>
<td>0.08 (0.12)</td>
<td>0.06</td>
<td>0.05</td>
<td>.53</td>
</tr>
<tr>
<td></td>
<td>ΔR² = .004</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < .05

When the two Grade 1 temporal processing variables were entered at Step 4, after all of the other variables, they did not account for additional variance, \( R^2 = .004, F(2, 89) = 0.28, p = .754 \). When the three Grade 1 phonological processing measures were entered last at Step 4, they accounted for an additional 8.10% of the variance, \( F(3, \)
Grade 1 Rhyme and Alliteration detection uniquely accounted for 5.86% of that variance. With all variables entered, 37.90% of the variance in Grade 2 Pseudohomophone Choice was accounted for. There was 1.90% of the variance commonly explained by the Grade 1 temporal and phonological processing predictors. With all measures entered, only school attended and Rhyme and Alliteration detection accounted for significant unique percentages of variance in Grade 2 Pseudohomophone Choice accuracy. \( \beta \) weights indicated that the school attended was the most important predictor of this measure of orthographic skill at Grade 2.

10.4.2.6 Discussion

The Grade 1 temporal processing measures accounted for significant additional variance in Grade 2 Reading Rate and Word Attack, with Auditory TOJ accounting for significant unique variance. Grade 1 Visual TOJ no longer accounted for unique variance in Letter Word Identification at Grade 2. The Grade 1 temporal processing measures could not account for significant additional variance in Grade 2 Letter Word Identification or Pseudohomophone Choice, over that already explained by the school attended and the control measures. Regardless of whether temporal processing was measured at Preschool or Grade 1, it could not account for unique variance in the Pseudohomophone Choice measure.

It is not clear why visual temporal processing was not related to this measure of orthographic processing, as was expected. Orthographic processing would only be emerging in Grade 2. Visual temporal processing may only become important in orthographic skills at a later point in development. Of the phonological processing measures, Grade 1 Rhyme and Alliteration detection predicted significant variance in
Grade 2 Pseudohomophone Choice. At this early point in the development of orthographic processing, children may first phonologically decode the word to determine what it is and then secondly match the visual presentation to that stored in the lexicon. This explains the relationship with phonological processing. Once orthographic skill is well developed, this initial phonological component may be reduced and disappear and visual processing may become the most important predictor, as seen in previous studies. That may only occur at older ages.

The results with the Grade 1 phonological processing measures predicting Grade 2 reading measures was very similar to that obtained using the Preschool phonological processing predictors. The Grade 1 phonological processing measures accounted for significant variance in all four Grade 2 reading measures, which was a similar result to the prediction of Grade 1 reading measures. Grade 1 Rapid Automatised Naming speed accounted for unique variance in Letter Word Identification and Reading Rate, consistent with the results at Grade 1. As discussed previously, shared variance due to automaticity of lexical access (and quality of the phonological representations associated with the lexicon) may explain these relationships. However, Grade 1 rapid naming speed accounted for a smaller percentage of variance in Grade 2 Letter Word Identification and a greater percentage of variance in Grade 2 Reading Rate, compared to prediction of these reading measures at Grade 1. This is consistent with Schatschneider et al. (2002) who found naming speed accounted for equivalent variance in word identification and fluency (reading rate) in Grade 1. However, by Grade 2, naming speed was more highly predictive of fluency than of other reading sub-skills.

Grade 1 Rhyme and Alliteration detection emerged as an important predictor of all four reading measures at Grade 2. Phonemic Segmentation accounted for unique
variance in Letter Word Identification and Word Attack, being a particularly important predictor of Word Attack. This makes sense as non-word decoding relies heavily on the ability to manipulate phonological segments. This finding is similar to Manis et al. (1999), who found Grade 1 Rapid Automatised Naming speed (digits and letters) accounted for significant unique variance in Grade 2 Word Identification, but sound deletion (like the current Phonemic Segmentation task) accounted for a greater percentage of unique variance in Grade 2 Word Attack than Rapid Automatised Naming did.

However, Manis et al.’s (1999) results differed to the present study for Grade 2 Pseudohomophone choice. They found Grade 1 Rapid Automatised Naming accounted for significant unique variance in Grade 2 Pseudohomophone Choice, whereas Grade 1 sound deletion did not. This makes sense because this task relies more on lexical access, which is involved in Rapid Automatised Naming, than on phonological skills. However, as already discussed the current study found only Grade 1 Rhyme and Alliteration detection accounted for unique variance in Grade 2 Pseudohomophone Choice. The difference between this study and that of Manis et al. may be due to differences in the control measures used. Manis et al. controlled for the effect of vocabulary. The current study used a wider range of controls (school attended, Parental Teaching, Memory, and Non-verbal Ability), but did not include vocabulary. In general, there were few significant results found in the current study in the prediction of Grade 2 Pseudohomophone Choice.

There was a trend for the phonological processing measures to account for more variance than the temporal processing measures in Letter Word Identification and this difference reached significance for Reading Rate. However, as mentioned previously, it was quite difficult to achieve a significant difference using Steiger’s test. Even with
around three times the variance being accounted for by the phonological processing measures compared to the temporal processing measures, the \( z \) score failed to reach significance. The consistent pattern with the Grade 1 predictors was for the phonological processing measures to account for a greater percentage of variance in the reading measures than the temporal processing measures did. The other consistent pattern was for the variance accounted for in both Grade 1 and Grade 2 reading measures by the Grade 1 temporal processing measures to be subsumed by the variance accounted for by the Grade 1 phonological processing measures, confirming that the relationship between these two sets of predictors and reading becomes less independent with development.

In contrast to the increasing variance in reading accounted for by phonological processing predictors measured after school-entry than before, there was little change in the percentage of variance accounted for in reading measures by the temporal processing measures regardless of when they were obtained. This difference most likely reflects a reciprocal relationship between reading development and phonological processing development that does not appear to be occurring between reading development and temporal processing. As reading develops in this early period of schooling, phonological processing skills are further enhanced, and there is a greater percentage of shared variance between reading and phonological processing. These results would support obtaining phonological processing skills after school entry rather than before school entry, because the later measures are able to account for more variance in all reading measures than the Preschool measures. This is consistent with the Scarborough’s (1998a) position, and with what is known about normal development in phonological processing skills. However, as there was little difference in the amount of variance explained in reading either by temporal
processing obtained before or after school-entry, timing of measurement was less important. However, what did change were the specific temporal predictors that accounted for unique variance. Visual temporal processing was more likely to be significantly related to reading if temporal processing measures were obtained after school entry (or if later reading abilities were being predicted as shown in Chapter 8). There was a consistent significant relationship between auditory temporal processing and reading, although, this was slightly more likely if the temporal processing measures were obtained before school entry (or if earlier reading abilities were being predicted as shown in Chapter 8). This would be consistent with developmental changes in the nature of reading over this early childhood period.
CHAPTER 11: CONCLUSIONS

This study examined the ability of measures of rapid sequential processing, one form of temporal processing, to account for variance in reading skills in beginner readers. It supports and extends the longitudinal findings of Lovegrove et al. (1986) who showed a relationship between pre-school magnocellular function and subsequent reading development. The auditory and visual temporal processing accuracy obtained at Preschool accounted for significant variance in various measures of reading skill in the first two years of school, even after the effects of age, early home environment, memory, attentional vigilance, nonverbal ability, school attended, and speech/language problems were controlled. Therefore, the covariation between temporal processing and reading skills found in older children and adolescents (Cornelissen et al., 1998; Marshall, et al., 2001; Olson & Datta, 2002; Talcott et al., 2000, 2002) was present from the beginning of reading. In fact, differences in auditory temporal processing abilities that covary with differences in reading ability were present before the emergence of reading, evident by the relationship found with pre-reading letter naming skill at Preschool. This is consistent with the hypothesis that neurological impairments that underlie the temporal processing deficits are present from a very early point in development, probably occurring in utero (Galaburda et al., 1985; Stein, 2001a). Visual temporal processing only began to predict significant percentages of variance in reading in the later phases, consistent with developmental changes taking place in the reading process.

Stein and Walsh (1997) argued that the sort of M pathway deficits found in dyslexia were quite mild. However, slight impairments in lower levels of the M pathway (e.g., LGN) may add up to greater deficits in the posterior parietal cortex, to
which the M pathway projects. The posterior parietal cortex is involved in eye-movement control, visuo-spatial attention, and peripheral vision, all of which are relevant to reading. These sorts of processes are important in the Visual TOJ and Temporal Dot tasks, as well as the Rapid Automatised Naming task, used in this study. There is evidence the M system is involved in directing automatic attention (Steinman, Steinman, & Lehmkuhle, 1997). Kinsey, Rose, Hansen, Richardson, and Stein (2004) demonstrated a relationship between visual attentional processing and reading, which was independent of age and intellectual ability. This relationship was stronger between visual attentional processing and non-word reading (phonological processing) than between visual attentional processing and irregular word reading (orthographic processing). This may partially explain the current study’s failure to find a relationship between the visual temporal processing measures and the Pseudohomophone Choice task. 

Hari and Renvall (2001) hypothesised that mild impairment at the level of the parietal cortex would impair attentional shifting across a range of sensory modalities. Conlon et al. (2004) argued that the temporal dot task might involve an initial sensory stage, followed by an attentional component that was either an M system function or part of a higher-level mechanism. Models of temporal order judgement also refer to the role of attentional shifting in making correct judgements (Ulrich, 1987). The model of rapid naming speed proposed by Wolf and colleagues (Wolf & Bowers, 1999; Wolf et al., 2000) also incorporated an attentional component. Thus the resultant sluggish attentional shifting would explain difficulties in reading, as well as in the rapid sequential temporal processing and rapid object naming measures used in the current study; producing the obtained predictive relationships between reading and these predictor measures.
The study also examined whether auditory and visual temporal processing abilities showed different relationships to reading. The auditory and visual temporal processing measures accounted for independent variance in many of the reading measures, despite the fact that there were significant moderate correlations between the temporal processing measures. This showed that performance on the visual and auditory temporal processing was related to different components of early reading. This was interpreted within a developmental context. Based on developmental models of early reading development, it was considered possible that auditory temporal processing would be more important in the earlier phases of reading emergence, and that visual temporal processing would become more important as reading developed. Unique variance in Preschool and Grade 1 pre-reading and reading skills was accounted for by Auditory TOJ performance at both Preschool and at Grade 1. Preschool measures of visual temporal processing did not account for independent variance in Preschool letter identification. Preschool Temporal Dot accuracy only began to independently account for a significant percentage of the variance in reading skills at Grades 1 and 2. However, when Temporal Dot was measured at Grade 1, it no longer accounted for significant unique variance in the reading measures. It is possible the increased overlap in variance between Auditory TOJ (which consistently predicted unique variance in reading) and Temporal Dot at Grade 1 explained this null result. Only when it was measured at Grade 1 did Visual TOJ accuracy account for significant components of variance in Grade 1 reading. This was most likely a result of the rapid development in performance on this task from Preschool to Grade 1 as well as the development occurring in the nature of reading over that period. Further follow-up of this sample is required to determine the
ongoing contribution of visual versus auditory temporal processing as reading develops further.

The results were consistent with hypotheses based on models of reading development. Phonological skills are initially important in reading, and orthographic skills become increasingly important with development. Ellis and Large (1988) found the nature of reading changed over the first three years of schooling, such that, after the initial period, reading involved correspondence between auditory and visual patterns and analysis of visual patterns. Previous research found significant relationships between auditory temporal processing and phonological skill, and between visual temporal processing and orthographic skill (Cornelissen et al., 1998; Talcott et al., 2000). However, using a larger same-age normative sample, Talcott et al. (2002) failed to obtain this separation. This is more consistent with the current study in which the only measures that accounted for significant independent variance in Grade 2 orthographic skill were Preschool and Grade 1 rhyme (and alliteration) detection.

Auditory temporal processing is predicted to be important in early speech perception and the formation of phonemic representations. This is important for the development of phonological processing and, subsequently, for reading development (Benasich & Tallal, 2002; Tallal, 1980). In the current study, when auditory temporal processing was measured at Preschool, it accounted for a significant small percentage of additional variance in early reading over that explained by phonological processing. Perhaps differences in speech perception and other verbal abilities (not measured in the current study) accounted for this additional relationship. However, when auditory temporal processing was measured at Grade 1, it did not account for any additional variance over that explained by the phonological processing measures.
While there were some concerns with ceiling effects in this auditory measure by Grade 1 that may have resulted in a restriction in the variance it accounted for, these results are consistent with auditory temporal processing being important for early phonological processing, which in turn is important in reading skill. With development in phonological processing around school-entry, the overlap between the variance in reading accounted for by auditory and phonological processing increased.

Visual temporal processing is predicted to be important in letter position encoding, global word form perception, binocular stability, and effective saccadic eye movements. Efficiency in these processes is important for effective reading (Habib, 2000; Stein & Talcott, 1999). However, this is probably only true after children systematically begin to analyse letters or orthographic units in words or to recognise words automatically as visual wholes. In other words, visual temporal processing is likely to be important in reading at a slightly later point in development than auditory temporal processing. The current results supported this, although the results with the visual temporal processing measures were less clear than were those obtained with the auditory temporal processing measure.

Based on these different hypothesised roles in the reading process, auditory temporal processing was expected to be more strongly related to non-word reading, which involves phonological decoding. This was supported. Preschool and Grade 1 measures of Auditory TOJ were important variables in discriminating between the children’s ability to decode non-words (Word Attack) at Grade 1, and accounted for significant unique variance in non-word reading at Grade 2. However, Preschool Temporal Dot accuracy also accounted for significant unique variance in Grade 2 non-word reading and Grade 1 Visual TOJ was important in Grade 1 non-word reading. This may reflect the importance of sequential analysis of letters that is
essential for the grapheme-phoneme conversion process. In this way, visual temporal sequencing ability may be important in the decoding of non-words.

Regardless of when the temporal processing measures were obtained (Preschool or Grade 1), neither measures of auditory or visual temporal processing accounted for significant unique variance in orthographic processing skill at Grade 2 (Pseudohomophone Choice), after the variance due to the control measures was accounted for. However, there was some evidence of weak trends toward the Preschool Temporal Dot task accounting for independent variance in orthographic processing ($p = .058$; see Table 8.14). Thus, there was no evidence to support a relationship between temporal processing and orthographic processing as measured by the Pseudohomophone Choice task that could not be explained by the control measures included. Nor was there much evidence for a relationship between phonological processing and this measure of orthographic processing. Only Rhymes at Preschool and Grade 1 accounted for significant independent variance in Pseudohomophone Choice.

One explanation is that orthographic skill was still quite undeveloped in children of this age, although there did not appear to be floor effects on the measure used; on average, performance was above chance level. The task used in the current study was modified from one developed for older children by Olson et al. (1994), and this modification may have rendered it less sensitive in some way than the original task. It may be that this measure is not useful for assessing orthographic skill in these young children and is measuring some other construct such as memory or prior exposure to words. Consistent with this, Parental Teaching and Memory both accounted for unique variance in this measure. Vellutino, Scanlon, and Chen (1995) argued that this task does not assess orthographic processing but is simply a measure of word
identification or spelling knowledge. However, if that were true, variance in this measure should be explained by similar predictors to that in Letter Word Identification. That was not observed. It is likely that at this early point in reading development, the aspects of orthographic processing that are measured by the Pseudohomophone task are only just emerging, and the significant predictors are different to those observed for this measure in samples of older children, for whom the skill has become automatised. Another possible reason the results with the present study differed from those of Cornelissen et al. (1998) and Talcott et al. (2000) is that they used measures of dynamic change and the current study focused on sequential temporal processing. The current study also controlled for a wider range of factors than those previous studies had, making it more difficult to account for additional variance. Other studies with older samples did not show a selective relationship between measures of the magnocellular system and orthographic skill (Kinsey et al., 2004; Talcott et al., 2002), and the current results may reflect that. Further work, following the sample as reading and orthographic skill develops further, may clarify this relationship.

This study also found developmental changes in the pattern of prediction with phonological processing. While there were no significant differences between the temporal and phonological processing measures in the amount of variance accounted for in reading skills when these predictors were measured at Preschool, when they were measured at Grade 1, the phonological processing measures accounted for increased percentages of variance.

Different phonological processing measures were important in accounting for variance in different reading measures, and at different phases in the development of reading. Rapid Automatised Naming was more important in predicting Letter Word
Identification at Preschool and Grade 1, and Reading Rate at Grade 2. This was consistent with the increasing role of rapid naming in fluency reported by Schatschneider et al. (2002). Phonological awareness, especially Phonemic Segmentation accuracy, was more important in predicting Word Attack, as would be expected given Word Attack relies on phonological decoding. Rhymes was the only predictor (apart from the control measures) that accounted for significant independent variance in Pseudohomophone Choice. Phonemic Segmentation and Rhyme and Alliteration detection accounted for more variance when measured at Grade 1 than at Preschool. This is consistent with development in phonological processing, in which phonemic segmentation is last to develop and most critical to more mature reading. However, Rhyme and Alliteration detection showed ceiling effects by Grade 2, consistent with previous studies (Nation & Hulme, 1997; Stanovich et al., 1984; Treiman & Zukowski, 1991). Thus, by Grade 2, Rhyme and Alliteration would be a less useful measure for predicting reading than the other phonological measures. This again confirms the need to consider developmental factors when selecting phonological predictors of reading ability. Measures of both rhyme and alliteration awareness and phonemic segmentation were included to account for these known developmental changes. The results support the arguments of Scarborough (1998a) and Bowey (2002) that phonemic awareness measured after school entry may be a better predictor of reading than rhyme awareness measured prior to school entry.

Similar developmental considerations most likely are important in the choice of temporal processing measures also. By contrast to the phonological processing measures, which have been extensively studied in many longitudinal predictive studies, there is little existing research on the relationship between temporal processing measures and beginning reading. Therefore, little is known about the type
of temporal processing measure or specific parameters that are most sensitive for use with this age range. The Auditory TOJ measure was chosen because it was suitable for use at the earlier phases; however, ceiling effects became problematic in the final phase. Using this measure at Grade 2 to predict reading ability would most likely produce a null result due to this developmental artefact. No studies have used visual temporal processing measures with this age range before. The parameters used for the Temporal Dot and Visual TOJ tasks were based on those used with older samples (Conlon et al., 2004; Reed, 1989, respectively). Further testing with younger samples is needed to fine-tune the sensitivity of these tasks. Stimulus durations and ISIs may need to be longer to accommodate the less developed temporal processing skills of younger children. Measures of ability to detect dynamic visual stimuli, such as coherent motion detection, may also prove useful in this younger age group, because global motion detection improves after 4 years of age (Braddick et al., 2003). However, like Temporal Dot and Visual TOJ performance, there is evidence that coherent motion detection only reaches maturity between 7 and 12 years of age (Booth et al., 2000; Cornelissen et al., 1995; May et al., 1988; Raymond & Sorensen, 1998). Therefore, careful consideration of the appropriate parameters and response formats for this younger age group would be required. Good longitudinal measures need to be not only developmentally appropriate at the earliest phase, but also to remain useful, or adaptable, over the period of the study.

The Preschool temporal and phonological processing measures generally accounted for independent components of variance in early reading skills. There was little variance in early reading common to these two sets of predictors. Thus, rapid sequential perception plays an independent role to phonological processing in early reading abilities. It is concluded that utilising both Preschool temporal and
phonological processing measures improves the prediction of early reading ability over that using just phonological processing measures. However, with development, there was increasing overlap in the variance accounted for by the two sets of predictors. When the predictors were obtained at Grade 1, the temporal processing measures no longer accounted for a significant percentage of additional variance in reading, after the variance due to the control measures and the phonological processing measures were already accounted for. The phonological processing measures were still able to account for additional unique variance after temporal processing abilities were accounted for. There was still a slight advantage in including both sets of predictors.

The significant linear relationships found between temporal and phonological processing abilities and reading ability support the idea that these are continuously distributed variables, which covary in the normal population. Gilger and Kaplan (2001) argued that dyslexia might be a manifestation of normal variability in the brain. A faulty gene that affects neurodevelopment is likely to affect multiple areas to varying degrees. Cestnick and Coltheart (1999) concluded that magno- cells, by virtue of their size, are more vulnerable to environmental insult, including prenatal immunological attack. Thus, it is likely there would be varying degrees of M pathway function in the population as a result of a combination of environmental influences and possibly due to normally distributed familial risk. This is consistent with continuously distributed temporal processing abilities. Therefore, it makes sense to examine the relationships between temporal and phonological processing and reading using a normative sample. This approach avoids many of the methodological issues associated with between-groups designs.
The longitudinal prospective design used also had advantages over previous studies that used older samples and cross-sectional designs. Using non-readers at the initial phase controlled for the autoregressive effects of previous reading ability, which Rack et al. (1993) argued is essential if causal links to reading are to be established. The current study was also important because it is the only study to date to provide a measure of the covariation between both auditory and visual perceptual abilities and reading, before any effects of reading failure or reading remediation had occurred. Successful remediation may obscure the expected relationships between reading and temporal processing in older readers because reading scores are elevated to normal levels or at least to a level above what would be attained without remediation (e.g., see Ahissar et al., 2000). It had also been suggested that the temporal processing deficits previously found in older dyslexic readers could be a result of, rather than a cause of, the reading failure (Ramus, 2004). As pre-existing differences in temporal processing were related to later differences in reading it is now clear that reading failure is not the cause of temporal processing deficits. Nor was the pattern of results consistent with a reciprocal relationship between reading and temporal processing, although it was consistent with a reciprocal relationship between reading and phonological processing as previously found (Wagner et al., 1994). Longer-term follow-up of the sample will further clarify the extent to which reading affects temporal processing abilities.

One of the strengths of the current study was that it controlled for a wide range of potentially confounding factors. There is a concern when studies fail to control for potentially confounding variables, but it could be argued that there is also a problem with over-control. Inclusion of too many control variables can reduce power if sample sizes are small to medium, leading to null results. It can also result in
important variance in reading that is shared with the focal predictors being already accounted for by the control measures, also leading to null results for the focal predictors. The current study could be viewed as erring on the side of over-control. This was deliberate in order to ensure that any relationships found between early temporal processing and reading could not be explained by potentially confounding factors, such as intelligence, memory, attention, and speech and language problems. The strength of the results is that the temporal processing measures could still account for a significant percentage of variance in reading, after the effects of all of these control measures were considered. In some cases, null results or results that differed from previous studies may be explained by the inclusion of a larger range of control measures than previously used in a single study. Verbal ability was deliberately not included as a control measure due to the strong relationship between it and reading ability and phonological processing skill, and auditory temporal processing (Snowling, 2000). Partitioning out that variance would have effectively removed variance that was of focal interest in the study.

Some previous studies concluded that the poorer performance on temporal processing tasks found in dyslexia was due to impaired attentional vigilance rather than to an underlying perceptual or neurological deficit (Davis, et al., 2001; Stuart, et al., 2001). The data presented here demonstrated that a significant relationship between temporal processing and reading remained after the variance due to Attentional Vigilance was accounted for. Furthermore, Attentional Vigilance only began to account for unique variance in reading measures at Grade 2. It is important that future studies control for the effects of attentional vigilance; however, it cannot explain the relationship between temporal processing and beginning reading in a normative sample.
Previous research also found the relationship between auditory TOJ performance and reading was mediated by the presence of language impairments (Heath, et al., 1999; Stark, et al., 1988; Tallal & Stark, 1982). Inclusion of the speech/language problem variable in the regression analyses showed it accounted for a small but significant percentage of unique variance in reading fluency (Reading Rate), but that it did not affect performance on the other reading measures. Furthermore, while the reported presence of speech and language problems affected reading fluency at Grades 1 and 2, it did not affect the rate of growth in this measure from Grade 1 to 2. This also supported the interpretation that the effect on Reading Rate was related to articulation rate, which did not influence the rate at which the sight word vocabulary developed during the early years of schooling. Importantly, there were no differences between the groups with and without speech and language problems on auditory temporal processing. In addition, auditory temporal processing still explained a significant amount of variance in Reading Rate after the variance due to speech/language problems was accounted for.

This study used parental report of speech/language problems, which is a coarse, subjective indicator. There was objective evidence of a problem for those few participants who were receiving speech therapy. Other studies have used objective criteria or test scores to define speech and language groups, which could explain the differing results. However, the focus of the current study was on a normative sample with as much control as possible, and not on selected groups. In this normative design, the presence of speech/language problems cannot explain the relationship between temporal processing and reading. The potential mediating role of articulation rate in the relationship between speech and language ability and reading fluency requires further investigation.
School attended was a very important predictor of early reading ability. This school effect was not related to differences in phonological processing, as the school that had the highest mean score on phonological processing was not the school that showed the highest mean reading scores. This group effect on reading ability could be due to differences in the way reading was taught or the time and importance given to reading activities between schools. There were some differences between schools in class structure, with one school having multi-age Grade 1 and 2 combined classes, and the other two schools having single Grade 1 classes. That same school also had some double classes with two teachers, as well as single classes with two part-time teachers sharing the teaching over the week. Possibly these sort of organisational factors affected the reading skills of the children. Share et al. (2002) argued that peer interactions result in higher intra-class correlations within the same school or class groups, compared to intercorrelations between schools or class groups.

Not only did school predict a significant percentage of variance in reading ability at each phase in primary school, it also predicted significant variance in the growth rate in reading scores. The school effect did not appear to be due to factors associated with the home environments of children attending the school. Indeed, home environment, specifically the frequency with which parents taught children reading and writing skills, was an important predictor of variance in pre-reading skill at Preschool and in Grade 1 reading skills, but the school environment became increasingly important as time at school increased. This is consistent with Vellutino et al.’s (2004) argument that for many children who appear to be at risk for reading difficulty at school-entry, the enriched school environmental experiences often result in them no longer showing risk factors within a year or so. There are other possible explanations for the school differences, such as socio-economic differences between
families at the schools. This was not measured in the current study. However, all three school communities generally consisted of low to middle class families, with no obvious differences between schools.

Another aim of the study was to examine development and stability in the temporal processing measures during this period of development. There was significant linear development in all three temporal processing measures from Preschool to Grade 2. By Grade 2, there was a ceiling effect in Auditory TOJ performance, with over half of the sample showing 100% accuracy. One of the difficulties with longitudinal research is selecting measures that are not too difficult in the initial phases, yet not too easy in the final phases. This measure was too easy for the majority of children by Grade 2. This ceiling effect very likely began to affect the relationship between the Grade 1 Auditory TOJ measure and the reading measures. There were no ceiling problems with the visual measures.

Reliability and stability of performance on the temporal processing measures was moderate over the 6- to 8-month period from Preschool to Grade 1, and over the 12-month period from Grade 1 to Grade 2. The reliability and stability were weaker, as would be expected, over the 18-month period from Preschool to Grade 2. Reliability of the phonological processing and Letter Word Identification measures was consistent with previous studies, suggesting these results are valid. Only one previous study examined test-retest reliability for a measure of M pathway function, visible persistence (Lovegrove & Slaghuis, 1989). However, that study had methodological flaws, and only looked at reliability over the shorter term from 1 week to 3 months. The current study provides the first data on reliability in measures of rapid visual sequencing over an extended period. With younger children, test-retest
reliability over long intervals (6 to 18 months) would be affected by normal development in temporal processing.

There was moderate consistency in the children’s relative positions in the distributions from Preschool to Grade 1. There was individual variation in development in these skills. The majority of children in the lowest quartile on temporal processing at Preschool, the "poor temporal processors", remained in the lowest quartile at Grade 1. Over half of those poor Preschool temporal processors remained in the lowest half of the distribution on temporal processing at Grade 2. Similar stability was observed for the children performing in the highest quartile on temporal processing at Preschool, the “good temporal processors”. Thus, temporal processing ability is quite stable for most children from Preschool to Grade 2. This supports the suitability of Preschool measures of temporal processing for use as screening measures. Similar stability was shown on the phonological processing, Memory, and Letter Word Identification measures. However, there were individual differences in developmental rates in these skills. For example, up to 10 to 15% of children moved from the lowest Preschool quartile to the highest Grade 1 quartile, or from the highest Preschool quartile to the lowest Grade 1 quartile. Some of this may be attributable to a regression to the mean effect on the measure. However, some children may have experienced what must amount to greater than average development in these skills, moving into a higher quartile by Grade 1. Other children experienced slower than average development and effectively moved backwards in the distribution (i.e., they fell into a lower quartile at a later phase than at an earlier phase). Children who are initially poor temporal or phonological processors but who catch up on those skills in the early grades of primary school may not experience any
long-term reading difficulties. Children who remain poor on these skills may be those who are at higher risk for long-term reading difficulties.

Despite the moderate stability on phonological processing, the results showed more variance was explained in reading when the measures were taken at Grade 1 than earlier. There was no substantial change in the variance explained in reading measures with the temporal processing measures, although there were changes in which measures accounted for unique variance. The issue is the trade-off between earlier prediction of reading in order to instigate earlier intervention for children deemed at risk for difficulties and waiting in order to achieve better prediction. Some of the children deemed at risk by Preschool measures are likely to improve on the predictor measures over the next two years. This may be a result of natural development, the influence of school experiences, or some combination of both. Targeting those children for early intervention would represent a misuse of limited funds. These children would be false positives on early screening instruments using these predictors. Others would be false negatives, who initially performed well on the predictors, and would not be deemed at risk, but who showed poorer performance on the predictors at a slightly later point in time and who would then be deemed at risk.

Future research needs to determine ways of identifying those children who do improve on temporal and phonological processing during this early childhood period versus those who do not. The long-term risk for reading difficulties may be more serious for those who do not improve. It is also unclear at present whether the children who do improve on these predictors in early childhood differ significantly in reading ability or in the rate of growth in reading ability from those whose performance does not improve. Ongoing results from this study will begin to answer these questions. Factors that lead to improvement in temporal processing may also
represent potential targets for new early intervention programs. Improving temporal processing skills may then lead to improved subsequent reading, as has been found with intervention to improve early phonological processing skills.

These results provide a solid argument for the increased use of cognitive and perceptual indicators in the prediction of reading ability. They also support the use of cognitive and perceptual factors in the definition or diagnosis of reading disability. An added advantage of using these indicators is that they can be measured before the emergence of reading. In this study, non-verbal intelligence showed at best weak relationships with the reading measures, but more often no significant relationship. This is consistent with previous studies (Scarborough, 1998a), and provides more evidence against sole reliance on an IQ discrepancy definition for diagnosis of dyslexia. In contrast, the temporal and phonological processing measures showed moderate relationships with reading that remained significant when variance due to a range of factors was partialled out.

The current study provided much needed evidence of a potentially causal role for temporal processing in reading development. This strengthens the temporal processing deficit hypothesis. The results showed that perceptual deficit or multi-factor hypotheses (Fletcher et al., 2002; Laasonen et al., 2001; Lundberg, 1999) provide a better model within which to consider reading development and dyslexia than a centralist hypothesis that postulates a single central causal deficit. Preschool temporal processing measures, especially auditory temporal processing, predicted as much variance in early reading ability as the Preschool phonological processing measures. Poorer temporal processing ability prior to reading was significantly related to poorer subsequent reading ability, and was independent of the relationship between phonological processing skill and reading, at least at Preschool and Grade 1.
However, this study also demonstrated that phonological processing deficits are consistently strong predictors of early reading and become increasingly good predictors with development, possibly due to their reciprocal relationship with reading. Initially, they do not account for more variance in reading than temporal processing measures, but over time, they do. The perceptual and multi-factor hypotheses are able to accommodate the more distal causal relationships between temporal processing and reading while still acknowledging the stronger proximal causal relationship between phonological processing and reading.

This study represented an initial exploration of the role of early temporal processing in reading. It attempted to incorporate a wide range of measures to examine relationships between different temporal and phonological processing measures and different reading skills, while controlling for a wide range of other factors. Factors were drawn from multi-level models (Fletcher et al., 2002; Lundberg, 1999). Results demonstrated the importance of accounting for the role of environmental factors, particularly the frequency with which parents teach literacy skills to children and the effect of the school attended. While other cognitive factors such as attentional vigilance and speech and language problems could not explain the relationship between temporal processing and reading, the results indicate they should be controlled. Some other cognitive factors like memory and non-verbal IQ were important in the prediction of some reading measures at some of the phases. This study did not take into account the psycho-emotional factors, but it is important that future research examines the role these factors play.

It is possible that some null results were due to low power caused by a medium size sample and the large number of variables included. The temporal processing effects on reading are widely regarded as small, and so a larger sample size resulting
in greater power may have lead to some of the marginally non-significant results achieving significance. This may have been a particular issue with prediction of Grade 2 reading, because of the smaller sample due to attrition over the time of the study. Repetition of this study with a larger sample is certainly warranted.

Future research examining a wider range of temporal processing measures, including those that measure perception of dynamic auditory and visual stimuli, is also needed. However, any future research must be conducted within a developmental framework as this study has clearly demonstrated that the best predictors of reading, both temporal and phonological, change with development. Difficulties with floor and ceiling effects are also an important developmental consideration. Further fine-tuning of temporal processing measures to suit the developmental level of Preschool-aged children is necessary to provide a valuable additional predictor of early reading development and risk.
References


Braddick, O., Atkinson, J., & Wattam-Bell, J. (2003). Normal and anomalous development of visual motion processing: motion coherence and 'dorsal-
stream vulnerability'. *Neuropsychologia, 41*, 1769 – 1784.


Breier, J. I., Panagiotis, G. S., Fletcher, J. M., Castillo, E. M., Zhang, W., &


Reviews, 36, 96 – 107.


Temporal Processing and Early Reading


York Academy of Sciences.


Fletcher, J. M., Foorman, B. R., Boudousque, A., Barnes, M. A., Schatschneider,


Goswami, U. (1986). Children’s use of analogy in learning to read: A


1015.


*Mapping Literacy Achievement: Results of the 1996 National School English*
Literacy Survey (1997). Canberra: DEETYA.


Share, D., Jorm, A., MacLean, R., & Matthews, R. (2002). Temporal processing and...


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decoding skills of impaired and normal readers. *Journal of Cognitive Neuroscience, 14* (6), 866 – 874.


Developmental dyslexia in different languages: Language-specific or universal.

Appendix A- Parent Questionnaire

Dear parent

Thank you for allowing your child to take part in the Early Reading Achievement research project. We need to know some details about your child’s normal activities and their early development. All details are completely confidential and anonymous—neither your name nor your child’s name will appear on this form and the details will not be forwarded to any other persons without your express permission.

Most of these questions simply require you to tick a box or circle a number. Occasionally you may be asked to write in some more details.

When complete, please place the questionnaire in the envelope provided and seal the envelope. Return this with your child to pre-school as soon as possible.

If you have any problems completing this or if you need some help please contact Michelle Hood on 55 94 8119. Thank you for your time.

1. In a typical week, how often do you, or other members of the family, read to your child?

   At bedtime:  
   - never
   - Once
   - 2 times
   - 3 times
   - 4 times
   - 5 times
   - 6 times
   - 7 times

   At other times:  
   - never
   - Once
   - 2 times
   - 3 times
   - 4 times
   - 5 times
   - 6 times
   - 7 times
   - more often. How often? __________________________

2. How many children are there in the household? __________________________
3. Please estimate the number of children’s books available in your household?

- none
- 1 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- 41 - 50
- more than 51 books. About how many? ______________

4. When being read a story, how interested does your child appear to be?

- Not interested at all
- Slightly interested
- Quite interested
- Very interested
- Don’t know

5. Please indicate how often, on average, your child would normally engage in the following activities. Please circle the appropriate number, where 1 means *daily* and 6 means *never*.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Daily</th>
<th>Weekly</th>
<th>Fortnightly</th>
<th>Monthly</th>
<th>Less than Monthly</th>
<th>Never Monthly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go to park</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Go to Library</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Go to playgroup</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Watch television</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Watch a video</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Play with toys</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Play electronic games (e.g., Nintendo)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>
6. Has your child ever used a computer?

[ ] No  [ ] Yes

If yes, how well can your child use a mouse?

[ ] Not at all  [ ] Very limited ability  [ ] Quite well  [ ] Very well

7. In a typical week, how often do you, or another family member, engage in the following activities? Please circle a number from 1 – 5 where 1 means never and 5 means very often.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Very often</th>
</tr>
</thead>
<tbody>
<tr>
<td>the alphabet letters</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>how to write own name</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>how to read words</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>how to tie shoelaces</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>how to catch a ball</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>how to use scissors</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>how to dress themselves</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

8. Has any one in your family experienced difficulties with reading or spelling?

[ ] No  [ ] Yes. Please give details of who and what the difficulty was (e.g., father has difficulty with reading)

__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________

9. What is the main language spoken in your home?

[ ] English

[ ] Other. What language? ___________________________
10. Does your child speak any language(s) other than English?
   - [ ] No
   - [ ] Yes. Please specify: _____________________________

11. Has your child ever experienced any serious illness or injury?
   - [ ] No
   - [ ] Yes. Please give details:
     __________________________________________________________
     __________________________________________________________
     __________________________________________________________
     __________________________________________________________

12. Did you experience any problems during the pregnancy or birth of this child?
   - [ ] No
   - [ ] Yes. Please give details:
     __________________________________________________________
     __________________________________________________________
     __________________________________________________________
     __________________________________________________________

13. How much, approximately, did your child weigh at birth? ____________

14. At what age, approximately, did your child say their first real words?
   __________________________________________________________

15. Is there anything unusual about the development of your child’s speech (e.g. can others understand what the child is saying, does the child have trouble with some sounds, etc.)?
   - [ ] No
   - [ ] Yes. Please give details:
     __________________________________________________________
     __________________________________________________________
16. Have you ever noticed that your child does not appear to hear what is being said to them—beyond the usual absorption of children in their play or a TV show?

[ ] No
[ ] Yes

17. Has your child experienced repeated ear infections, or had grommets or tubes inserted in their ear(s)?

[ ] No
[ ] Yes

18. Does your child seem to get confused about following instructions, for example, when playing a game?

[ ] No
[ ] Yes

19. Have you ever had any concerns about your child’s eyesight?

[ ] No
[ ] Yes

If yes, has your child’s eyesight been tested? Please give details:

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
20. Below is a list of children’s book titles. Please tick all of the ones that you can remember your child having had read to them.

[ ] Mike Mulligan and His Steam Shovel
[ ] Corduroy
[ ] Are You My Father? *
[ ] Winnie the Pooh
[ ] Possum Magic
[ ] Postman Pat at the Beach *
[ ] Old Fox *
[ ] Tooth Fairy
[ ] Hello Morning, Hello Day *
[ ] The Very Hungry Caterpillar
[ ] Are you my Mother?
[ ] The Velveteen Rabbit
[ ] The Cat in the Hat
[ ] Green Eggs and Ham
[ ] Dairy Wood *
[ ] Koala Lou
[ ] Where’s Spot?
[ ] The Complete Adventures of Blinky Bill
[ ] The Very Naughty Fairy *
[ ] Hairy MacLary from Donaldson’s Dairy
[ ] Elephant Magic *
[ ] Where the Wild Things Are
[ ] Thomas the Tank Engine’s White Christmas *
[ ] Who Sank the Boat?
[ ] Harry the Dirty Dog
[ ] We’re Going on a Bear Hunt
[ ] Saggy Baggy Elephant
[ ] Just Me and My Dad
[ ] How Andrew Saved the Day *
[ ] Toby the Terrible Tip Truck *

* indicates foils

THANK YOU FOR YOUR ASSISTANCE.

PLEASE PLACE COMPLETED QUESTIONNAIRE IN ENVELOPE,

SEAL IT, AND RETURN IT TO PRESCHOOL.
Appendix B- Principal Components Analysis of Early Home Reading Environment Items

The early home reading environment items (Appendix A questions 1, 3 – 5, 7, and 20) were entered into a Principal Components Analysis. Three items (frequency of library visits, number of children's books in the home and the child's interest in being read to) were removed from the analysis based on their low communalities. Two factors emerged, which accounted for 57.31% of the variance in the remaining six items. The factors related to Frequency of Parental Literacy Teaching (Parental Teaching) and Frequency of Parental Reading Activities (Parental Reading). The factors were only weakly correlated, \( r = .28 \), so the orthogonal solution was reported. Table B.1 presents the items included and the factors on which they showed significant loadings – 0.50 was considered the minimal factor loading required to be significant at an alpha of 0.05 (Hair, Anderson, Tatham, & Black, 1998). There were no cross loadings exceeding 0.50. Teaching letter knowledge (teaching the alphabet and teaching writing) loaded more highly on the Parental Teaching factor than did teaching reading. Frequency of reading to the child was more important to the Parental Reading factor than was the CTC score. Composite Parental Teaching and Parental Reading scores were constructed by summing responses on the relevant items.
### Table B.1

*Principal Components Analysis of Items Measuring Early Home Reading Environment*

<table>
<thead>
<tr>
<th>Item</th>
<th>Parental Teaching</th>
<th>Parental Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency teach alphabet</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>Frequency teach write name</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td>Frequency teach reading</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>Frequency reading at bedtime</td>
<td></td>
<td>0.75</td>
</tr>
<tr>
<td>Frequency reading at other times</td>
<td></td>
<td>0.71</td>
</tr>
<tr>
<td>Children's titles checklist score</td>
<td></td>
<td>0.68</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Eigenvalues</th>
<th>Percentage of Variance</th>
<th>Kaiser-Meyer-Olkin measure</th>
<th>Bartlett's test of sphericity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.16</td>
<td>27.14</td>
<td>0.66</td>
<td>$\chi^2 (15) = 94.82, p &lt; .0001$</td>
</tr>
</tbody>
</table>
Appendix C- Principal Components Analysis of Attentional Vigilance Items

Scores on the catch trials on the three temporal processing measures plus the score on the GATSB were entered into a Principal Components Analysis in order to reduce the number of items for use in further analyses. The auditory TOJ catch trials score was removed because of very low communality. The remaining three measures loaded on a single factor, which accounted for 45.90% of the variance in those three items. This factor related to Attentional Vigilance. Table C.1 presents the loadings. A composite Attentional Vigilance score consisted of the sum of scores on the catch trials of the two visual temporal processing measures plus the GATSB score. Higher scores indicated better attentional vigilance. The score on the Auditory TOJ Catch Trials was used as a second categorical measure of attentional vigilance. Children who scored 0 or 1 \( (n = 12) \) were categorized as low attentional vigilance (coded 0) and those who scored 2 \( (n = 132) \) were categorised as high attentional vigilance (coded 1).
Table C.2

*Principal components analysis of tasks measuring participants' attentional vigilance during testing*

<table>
<thead>
<tr>
<th>Item</th>
<th>Loadings on Attentional Vigilance Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catch trials Visual TOJ</td>
<td>0.70</td>
</tr>
<tr>
<td>Catch trials Temporal Dot</td>
<td>0.68</td>
</tr>
<tr>
<td>GATSB score</td>
<td>0.66</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalue</td>
<td>1.38</td>
</tr>
<tr>
<td>Percentage of Variance</td>
<td>45.90</td>
</tr>
<tr>
<td>Kaiser-Meyer-Olkin measure</td>
<td>0.58</td>
</tr>
<tr>
<td>Bartlett's test of sphericity</td>
<td>$\chi^2 (3) = 13.11, p = .004$</td>
</tr>
</tbody>
</table>
Appendix D- Reading Rate Word List

the  this  we
of   had   him
and  not   been
to   are   has
a    but   when
in   from  who
that or    will
is   have  no
was  an    if
he   they  out
for which so
it   one   said
with you   what
as   were  up
his  her   its
on   all   about
be   she   into
at   there them
by   would can
I    their only
<table>
<thead>
<tr>
<th>new</th>
<th>before</th>
<th>get</th>
</tr>
</thead>
<tbody>
<tr>
<td>some</td>
<td>must</td>
<td>here</td>
</tr>
<tr>
<td>could</td>
<td>where</td>
<td>both</td>
</tr>
<tr>
<td>these</td>
<td>much</td>
<td>under</td>
</tr>
<tr>
<td>two</td>
<td>your</td>
<td>never</td>
</tr>
<tr>
<td>many</td>
<td>well</td>
<td>know</td>
</tr>
<tr>
<td>then</td>
<td>down</td>
<td>us</td>
</tr>
<tr>
<td>do</td>
<td>because</td>
<td>old</td>
</tr>
<tr>
<td>first</td>
<td>just</td>
<td>hurt</td>
</tr>
<tr>
<td>any</td>
<td>those</td>
<td>wash</td>
</tr>
<tr>
<td>my</td>
<td>how</td>
<td>thank</td>
</tr>
<tr>
<td>now</td>
<td>too</td>
<td>sing</td>
</tr>
<tr>
<td>like</td>
<td>little</td>
<td>fly</td>
</tr>
<tr>
<td>our</td>
<td>good</td>
<td>laugh</td>
</tr>
<tr>
<td>over</td>
<td>very</td>
<td>jump</td>
</tr>
<tr>
<td>me</td>
<td>make</td>
<td>ate</td>
</tr>
<tr>
<td>made</td>
<td>own</td>
<td>more</td>
</tr>
<tr>
<td>after</td>
<td>see</td>
<td>than</td>
</tr>
<tr>
<td>did</td>
<td>work</td>
<td>other</td>
</tr>
<tr>
<td>many</td>
<td>long</td>
<td>time</td>
</tr>
</tbody>
</table>
Appendix E- Stimuli Used in the Pseudohomophone Choice

Task

Note: Correct words are bolded

Practice Trials

<table>
<thead>
<tr>
<th>iz</th>
<th>is</th>
<th>you</th>
<th>yoo</th>
</tr>
</thead>
<tbody>
<tr>
<td>do</td>
<td>doo</td>
<td>az</td>
<td>as</td>
</tr>
<tr>
<td>cat</td>
<td>kat</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Experimental Trials

<table>
<thead>
<tr>
<th>ov</th>
<th>of</th>
<th>duck</th>
<th>duk</th>
</tr>
</thead>
<tbody>
<tr>
<td>when</td>
<td>wen</td>
<td>made</td>
<td>mayd</td>
</tr>
<tr>
<td>thees</td>
<td>these</td>
<td>which</td>
<td>wich</td>
</tr>
<tr>
<td>first</td>
<td>ferst</td>
<td>rane</td>
<td>rain</td>
</tr>
<tr>
<td>yor</td>
<td>your</td>
<td>wonse</td>
<td>once</td>
</tr>
<tr>
<td>like</td>
<td>lik</td>
<td>bocks</td>
<td>box</td>
</tr>
<tr>
<td>thay</td>
<td>they</td>
<td>boat</td>
<td>bote</td>
</tr>
<tr>
<td>becors</td>
<td>because</td>
<td>farst</td>
<td>fast</td>
</tr>
<tr>
<td>where</td>
<td>wair</td>
<td>should</td>
<td>shood</td>
</tr>
<tr>
<td>wosh</td>
<td>wash</td>
<td>hed</td>
<td>head</td>
</tr>
<tr>
<td>agane</td>
<td>again</td>
<td>sed</td>
<td>said</td>
</tr>
<tr>
<td>was</td>
<td>woz</td>
<td>fourty</td>
<td>forty</td>
</tr>
<tr>
<td>does</td>
<td>duz</td>
<td>only</td>
<td>onlee</td>
</tr>
<tr>
<td>kan</td>
<td>can</td>
<td>thoz</td>
<td>those</td>
</tr>
<tr>
<td>found</td>
<td>fownd</td>
<td>little</td>
<td>little</td>
</tr>
<tr>
<td>peepel</td>
<td>people</td>
<td>February</td>
<td>February</td>
</tr>
<tr>
<td>skool</td>
<td>school</td>
<td>enuff</td>
<td>enough</td>
</tr>
<tr>
<td>cum</td>
<td>come</td>
<td>hert</td>
<td>hurt</td>
</tr>
<tr>
<td>arsk</td>
<td>ask</td>
<td>mutch</td>
<td>much</td>
</tr>
<tr>
<td>small</td>
<td>smorl</td>
<td>has</td>
<td>haz</td>
</tr>
</tbody>
</table>