RAPID AUTOMATIZED NAMING, PHONOLOGICAL AWARENESS, AND READING COMPREHENSION: IMPLICATIONS FOR THE DOUBLE-DEFICIT HYPOTHESIS OF READING DISABILITY

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ABSTRACT

This investigation examined relations between rapid automatized naming (RAN) and phonological awareness in predicting reading achievement in a sample of seventy, 8 to 10 year old, low average readers. Results showed that RAN-Letters contributed unique variance to Word Attack, Word Identification, Reading Fluency, and Passage Comprehension after age, Vocabulary and Elision (phonological awareness) were taken into account. Further analyses showed that RAN's contribution to reading comprehension is through its shared association with accuracy and speed of word recognition. Results suggest that rapid automatized naming and phonological awareness reflect unique processing deficits for some poor readers.

To my family:

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whose unending support of me and this work
has made it at all possible;

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CHAPTER 1: INTRODUCTION

According to a double-deficit hypothesis of reading disability, some poor readers have constraints in phonological awareness combined with the rapid automatized naming (RAN) of visual symbols, while other poor readers have deficits in phonological awareness or rapid automatized naming alone (Wolf & Bowers, 1999). Wolf & Bowers (1999) suggest that slow naming ability interferes with both recognition and storage of orthographic information in print. These deficits, in turn, may adversely affect the process of making connections between sounds and orthographic patterns, limit orthographic code quality in stored representations, as well as increase the amount of exposure to orthographic information necessary before orthographic codes can be adequately formed in long-term memory.

Evidence in support of the double deficit hypothesis of reading disability comes indirectly from studies that show RAN is a strong predictor of reading for typically developing readers in English (Wolf & Bowers, 1999), German (Wimmer, Mayringer & Landerl, 2000), Dutch (Yap & Van der Leij, 1993) and Finnish (Korhonen, 1995). More direct evidence is found in research that shows individual differences in rapid naming ability distinguish dyslexic readers classified according to IQ-achievement discrepancy criteria from poor readers who fail to meet IQ-achievement criteria (Ackerman & Dykman, 1993; Badian, 1997; Wolf & Obregon, 1992). Studies also show that older dyslexic readers have deficits on RAN measures in comparison to younger reading level matched readers (Wolf, 1991; Wolf & Bowers, 1999); thus, the RAN deficits of children with reading disabilities are not products of their deficits in reading.

Although there is growing evidence in support of the double-deficit hypothesis, two issues remain unresolved in the literature. One issue concerns the nature of processes that contribute to individual differences in RAN for children who struggle with reading. RAN is thought by some theorists to reflect underspecified or immature phonological representations (Pennington, Cardoso-Martins, Green, & Lefly, 2001), inefficient retrieval of phonological codes from long-term memory (Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993) or difficulties in phonological recoding (Wagner & Torgesen, 1987). Thus, in this view, phonological processing is central to children's performance on RAN tasks.

Evidence in support of the idea that RAN reflects primarily phonological processing is found in Wagner, Torgesen, & Rashotte's (1994) longitudinal study of reading development of children in Kindergarten through the end of Grade 2. Results showed that RAN failed to contribute significant variance to the prediction of decoding beyond that attributable to phonological processing, prior decoding, and vocabulary. In a follow-up study, Torgesen, Wagner, Rashotte, Burgess and Hecht (1997) studied the reading growth of two cohorts of children, one cohort from 2nd to 4th grade, the other from 3rd to 5th grade, and found that both phonological awareness and RAN were predictive of word identification, word analysis, reading comprehension, reading speed and orthographic accuracy two years later, but only when the prior reading skill level was not taken into account.

In contrast to the phonological awareness account of RAN deficits, Wolf and Bowers (1999) suggest that RAN taps speed of processing which in turn, accounts for unique variance in word identification and reading fluency (Bowers, 1995; Young and Bowers, 1995; Wolf et al., 2002). Wolf and Bowers (1999) suggest that rapid letter naming requires:

> (a) attention to the letter stimulus; (b) bihemispheric, visual processes that are responsible for initial feature detection, visual discrimination, and letter and letter-pattern identification; (c) integration of visual feature and pattern information with stored orthographic representations; (d) integration of visual information with stored phonological representations; (e) access and retrieval of phonological labels; (f) activation and integration of semantic and conceptual information; and (g) motoric activation leading to articulation (p. 418).

Wolf and Bowers suggest that precise rapid timing is necessary for efficient operation both within and across these independent subprocesses. Therefore, although the role of phonological processing is associated with RAN, processing speed and the integration of lower level visual processes with higher level cognitive and linguistic processes is thought to account for a greater portion of the variance in RAN.

Evidence in support of the idea that RAN is to some degree, independent of phonological processing is found in studies that report moderate correlations between measures of the two constructs (Blachman, 1984; Bowers, 1995; Cornwall, 1992; Felton & Brown, 1990; Mann, 1984; Wimmer, 1993, Wolf et al., 2002). Plaza and Cohen (2003) found a modest correlation between RAN-Letters and initial phoneme elision ($r = .22, p < .05$) for a group of French speaking Grade 1 children. Manis, Doi and Bhadha (2000) also reported a modest correlation between RAN-Letters and Sound Deletion ($r = -.31, p < .05$) for a sample of Grade 2 readers representative of a full range of reading ability.

Wolf and Bowers (1999) provide three reasons to account for the failure of RAN to contribute significant variance to the prediction of children's performance on measures of reading in the longitudinal study of reading development conducted by Torgesen et al. (1997). First, children in that study were, on average, typically developing readers, and rapid automatized naming may be more predictive of constraints in reading achievement among samples of more severely impaired readers (McBride-Chang, & Manis, 1996; Pennington et al., 2001). Second, speed related processes such as rapid automatized naming may reach an asymptote during the early years and this ceiling effect may result in limited variance available to predict further reading development. Empirical support also comes from Schatschneider, Carlson, Francis, Foorman and Fletcher (2002) who found that the correlation between phonological awareness and rapid letter naming among Grade 1 children ($r = .44, p < .05$) was larger than that of Grade 2 children ($r = .33, p < .05$). Third, RAN and phonological processing appear to be associated with different components of the reading process for both typically developing readers and children who experience difficulty with reading acquisition. Research shows that for children in the early phases of reading development, phonological awareness accounts for variance in decoding independent of orthographic awareness, whereas RAN has been found to be strongly associated with orthographic awareness (Manis, Doi, & Bhadha, 2000; Schatschneider et al., 2002; Torgesen et al, 1997). RAN-Digits has been found to provide unique variance to in-context reading rate, after accounting for phonological awareness, word identification and vocabulary (Bowers, 1993; Levy, Abello & Lysynchuk, 1997; Pennington et al., 2001; Savage & Frederickson, 2005; Young & Bowers, 1995). In contrast, studies show that RAN's contribution to reading comprehension is accounted for by its shared variance with word identification (Bowers & Swanson, 1991; Kail & Hall, 1994; Kail, Hall & Caskey, 1999; Spring & Davis, 1988). A similar pattern of results is shown for children who struggle with reading.

Wolf et al. (2002) examined the relationship between RAN and measures of phonological awareness, word attack, word identification and reading comprehension involving a sample of children in Grades 2 and 3 selected for severe reading disability. Results showed modest correlations between RAN-Letters and phonological processing as measured by Blending Phonemes ($r = .25, p < .01$) and Elision ($r = .28, p < .01$) for this sample of children. Despite this growing body of evidence, the idea that RAN and phonological processing predict independent variance in reading outcomes for children who struggle with the reading process remains somewhat controversial. Thus, this issue is explored in detail in this study.

A second issue addressed by this study concerns whether RAN explains reading comprehension difficulties of poor readers. Studies suggest that RAN is associated with lower order reading processes such as word attack and orthographic processes which in turn contribute to word reading fluency. Comprehension of written text requires this fluency in lower order (word level) processes as well as higher order processes (Pressley, 2000). It follows, therefore, that the contribution of word reading fluency to the prediction of reading comprehension may be mediated by individual differences in RAN.

Jenkins, Fuchs, van den Broek, Espin and Deno (2003a) studied the oral reading of children in fourth grade and found that, on average, children with reading disabilities scored significantly lower than skilled readers on measures of accuracy and rate of word recognition and they encountered fewer (mean = 8) idea units per minute than skilled readers (mean = 24 idea units per minute). The researchers also found that on average, rates of word reading on a context-free list and within a reading passage were comparable for children who were poor readers. Taken together, the results suggest that children with reading disabilities do not experience problems with reading words in context specifically, but rather that a slow rate of word identification in general contributes to a slow rate of passage reading. It follows that this slow rate of word reading within a passage is associated with slower processing of idea units and this in turn, may affect overall comprehension of the text. However, more research is required to investigate the relations between RAN, word recognition, word reading fluency, and passage comprehension. This is a second aim of the current study.

In summary, the main purpose of this study is to investigate the two issues raised in this discussion of the double deficit hypothesis. First, it is of interest to examine the relations between RAN, phonological processing and reading among young children who have been identified by their teachers as poor readers. Second, this study also examines the relationship between RAN, fluency of word reading, and reading comprehension for this group of children.

Two main research questions guide the study:

1) **Does RAN contribute unique variance to individual differences in decoding, word identification, reading fluency, and reading comprehension, beyond what is accounted for by phonological awareness, in a community-referred sample of 8 – 10 year old poor readers?**

Support for the idea that RAN predicts independent variance in word decoding, word identification, reading fluency and reading comprehension beyond phonological awareness will be found if partial correlations between RAN and the achievement measures of reading remain significant after the effects of phonological awareness are partialed from the association.

2) **Does RAN mediate the effect of word reading fluency on reading comprehension for this sample of children?**

Support for the idea that RAN mediates the role of reading fluency on reading comprehension will be found if the partial correlation between reading fluency and reading comprehension is reduced when the effects of RAN are partialed from the association. On the other hand, if RAN has little effect on reading fluency - passage comprehension relations, then the partial correlation between reading fluency and passage comprehension will not be significantly affected by first partialling out the contribution of RAN.

This study aims to contribute to the somewhat divergent results found in previous investigations regarding the contribution of RAN to reading development. Investigating the RAN – reading relationship also has practical significance in the classification of children with reading disabilities and has implications for intervention practices, in that assessment of RAN and instruction in rapid letter naming may be warranted as part of reading interventions for poor readers with RAN deficits.

CHAPTER 2: LITERATURE REVIEW

This chapter synthesizes the research that concerns relations among rapid automatized naming (RAN), phonological processing and reading comprehension for children who are typically developing readers as well as for children who struggle with reading. First, research on phonological awareness and reading development for children with and without reading disabilities is explored. Second, research on RAN, the relationship of RAN to reading and the double-deficit hypothesis of reading disability is reviewed. Finally, the chapter concludes with a review of research on the relations among RAN, the accuracy and rate of word reading and reading comprehension.

2.1 Phonological Awareness, Reading and Reading Disability

A substantial body of research is currently available that suggests phonological processing is important to the reading process. These findings are robust in studies with samples of young children in the early phases of reading development and among studies with samples of older children with reading disability (Wagner & Torgesen, 1987). Evidence from longitudinal studies of reading development also suggests that phonological awareness accounts for considerable variance in subsequent reading achievement (Blachman, 1984; Bradley & Bryant, 1983; Fletcher et al., 1994; Juel, 1988; Mann & Liberman, 1984; Torgesen et al., 1997; Vellutino & Scanlon, 1987; Wagner et al., 1994). As discussed in Chapter one, Torgesen et al.'s (1997) longitudinal study of children's early reading development over two years showed that early phonological awareness predicts later word identification, word analysis, reading comprehension, reading speed and orthographic accuracy; however, the influence of RAN on later reading achievement became statistically non-significant when prior reading ability was taken into account. For example, phonological awareness predicted word identification (partial R^2 =.03, $p < .01$), word analysis (partial R^2 =.06, $p < .01$), and reading comprehension (partial R^2 =.03, $p < .01$) in 4th grade, after controlling for the variance attributable to differences in children's phonological awareness in the 2nd grade. When the variance due to 2nd grade word analysis, vocabulary and phonological awareness was controlled, RAN contributed a significant, but marginal amount of variance to the prediction of word analysis in 4th grade (partial R^2 =.01, $p < .05$). With respect to 5th grade reading, only phonological awareness accounted for significant variance in word identification (partial R^2 = .02, $p < .05$), word analysis (partial R^2 = .02, $p < .05$), and reading comprehension (partial R^2 = .02, $p < .05$) once 3rd grade performance on the reading-related dependent measures was taken into account. This pattern of results was also found among groups of 4th and 5th grade children who scored below the 20th percentile on the word identification subtest two years earlier (i.e. in Grade 2 or 3). RAN failed to contribute significant variance to the prediction of any measure of reading, once the variance attributable to vocabulary and phonological awareness was taken into account. On the other hand, phonological awareness contributed significant variance to the prediction of word identification (partial R^2 = .14, $p < .01$), and reading comprehension (partial R^2 = .19, $p < .01$) beyond that attributable to vocabulary and RAN for poor readers in 4th grade. In summary, RAN did not contribute significant variance to the prediction of any measure of reading in 5th grade beyond vocabulary and phonological awareness; however, phonological awareness contributed significant variance to the prediction of word analysis beyond vocabulary and RAN (partial R^2 =.07, $p < .05$). The authors concluded that during the developmental period that occurs during the middle elementary school years, variation in reading growth is better predicted by individual differences in phonological awareness than by individual differences in RAN.

Weaknesses in phonological awareness evidenced among young children who struggle with learning to read in the primary grades appear to persist well into the teen and adult years (Bruck, 1992; Fawcett & Nicolson, 1995; Pennington, Van Orden, Smith, Green, & Haith, 1990). Moreover, these deficits in phonological processing also remain pervasive among older children whose word recognition skills have improved after intervention (Bruck, 1992; Gallagher, Laxon, Armstrong, & Frith, 1996; Pratt & Brady, 1988).

Evidence in support of the causal role of phonological awareness on reading development is shown in studies reporting that increases in phonological awareness due to training result in corresponding gains in word recognition, reading fluency and reading comprehension for typically developing readers (Ball & Blachman, 1991; Castle, Riach, & Nicholson, 1994; Cunningham, 1990; Lie, 1991; Lundberg, Frost & Petersen, 1980) and for children at-risk of reading difficulties (Bradley & Bryant, 1983; Felton, 1993; Foorman , Francis, Fletcher, Schatschneider & Mehta, 1998; Lovett et al., 1994; Lovett et al., 2000; Lovett, Steinbach & Frijters, 2000; Lovett, Warren-Chaplin, Ransby & Borden, 1990; Torgesen, Wagner & Rashotte, 1997; Vadasy, Jenkins & Pool, 2000; Wise, Ring, & Olson, 1999). Bradley and Bryant (1983) divided child participants into four groups, matched on age, verbal intelligence and sound categorization scores; two groups received intensive training in sound categorization over a two-year period and two groups served as controls. Group I received sound categorization training using picture cards; Group II received the same training with the addition of alphabet letters to teach the letter/sound connections; Group III (control) used the same pictorial materials as the intervention groups but was taught instead to categorize the pictures conceptually; Group IV (control) received no training at all. Results showed that, on average, children in Group II outperformed both control groups on measures of reading and spelling but not mathematics. Results of an analysis of covariance that controlled for average group differences in age and IQ, showed that mean group differences on measures of reading (F (3,58)=5.23, $p < .003$) and spelling (F (3,58)=7.80, $p < .001$) were statistically significant; however, average group differences on measures of mathematics (F (3,39)=1.64, $p > .05$) did not reach statistical significance. Mean performance differences between Group I and II on measures of post-test reading did not reach significance, however, Group II significantly outperformed Group I ($p < .05$) on the spelling achievement measure.

Vellutino et al. (1996) suggest that individual differences in phonological processing abilities may be the factor that distinguishes poor readers whose reading problems are difficult to remediate from those poor readers whose reading difficulties are relatively easy to overcome through intervention. This conclusion was drawn from a study that examined the efficacy of a comprehensive early intervention reading programme for 1st graders during which Vellutino et al. found that children who failed to respond to intervention performed below normal readers and remediated poor readers on tests of phonological skills in Kindergarten and Grade 1($ps < .05$).

In summary, results from a large body of research have found that phonological processing is associated with reading achievement. Longitudinal studies (eg. Torgesen et al., 1997) have found that measures of phonological awareness in children's early reading development predicts later word analysis, word identification, reading speed and reading comprehension. Although weaknesses in phonological awareness are associated with poor reading achievement, and tend to persist into the teen and adult years (Bruck, 1990; Fawcett & Nicolson, 1995; Pennington, Van Orden, Smith, Green, & Haith, 1990), gains in phonological awareness due to training have been realized. However, it has also been suggested (Vellutino et al.; 1996) that phonological processing deficits may be what distinguish poor readers whose reading problems are difficult to remediate from those poor readers who benefit from reading intervention efforts.

Although the finding that phonological processing correlates with measures of reading for both typically developing and poor readers is robust, not all variance in performance on reading achievement is accounted for by this construct. Another construct that has potential to explain reading development is rapid automatized naming.

2.2 Rapid Automatized Naming and Reading

Several studies show that RAN is important to the development of reading skills among beginning readers (Blachman, 1984; Bowers, 1993; Bowey, Storey, & Ferguson, 2004; Spring & Davis, 1988; Vellutino et al., 1996; Wagner, et al., 1994; Wimmer et al., 2000; Wolf, Bally, & Morris, 1986). For example, Manis et al. (2000) investigated the relationships between RAN, phonological awareness, orthographic skill, word identification, word attack and reading comprehension among 85 children in the spring of their Grade 2 year. The only exclusionary criterion used in sample selection was limited proficiency in English. The results of regression analyses showed that RAN-Letters accounted for unique variance in word identification (partial $R^2 = .17, p < .01$), nonword reading (partial $R^2 = .07, p < .01$), word attack (partial $R^2 = .06, p < .01$), exception word reading (partial $R^2 = .22, p < .01$), reading comprehension (partial $R^2 = .09, p < .01$), orthographic choice (partial $R^2 = .13, p < .01$), and letter string choice (partial $R^2 = .11, p < .01$) beyond the contributions of vocabulary and phonological awareness.

Whereas RAN appears to explain variance in reading achievement, the nature of the processes that underlie RAN and RAN-reading relations has been the subject of much debate in the research literature. Whereas some researchers argue that RAN involves primarily phonological processing, other researchers argue that RAN includes processing of orthographic information. Compton (2003) used four different versions of rapid letter naming tasks in a study of the phonological-RAN associations with reading over the course of first grade (N =383 children). The first array included the letters *a, d, o, p*, and *s*; the second array substituted the letter *q* for the letter *o*, to increase the likelihood that children would be confused by the visually similar orthography between *d, p,* and *q*; the third array increased the possibility that children would be confused by similar sounding letter names by substituting the letter *v* for *o* (the letter name *v* rhymes with the letter names *d* and *p*) ; the fourth array increased the likelihood of confusion from both visually and phonologically similar information by substituting the letter *b* for *o*. The letter names that sounded alike (*b*, *d*, *p*) placed increased demands on phonological processing, whereas visually similar letters (*d, p, q*) placed more demands on orthographic processing. Results of this study showed that RAN slowed under increased orthographic processing demands and relative to conditions that placed relatively more demands on phonological processing. Furthermore, increasing both visual and phonological complexity together did not slow RAN any more than increasing the visual complexity alone.

An examination of the Rapid Automatized Naming (RAN) – reading relationship, however, showed that increased visual complexity of the stimuli in the RAN task resulted in decreased rates of RAN; however, this slowing of speed in naming did not significantly change the correlations between RAN and word identification. On the other hand, increasing the phonological complexity of stimuli in the RAN task increased the variance in word identification attributed to rate of RAN, and this additional variance explained was independent of that accounted for by RAN on the visually complex RAN task. On the basis of these results, Compton concluded that variance in phonological processing on the RAN task explains the predictive association between RAN and word identification skill.

Tallal, Miller, Jenkins, & Merzenich (1997) hypothesized that rather than specific phonological or orthographic processing systems, a domain-general temporal processing system underlies RAN and RAN-reading relations. According to this view, children with reading disability as well as children with language impairments have a general deficit in processing temporal information quickly, and it is this temporal processing deficit that interferes with identification of individual phonemes and synthesizing these phonemes into larger chunks such as words and syllables. Tallal (1980) supported this position by drawing on research findings that show that children with reading disability have more difficulty than normally achieving controls identifying tones as well as the order of presentation when tones were presented with brief interstimulus intervals (8-305 msec).

Chiappe, Stringer, Siegel and Stanovich (2002) examined the relationship between temporal processing and phonological processing, word reading and spelling for adult poor readers. Three groups of readers were identified: The RD group (n=30) included adults with reading disability, who read at or below the 25th percentile on the reading subtest of the Wide Range Achievement Test – 3rd edition, (WRAT-3; Wilkinson, 1993); the CA group (n=32) included adult average readers (reading above the 29th percentile on the WRAT-3) who served as chronological age controls; and the RL control group (n=31) included children who were average readers (reading at or above the 30th percentile on the WRAT-3) who read at the same level as the adults in the RD group. Results showed that the average performance of the group of adults with reading disabilities did not significantly differ from the mean performance of the CA matched group on measures of accuracy of identification of speech sounds; however, significant group differences were found on measures of latency. Scheffe post-hoc analyses showed that average performance of the RD group on measures of latency were significantly lower than the mean performance of the CA adult control group (Temporal Order Judgement task, $t(58) = 4.41, p < .01$, CV Same/Different task, $F(2,84) = 13.73, p < .01$, Auditory Gap Detection task, $F(2,86) = 26.6, p < .01$, Visual Gap Detection task, $F(2,85) = 29.32, p < .01$). However, on average, the group of RD adults performed significantly faster than the RL control group on both Gap Detection tasks. Significant group differences were found on the RAN - digit naming task $F(2, 87) = 5.64, p < .01$. Scheffe post-hoc tests showed that on average, the group of RD adults named digits more slowly than the group of CA matched adults but not more slowly than the RL control group. This result also failed to support the temporal processing deficit hypothesis: the mean performance of RD adults on RAN tasks was not significantly inferior to the average performance of reading level matched controls. Moreover, results of regression analyses showed that no timing variable (temporal order judgement, visual gap detection, auditory gap detection, syllable repetition, or a tapping task) was predictive of word reading for the RD group once phonological processing and RAN were added to the equation. Because RAN digits predicted word reading beyond phonological awareness, a stepwise regression analysis was conducted to determine whether timed, temporal processing contributed to variance in RAN digits. Results showed significant contributions of the following variables: WRAT-3 reading (Step 1, $R^2 = .34, p < .01$), RAN response time (Step 2, partial $R^2 = .09, p < .01$), RAN errors (Step 3, partial $R^2 = .06, p < .05$). No timing variable predicted variance in RAN. Chiappe, Stringer, Siegel and Stanovich concluded that their results support the phonological basis of reading disability and that deficits in RAN can be explained by concomitant deficits in phonological processing. In addition, they suggested that phonological awareness reflects receptive phonological processing in the auditory domain, while RAN reflects expressive phonological processing in speech production.

In summary, rapid automatized naming has been found to be associated with reading achievement. Studies (eg. Manis et al., 2000) have shown that RAN contributes uniquely to measures of decoding, word identification, orthographic knowledge and reading comprehension beyond the contributions of vocabulary and phonological awareness.

Although the association of RAN with reading achievement has been demonstrated, the nature of processing involved in RAN has been the topic of much debate. Some researchers consider RAN to be primarily a phonological process, whereas, others consider RAN to involve orthographic processing. Further research into the RAN – reading relationship centres around the issue of whether RAN involves domain general temporal processing rather than specific phonological or orthographic processing. This temporal processing account of reading disability is also a topic of debate in the literature, with evidence being unequivocal at the present time.

2.2.1 The Double-Deficit Hypothesis

Wolf & Bowers (1999) described several areas of research support for the Double-Deficit hypothesis including evidence of: three subtypes of reading disability (phonological, RAN and phonological/RAN together); the independent contribution of RAN to word reading fluency; RAN deficits in impaired readers of several languages; the differential relationships of RAN and phonological awareness to different reading subskills (e.g., word attack, word identification, reading speed, and comprehension); and the modest relationship between RAN and phonological awareness. The identification of subtypes of reading disability, and the contribution of RAN to variability in reading subskills beyond that explained by phonological awareness are particularly relevant to this investigation.

Wolf and Bowers (1999) described three subtypes of reading disability that included phonological processing and RAN. Classification criteria for a "double deficit" include scoring 1 standard deviation below the mean on measures of both phonological awareness and RAN. In their recent investigation involving 144 Grade 2 and 3 readers with severe reading disabilities, Wolf et al. (2002) identified 27 children (19%) with a single phonological deficit, 22 children (15%) with a RAN deficit, 86 children (60%)

with a double deficit and 9 children (6%) could not be classified. Lovett et al. (2000) were able to classify 140 of 166 children (84.3%) with severe reading disabilities aged 7 to 13 according to one of the Double-Deficit hypothesis sub-types. Thirty-three children (23.6%) were classified as having a single RAN deficit, 31 children (22.1%) were classified as having a single phonological awareness deficit, and 76 children (54.3%) were classified as having a double deficit in both processes. This sub-type criteria has also been used to classify undifferentiated classroom populations. Manis, Doi and Bhadha (2000) classified their representative sample of 85 Grade 2 readers, which included 8 children (9.4%) with a single RAN deficit, 13 children (15.3%) with a single phonological awareness deficit, 8 children (9.4%) with a double deficit, and 50 children (58.8%) with no deficit.

Children with a double deficit reading disability appear to have more severe reading and spelling impairments than children with single deficits in either RAN or phonological awareness. In two recent investigations involving Grade 3 children, Sunseth (as cited in Bowers, 2001) found that on average, groups of children with a deficit in RAN only were considerably impaired in reading rate, and spelling. Average group performance of children with single phonological deficits was weaker on measures of phonological decoding and spelling dictation but their rate of reading was faster than children with double deficits. Children with deficits in both phonological processing and RAN appeared to have weak skills in all areas of reading. Ninety percent of children classified as having a double deficit scored below the 25th percentile in word identification compared to only 20 – 30 % of children with a single deficit in either phonological processing or RAN.

Wolf et al. (2002) conducted an investigation into the independence of RAN and phonological awareness deficits among children with dyslexia. Their study was a multi-faceted investigation of the double-deficit hypothesis, and included an examination of the relationship between phonological awareness and RAN, and the relationship between these two variables and word attack, word identification, and reading comprehension in a group of young, severely impaired readers. The participants were 144 children in Grades 2 and 3 from Boston, Atlanta, and Toronto. Inclusion criteria included English as the primary language, between the ages of 6 years 6 months and 8 years 6 months, enrolled in Grade 1 or 2 at time of screening, normal hearing and vision, either Caucasian or African heritage, low achievement (standard reading scores below 85) or discrepancy criteria (1 standard deviation between IQ and reading achievement).

Results showed standard score correlations between RAN-Letters and blending phonemes ($r = .25, p < .01$) and phoneme elision ($r = .28, p < .01$). Both phonological awareness measures were correlated at the same level with IQ ($r = .57, p < .01$). Both phonological variables were also correlated with age (blending phonemes $r = .18, p < .05$, elision $r = .27, p < .01$). However, RAN was not significantly correlated with either IQ or age. Wolf et al. concluded that, although correlations were found between rapid automatized letter naming and the two phonological awareness measures, these associations demonstrate that phonological processing plays a critical but limited role in the ensemble of multiple lower-level perceptual, lexical and motoric processes involved in RAN. Moreover, a different pattern of correlations emerged between RAN and reading than between phonological awareness and reading for this group of children. Significant correlations were reported between phonological awareness and word attack (blending phonemes $r = .61, p < .001$, elision $r = .63, p < .001$), word identification (blending phonemes $r = .39, p < .01$, elision $r = .44, p < .01$), and reading comprehension (blending phonemes $r = .38, p < .01$, elision $r = .53, p < .01$). RAN-Letters raw scores were also significantly correlated to word attack ($r = .35, p < .01$), word identification ($r = .57, p < .01$) and reading comprehension ($r = .51, p < .01$).

In order to examine the independent contributions of phonological awareness and RAN to the reading measures for children with reading disabilities, a series of stepwise regression analyses were performed. Results showed that IQ (Step 1, $R^2 = .31, p < .01$), age (Step 2, partial $R^2 = .13, p < .01$), elision (Step 3, partial $R^2 = .12, p < .01$), blending phonemes (Step 4, partial $R^2 = .05, p < .01$) and RAN-Letters (Step 5, partial $R^2 = .02, p < .01$) all contributed variance toward word attack (total $R^2 = .62, p < .01$). Results for word identification as the dependent variable (total $R^2 = .43, p < .01$) showed significant contributions made by IQ (Step 1, $R^2 = .22, p < .01$), RAN-Letters (Step 2, partial $R^2 = .11, p < .01$), age (Step 3, partial $R^2 = .04, p < .01$), and Elision (Step 4, partial $R^2 = .06, p < .01$). For Passage Comprehension (total $R^2 = .36, p < .01$) contributions were made by IQ (Step 1, $R^2 = .19, p < .01$), RAN-Letters (Step 2, partial $R^2 = .08, p < .01$), age (Step 3, partial $R^2 = .04, p < .01$), and Elision (Step 4, partial $R^2 = .04, p < .01$).

Results from the regression analyses demonstrated that although both phonological awareness and RAN accounted for variance in all three reading measures, phonological awareness contributed greater variance to word attack and RAN contributed greater variance to word identification for this group of children. Although variance in both RAN and phonological awareness contributed to the prediction of passage comprehension, the authors suggested that this variance overlaps with that attributed to word attack and word identification. Thus, the variance in reading comprehension attributed to RAN is fully mediated by word attack and word identification.

In summary, the Double-Deficit hypothesis (Wolf & Bowers, 1999) suggests that the processes underlying rapid automatized naming represent a second core deficit contributing to developmental reading disability, and that children with deficits in both phonological processing and RAN will present with the most severe reading impairments. Several lines of evidence, relevant to this investigation, have been presented suggesting that the processes underlying RAN contribute uniquely to reading dysfunction apart from phonological processes including: the modest relationship between RAN and phonological awareness; the identification of 3 deficit subtypes (RAN, phonological, and a double deficit of RAN and phonological); and the unique contribution of RAN to reading achievement beyond phonological processing.

2.3 RAN, Accuracy and Rate of Word Reading, and Comprehension

Theories of reading development generally emphasize that accurate and automatic word identification supports reading comprehension (eg. LaBerge & Samuels, 1974; Perfetti, 1985; Samuels, 1979). Recent studies have examined factors that mediate the accuracy and rate of word identification and/or passage comprehension for typically developing readers as well as for children with reading disabilities.

As discussed previously in Chapter One, Jenkins et al. (2003a), examined the effect of rate of reading words on reading comprehension outcomes. Word identification rates of 85 skilled Grade 4 readers and 24 Grade 4 students with reading disability were estimated using the measures of words read correctly per minute from a grade level passage (in-context) and words read correctly when reading the same words arranged randomly in list format (context-free). The skilled readers read 3 times faster than the readers with reading disability in-context (155 wcpm compared to 52 wcpm) and 2 times faster in lists (93 wcpm compared to 43 wcpm). To examine the effect of reading rate on comprehension, the idea-units in the passages read were examined. It was found that the skilled readers encountered an average of 24.35 idea units per minute, whereas the readers with reading disability encountered an average of 8.1 idea units per minute. Jenkins and colleagues argued that slower processing of ideas in text would hinder comprehension through temporally distant processing of ideas in a cognitive system that depends on efficient processing due to limited processing capacity.

In a follow-up study, Jenkins, Fuchs, van den Broek, Espin and Deno (2003b) studied the reading ability of 113 Grade 4 students randomly selected to represent a normal distribution of reading ability. Measures included words read correctly per minute when reading a grade level passage (in-context reading speed), and when reading the words from the passage arranged in a random list (context-free reading speed), as well as reading comprehension as measured by the Reading Comprehension subtest of the Iowa Test of Basic Skills (ITBS; Hoover, Dunbar & Frisbie, 1994). Results of hierarchical regression analyses showed that list reading speed accounted for considerable variance in reading comprehension (partial $R^2 = .29, p < .01$) and in-context reading speed accounted for unique variance beyond list reading speed (partial $R^2 = .41, p < .01$) (total $R^2 = .71, p < .01$). List reading speed did not account for any significant variance beyond in-context reading speed that accounted for 70 % ($p < .01$) of the variance in reading comprehension. Although this study showed a large amount of variance in reading comprehension was accounted for by in-context reading speed, this study did not take IQ into account in the regression analyses, and therefore, general verbal ability may be a confounding factor. A second analysis investigated the contribution of passage comprehension to in-context reading speed beyond list reading speed. Results showed that Passage Comprehension (partial $R^2 = .27, p < .01$) contributed variance to in-context reading speed beyond list reading speed (partial $R^2 = .54, p < .01$) (total $R^2 = .81, p < .01$). The authors suggested that list reading speed, in-context reading speed, and reading comprehension all share word level processes, but that verbal ability involved in reading comprehension may also be involved in in-context text reading speed.

Intervention studies investigating the effects of reading fluency on reading comprehension have reported mixed results. Several studies have found that simply improving the speed of single word recognition does not improve reading comprehension outcomes (Fleisher, Jenkins & Pany, 1979; Samuels, Dahl, & Archwamety, 1974). However, Tan and Nicholson (1997), in a replication of Fleisher et al.'s (1979) study, found that training in either single word reading or phrase reading until the subjects could read the words without hesitation, resulted in significantly higher reading comprehension than that produced by discussing the meaning of words presented orally only. However, their word training treatment groups also provided instruction regarding the meaning of words if the children did not seem to know them. Therefore, their results may have differed from Fleisher et al.'s because the students could both decode and understand the words they read quickly. In other words, identifying words quickly may be necessary but not sufficient to ensure adequate reading comprehension.

In studies of primary grade children in Israel, Breznitz (1987a, 1998, 1990) consistently demonstrated that reading comprehension can be improved by increasing children's word reading rate. By increasing children's reading pace, through increasing the presentation and removal of passage words on a computer screen, increases in children's inferential and factual comprehension of text were evident. Breznitz replicated this finding with samples of Israeli children from lower socio-economic backgrounds (Breznitz, 1987b), and with children with dyslexia (Breznitz, 1997).

In summary, based on theories of reading development that view accurate and automatic word identification as necessary to support reading comprehension, factors mediating reading fluency and reading comprehension have been investigated. Jenkins et al. (2003a) found that subjects with reading disabilities read more slowly than their average achieving peers and consequently encountered fewer idea units in text which in turn may have affected their reading comprehension. Although, some studies have found that increasing children's reading of text improves their reading comprehension, other studies have failed to find gains in reading comprehension from increased rate of single word recognition. Therefore, the factors involved in reading fluency and reading comprehension and the relationship between them are currently unresolved.

2.4 Summary

This review of the literature explores several areas of research pertinent to this investigation. First, there is robust evidence demonstrating the association between phonological processing and reading achievement. Weaknesses in phonological awareness may be what distinguishes poor readers whose reading problems are difficult to remediate from those who benefit more readily from reading interventions. Rapid automatized naming is also associated with reading achievement, however, the nature of the processing involved in RAN is currently unclear. Theories regarding the nature of processing involved in RAN suggest that RAN may involve phonological, orthographic or domain general temporal processing.

Wolf & Bowers (1999) argue that RAN represents a second core deficit in developmental reading disability and should not be considered a phonological process. Evidence supporting the unique contribution of RAN to reading disability includes the modest association between RAN and phonological awareness, the identification of children with single and double deficits in RAN and phonological awareness, and the unique contribution of RAN to reading achievement beyond phonological awareness.

There are two main issues that are raised by this review of the literature. One issue concerns whether RAN contributes unique variance to the prediction of reading skills beyond that attributable to phonological processing for children identified as poor readers. A second issue that remains unresolved is whether RAN contributes to reading comprehension through its association with rate of word identification, or whether RAN contributes unique variance to this association.

CHAPTER 3: METHODS

3.1 Research Design

This study employed a correlational design to look at concurrent relationships between RAN, phonological awareness, decoding, word identification, reading fluency and reading comprehension for a group of children identified by their teachers as having reading difficulties. In addition to correlational analyses, a series of hierarchical regression analyses were performed to investigate the relative contribution of RAN and phonological awareness to reading achievement. Dependent reading achievement measures included: Word Attack, Word Identification, Reading Fluency and Passage Comprehension. The independent measures of interest were Elision (phonological awareness) and RAN-Letters. Vocabulary and age of the children potentially mediated the contribution of the independent variables to the prediction of reading and were therefore, added first into all regressions.

3.2 Sample

Seventy children, ranging in age from 7:9 to 10:9 years participated in this study (females = 31 and males = 39). Participants were drawn from a group of children referred to a remedial reading program held in a university setting in the lower mainland of British Columbia. The students were referred to the remedial reading program by teachers and parents. Children for whom English was a second language and who had lived in Canada for less than 5 years were excluded from study participation.

3.3 General Procedures

The following test battery was individually administered at the university by the primary investigator and three trained research assistants, in a single, 50-minute session during April-July of 2005. Tests were administered in this order for all children: RAN-Letters, Word Attack, Letter-Word Identification, Reading Fluency, Vocabulary, Elision, Passage Comprehension.

3.3.1 Vocabulary

Vocabulary was measured using the Vocabulary subtest of the Stanford Binet Intelligence Scale: Fourth Edition (Thorndike, Hagen & Sattler, 1986). This subtest requires that the participant give oral definitions of words spoken by the examiner. Each correct item scored one point and items were considered correct if the participant provided a definition that matched an acceptable definition listed in the manual. The internal consistency *KR 20* reliability reported for this subtest ranges from .82 to .88 in the 8 to 10 year old age ranges.

3.3.2 Reading Achievement

Four subtests of the Woodcock-Johnson Tests of Achievement - 3rd Edition (Woodcock, McGrew & Mather, 2001) were administered.

Letter-Word Identification measures the participant's word identification skills. Participants in this age range are required to correctly pronounce words written eight to a page presented in increasing difficulty. This test has a median split-half reliability of .91 in the age 5 to 19 range.

For the purposes of this study, reading fluency is operationally defined as performance on the Reading Fluency subtest of the Woodcock-Johnson Tests of Achievement – 3rd Edition (Woodcock, McGrew & Mather, 2001). The Reading Fluency subtest measures the participant's ability to quickly read simple sentences, decide if the statement is true, and then circle Yes or No. The difficulty of the sentences gradually increases. A three-minute time limit is set in which the participant completes as many items as possible. The median split-half reliability of the Reading Fluency subtest is .90 in this age range.

During the Passage Comprehension subtest, participants were required to read a short passage and identify a missing key word that makes sense in the context of the passage. Difficulty is increased by removing pictorial stimuli and by increasing passage length, level of vocabulary, and complexity of syntactic and semantic cues. If a basal limit of 6 correct responses was not reached at this initial starting point then the examiner tested backward until the basal criterion was met. The earlier test items involved a multiple-choice format in which the participant was required to read a phrase and then point to the picture representing that phrase. The Passage Comprehension has a median split-half reliability of .83 in this age range.

The Word Attack subtest measures the participant's skill in applying phonic and structural analysis skill to pronounce nonwords. Initial items involve producing sounds for single letters. The remaining test items require the participants to pronounce non-word letter combinations that are phonetically regular in the English language. The median split-half reliability for the Word Attack subtest is .87 for this age range.

3.3.3 Phonological Awareness

Phonological awareness was estimated using the Elision subtest of the Comprehensive Test of Phonological Processing (CTOPP) (Wagner, Torgesen & Rashotte, 1999). This test involves 20 items in which the participant must listen to a word, repeat the word and then say the word without a specific sound (such as "say bold without the /b/"). The average reliability (internal consistency Cronbach's coefficient alpha) reported for the Elision subtest is .89 across all ages.

3.3.4 Rapid Automatized Naming

RAN was estimated using the Rapid Letter Naming subtest of the CTOPP (Wagner, Torgesen & Rashotte, 1999). This timed test requires the participant to name as quickly as possible all the letters in a 9 x 4 array of the letters s, *t, n, a, k,* and *c* randomly repeated. The participant was asked to complete two different forms of the test and their score consists of the total combined time to read both forms. The average internal consistency coefficient reported for the Rapid Letter Naming subtest is .82 across all ages.

3.4 Data Analysis

Data was coded and analyzed using SPSS statistical software (SPSS Inc., 2004). One child was unable to respond to the RAN-Letter task because he did not know his letter names. Data for this child on this variable was eliminated listwise in the SPSS program.

CHAPTER 4: RESULTS

This chapter presents the results that address the questions posed in this investigation. The data were submitted to three analyses. First, a descriptive analysis of the sample provides information about sample mean performance on measures of RAN, phonological awareness and reading. The sample is also described in terms of the double deficit criteria. Second, correlational analyses were conducted to show the associations among RAN, phonological processing and reading for this sample of poor readers. Finally, hierarchical regression analyses were conducted to investigate the contribution of RAN to word attack, word identification, word recognition fluency and passage comprehension beyond the contribution of phonological awareness and to examine whether RAN mediates relations between word recognition fluency and passage comprehension.

4.1 Descriptive Analyses

As shown in Table 1, study participants included 70 children (39 males and 31 females). The participants ranged in age from 94 to 131 months (M = 109.62, SD = 9.19). The mean standard score of the sample on the Vocabulary subtest of the Stanford Binet Intelligence Scale: 4th Edition (Thorndike, Hagen & Sattler, 1986) fell in the mid-average range relative to age peers (M = 100, SD = 11.2).

Mean sample standard scores for all four measures of reading fell in the low average range, relative to age peers in the norming samples. The mean standard score for the Word Identification subtest was 91 ($SD = 8.6$). The mean standard score for the Word Attack subtest was 93 ($SD = 8.1$). The mean standard score for the Reading Fluency subtest was 94 ($SD = 9.7$). The mean standard score for the Passage Comprehension subtest was 91 ($SD = 6.9$). Taken together, these results suggest that this sample of children is representative of a group of children with low average performance across diverse measures of reading achievement.

The children in the sample were identified according to the Double-Deficit criteria (Wolf & Bowers, 1999). A deficit in either phonological awareness or RAN was determined if scores on the Elision or RAN-Letters subtests of the CTOPP were less than or equal to one standard deviation below the average performance of the children in the standardization sample as reported in the CTOPP Examiner's Manual (Wagner, Torgesen and Rashotte, 1999). Sixty-nine of the 70 children were classified (the RAN-Letters score was missing for one child participant because the child did not know a sufficient number of letter names). Thirty-eight children (55%) had no deficit in either phonological awareness or RAN, 21 children (30%) had a single phonological deficit, 4 children (6 %) had a single RAN deficit, and 6 children (9 %) were classified as having a double-deficit in phonological awareness and RAN.

4.2 Correlational Analyses

Table 2 presents the Pearson inter-correlations among RAN, phonological awareness, age, vocabulary, and the reading variables. Significant negative correlations were found between RAN-Letters and Word Attack ($r = -.44, p < .01$), Word Identification ($r = -.54, p < .01$), Reading Fluency ($r = -.59, p < .01$), Passage Comprehension ($r = -.50, p < .01$), and age ($r = -.33, p < .01$). Thus, higher RAN times (slower naming of letters) were associated with lower scores on the reading measures. Correlations between RAN-letters and Vocabulary and Elision did not reach statistical significance ($ps > .05$).

Phonological awareness as measured by the Elision task, was significantly correlated with Word Attack ($r = .58, p < .01$), Word Identification ($r = 0.45, p < .01$), Reading Fluency ($r = .25, p < .05$), Passage Comprehension ($r = 0.35, p < .01$), and age ($r = .24, p < .05$). Correlations between Elision and Vocabulary, and Elision and RAN-Letters were not statistically significant ($ps > .05$).

4.3 Hierarchical Regression Analyses

4.3.1 Contribution of RAN to Reading Measures beyond Phonological Awareness

For purposes of statistical analyses raw scores for all measures were converted to z-scores. Using z-scores controls for sampling variance among the reading and cognitive measures. This allows comparisons between partial correlations in regression models.

In order to evaluate the unique contribution of RAN to reading achievement beyond the contribution of phonological awareness, a series of hierarchical regression analyses were performed with decoding, word identification, reading fluency and reading comprehension as criterion variables. As shown in Models 1a and 1b, altering the order of entry of RAN and phonological awareness into the regression equation compared the unique contribution of these two predictor variables to decoding after controlling for age and vocabulary. Model 1a (total $R^2 = .46, p < .01$) indicates that Elision accounted for 26% of variance in Word Attack beyond age and Vocabulary, and RAN-Letters accounted for a further 11% of unique variance in Word Attack beyond the variance attributable to Elision. Model 1b shows similar results when the order of entry is reversed. Following the entry of age and Vocabulary, RAN-Letters accounted for 12% of the variance in Word Attack, and Elision accounted for a further 24 % of unique variance beyond the variance explained by RAN-Letters.

Model 2a (total R^2=.46, $p < .01$) explores the unique contribution of RAN to word identification beyond phonological awareness. Elision accounted for 10 % of additional variance in Word Identification after age, and Vocabulary were entered into the model. RAN-Letters accounted for a further 16% of variance in Word Identification beyond the variance accounted for by Elision. Model 2b shows that when RAN-Letters is entered after age and Vocabulary, but before Elision, 17% of the variance in Word Identification is explained, followed by a further 9% of unique variance accounted for by Elision.

Model 3a (total R^2=.47, $p < .01$) examines the unique contribution of RAN to reading fluency beyond the contribution of phonological awareness. The results indicate that the contribution of Elision to Reading Fluency was not statistically significant when the effects of age and Vocabulary were controlled prior to the entry of Elision. RAN-Letters; however, accounted for 21 % of the variance in Reading Fluency beyond that attributable to age, Vocabulary and Elision. Model 3b shows that reversing the order of entry of Elision and RAN-Letters resulted in a similar pattern of results. RAN-Letters accounted for 21% of variance in Reading Fluency beyond that attributable to age and Vocabulary; however, Elision did not explain significant variance in the model beyond that explained by RAN-Letters.

Models 4a and 4b (total R^2=.48, $p < .01$) explore the contribution of RAN to reading comprehension beyond the contribution of phonological awareness. The results show that Elision did not account for unique variance in Passage Comprehension beyond that attributable to age and Vocabulary, whether entered in the regression equation before or after RAN-Letters. RAN-Letters, however, accounted for 14% of additional variance in Passage Comprehension when entered following age and Vocabulary, and 13% of additional variance beyond the contribution of age, Vocabulary and Elision.

In summary, these findings show that RAN explains unique variance in all four reading variables including decoding, word identification, reading fluency, and reading comprehension, beyond the contribution of phonological awareness. Phonological awareness, on the other hand, explained unique variance in only two of the four reading variables including decoding, and word identification.

4.3.2 Relations among RAN, Word Recognition Fluency, and Comprehension

In order to investigate the possible mediating role of RAN on the contribution of reading fluency to passage comprehension, a final set of hierarchical regression analyses were performed. As mentioned previously, for the purposes of this investigation reading fluency has been operationally defined as performance on the Reading Fluency subtest of the Woodcock-Johnson Tests of Achievement – 3rd Edition (Woodcock, McGrew & Mather, 2001). Models 5a and 5b indicate that Reading Fluency accounted for an additional 34% of unique variance in Passage Comprehension beyond the contributions of age and Vocabulary. RAN-Letters and Elision failed to contribute significant variance to the model beyond that explained by age, Vocabulary and Reading Fluency.

When RAN-Letters and Elision (Models 5c and 5d) are entered into the model following age and Vocabulary, but before Reading Fluency, the amount of variance in Passage Comprehension attributed to Reading Fluency was reduced from 34% to 19%. This reduction in variance explained by Reading Fluency was attributable entirely to RAN-Letters. As in earlier regression analyses, Elision did not significantly contribute to the prediction of Passage Comprehension. Model 5e indicates that when Elision is removed from the analysis the addition of RAN-Letters reduces the amount of variance in Passage Comprehension attributed to Reading Fluency from 34% to 21%.

Models 5f, 5g and 5h explore whether RAN contributes unique variance to the prediction of reading comprehension beyond that shared with word identification. Model 5f shows that when entered after age and Vocabulary, 29% of the variance in Passage Comprehension is explained by Word Identification. The variance in Passage Comprehension explained by RAN-Letters after variance attributable to Word Identification is taken into account does not reach statistical significance. However, Reading Fluency explains 5% of additional variance in passage comprehension beyond that explained by age, Vocabulary, Word Identification and RAN-Letters. Model 5g indicates that when RAN-Letters is entered to the model after age and Vocabulary, but before Word Identification and Reading Fluency, RAN-Letters accounts for 14 % of variance in Passage Comprehension and the variance attributed to Word Identification is reduced from 29% to 17%. Finally, Model 5h shows that when Reading Fluency is entered first into the equation, after age and Vocabulary, Word Identification fails to explain significant variance in Passage Comprehension.

In summary, these findings show that RAN did not account for unique variance in reading comprehension beyond that attributable to word identification and reading fluency. Rather, RAN's contribution to reading comprehension is through its shared association with accuracy and speed of word recognition.

CHAPTER 5: DISCUSSION

5.1 Theoretical Implications

The purpose of this study was to examine the role of rapid automatized naming in the reading achievement of a sample of community referred poor readers. Specifically, this study examined two main issues. First, the relationship between RAN and phonological processing for this group of poor readers was investigated. Second, it was of interest to determine whether RAN underlies the relations between reading fluency and reading comprehension.

5.1.1 Relations between RAN and Phonological Awareness

The sample of children who participated in this study performed in the low average range on measures of reading achievement across domains of decoding, word identification, reading fluency and reading comprehension. When sub-groups of poor readers based on criteria consistent with the Double-Deficit hypothesis were formed, over half (55%) of the poor readers in the study sample did not have a phonological awareness or a RAN deficit. However, 30% of the children met the criteria for a single phonological awareness deficit, 6% of the children were classified with a single RAN deficit, and 9% of the children met the cut-off criteria for a double-deficit in RAN and phonological awareness. Wolf & Bowers (1999) suggest that finding these subgroups of readers with either single or double deficits lends support to arguments for the separation of RAN from the family of phonological processes. The findings of the current study support this position and are consistent with previous studies (Badian, 1997; Manis et al., 2000; Wolf et al., 2002) which have identified poor readers with single and double deficits. The small number of children in this sample of low average readers identified with a deficit in RAN alone ($n = 4$) or in combination with a deficit in phonological awareness ($n = 6$), is consistent with findings that RAN is found to be strongly associated with word reading only for children with severe reading impairments (McBride-Chang & Manis, 1996). This sample may not have included enough severely impaired readers to find large numbers of the participants with RAN deficits.

The findings of this study are consistent with previous research that shows weak or non-significant correlations between phonological processing and rapid automatized naming (Blachman, 1984; Bowers, 1995, Cornwall, 1992; Felton & Brown, 1990; Wimmer, 1993; Wolf et al., 2002). The correlation between RAN and phonological awareness did not reach statistical significance ($r = -.11, p > .05$). Wolf & Bowers (1999) suggest that a robust correlation between the two variables would be anticipated if they were both to be considered phonological processes. Of significance, the findings in this study contrast with previous studies that report moderate correlations between RAN and phonological processing (Schatschneider et al., 2002; Wagner et al., 1994). Wolf and Bowers suggest that correlations between RAN and phonological awareness may be greater in unselected samples of children compared to samples of very disabled readers. However, the results from this study suggest that among samples of low average readers, the correlations between RAN and phonological awareness are not statistically significant.

In summary, the results of this study suggest that RAN and phonological awareness reflect unique constructs for some poor readers. Moreover, the results of the study suggest that among poor readers, phonological awareness and RAN are associated with different components of the reading process. Phonological awareness formed a moderate association with decoding and word identification, but was not associated with reading fluency and reading comprehension. On the other hand, RAN formed significant and moderate associations with all four reading variables including decoding, word identification, reading fluency and reading comprehension and these associations were independent from phonological awareness.

These results support the position (Wolf & Bowers, 1999) that RAN contributes uniquely to reading achievement, specifically Word Attack (partial $R^2 = .11, p < .01$), Word Identification (partial $R^2 = .16, p < .01$), Reading Fluency (partial $R^2 = .21, p < .01$), and Passage Comprehension (partial $R^2 = .13, p < .01$), beyond measures of phonological awareness. This unique contribution was clearly demonstrated within this sample of community referred low average readers.

5.1.2 Relations between RAN and Reading Comprehension

The second purpose of this study was to examine whether RAN mediates the effect of reading fluency on passage comprehension. The hierarchical regression analyses conducted showed that the variance in Passage Comprehension accounted for by RAN-Letters was not significant beyond the contribution of Reading Fluency. Therefore, although, RAN-Letters accounted for variance in Passage Comprehension beyond age, Vocabulary and Elision, the contribution of RAN to Passage Comprehension is entirely mediated by Reading Fluency. However, when entered first into the equation, RAN-Letters reduced the variance in Passage Comprehension accounted for by Reading Fluency from 34% to 21%. Taken together, RAN appears to mediate weak readers' development of reading comprehension through an association with reading fluency. These results are consistent with previous research and theories of reading that suggest for children to understand the text they read, they must quickly and effortlessly read words on the page in order to free up limited working memory space for higher order processing in the aid of text comprehension (Laberge & Samuels, 1974).

Taken together, the two findings, a) that RAN was not associated with phonological awareness and b) that RAN mediates the effect of reading fluency on reading comprehension, suggest that RAN may affect reading comprehension through processing of orthographic (not phonological) codes. Bowers (2001) suggests that this may reflect rapid integration of lower level visual, auditory and motoric (articulatory) processes with higher level lexical access.

A related issue concerns whether accuracy in word identification or rate of reading words is critical to the comprehension of text for poor readers. If reading fluency explains unique variance in reading comprehension, this could be seen as support that deficits in RAN as well as phonological processing may describe the poor reading of some children with reading comprehension difficulties. Results showed that Reading Fluency accounted for a small (partial $R^2 = .05$, $p < .01$) but significant amount of variance beyond the contribution of Word Identification, after age, Vocabulary, and RAN-Letters were taken into account; however, Word Identification did not significantly account for variance in Passage Comprehension beyond that explained by Reading Fluency. Taken together with the finding that RAN-Letters contributed unique variance to both Word Identification and Reading Fluency, these results indicate that RAN influences reading comprehension through shared variance with both accuracy and rate of word identification.

5.2 Implications for Practice

Several implications for practice arise from the findings from this study. The finding that more than half (55%) of the children referred to a remedial summer reading program did not have deficits in either RAN or phonological awareness suggests that although these constructs may have theoretical value, their usefulness for widespread screening for children "at-risk" for reading difficulties may be limited. Intervention efforts should be tailored to specific reading difficulties.

The majority of the children in this sample did not have deficits in phonological awareness; however, 39% of the children scored at or below the 25^{th} percentile on the Elision task. Therefore, although the current emphasis on phonological awareness in many early intervention programs may not be warranted for many low average readers, for many poor readers an emphasis on developing phonological awareness may be warranted. Further, the finding that 14.5% of the children had deficits in RAN either alone or combined with phonological deficits suggests the need for identification of RAN deficits in struggling readers, and targeted intervention in rapid naming of letters in the early stages of reading instruction for children identified with this deficit.

This study highlights the role of the rate of identification of letters and words in the reading process. Accurate and automatic word recognition is important in the ability to derive meaning from print (Adams, 1990; Laberge & Samuels, 1974). Therefore, in practice, schools should ensure adequate instructional time is devoted to the development of automaticity from the earliest levels of letter identification, through quick and effortless identification of individual words and accurate, automatic reading of connected text. It is accurate, automatic and effortless word recognition that will lay the foundation for children to comprehend text at a level that is commensurate with their general verbal ability (Torgesen, 2002).

5.3 Limitations

Several limitations of this study warrant discussion.

First, the sample of children participating in the study was selected on a volunteer basis and was not randomly selected. Thus, the sample may not be representative of the larger population of low achieving readers. The parents of these children agreed to bring their child up to the university for a one-hour testing session prior to the reading program and then ensure that their child was taken to the university every day for three weeks in the summer to participate in a reading program. These children may live in families who place a high value on learning to read and they may differ from low achieving readers whose parents did not enrol them in a remedial reading program.

Second, this study was limited to 70 participants. Although some previous research has involved small sample sizes (Bowers, 1993; Levy et al., 1997; Manis et al., 2000; Pennington et al., 2001; Sabatini, 2002), larger samples increase the statistical power of the analyses. Also, the standard deviations for the cognitive and reading achievement measures used were smaller than the norming samples for the standardized tests. This suggests that the distribution of scores was narrow and this might have been a very homogeneous group of low average readers, not representative of a larger population of children with reading difficulties.

Third, although phonological awareness and verbal ability are complex cognitive constructs, a single measure of each construct was used in the study. Phonological awareness was measured with the Elision task. Incorporating other measures of phonological awareness such as Blending Phonemes may have strengthened the analyses. Also, a measure of vocabulary was utilized to estimate and control for general verbal ability.

5.4 Future Directions for Research

Although results of this study contribute to the literature regarding the contribution of rapid automatized naming to reading achievement, several areas for further inquiry are apparent.

First, this study included a small volunteer sample of children with low average reading achievement. Future research utilizing a larger sample of children with more diverse reading achievement would help to clarify the role of RAN beyond phonological awareness for children with a wider range of reading achievement. Further, a larger sample of children with a wider range of reading achievement may permit analyses involving single and double deficit groups such that investigations into the severity of reading impairments by group could be undertaken.

Second, undertaking a quasi-experimental intervention study would extend this study's correlational analysis to a causal analysis. Questions to investigate include: Is rapid automatized naming amenable to intervention? Does improving RAN lead to improved reading fluency and reading comprehension?

Finally, extensive further research into the nature of processing involved in RAN and its contribution to reading disability is necessary to provide some clear convergence of results. At this time, the body of work regarding RAN as an extra phonological contributor is largely divergent.

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TABLES

Table 1

Sample Description

	Raw Score Mean (*SD*)	Range	Standard Score Mean (*SD*)	Range
Age in Months	109.62 (9.19)	94 - 131	n/a	n/a
SB:IV** Vocabulary	22.48 (2.51)	16 – 27	99.74 (11.22)	74 - 120
RAN-Letters	41.35 (10.51)	26.00 -79.47	10.04 (2.27)	6 - 14
Elision	10.62 (4.42)	4 - 19	8.56 (2.47)	4 - 15
Word Attack	12.67 (5.62)	3 - 26	93.30 (8.15)	70 - 114
Word ID	40.32 (6.55)	19 - 51	91.30 (8.59)	69 - 111
Reading Fluency	26.77 (12.09)	0 - 49	94.10 (9.69)	68 - 116
Passage Comprehension	22.81 (3.97)	9 - 31	91.00 (6.94)	71 - 107

**SB:IV = Stanford Binet Intelligence Scale: Fourth Edition

Table 2

Pearson Inter-Correlations among Reading, Age, Vocabulary, RAN and Phonological Variables

		1	2	3	4	5	6	7	8
1.	Word Attack	—	.76**	.56**	.44**	.33**	.08	.58**	-.44**
2.	Word Identification		—	.83**	.71**	.46**	.22	.45**	-.54**
3.	Reading Fluency			—	.78**	.50**	.27*	.25*	-.59**
4.	Passage Comprehension				—	.52**	.44**	.35**	-.50**
5.	Age in Months					—	.38**	.24*	-.33**
6.	Vocabulary						—	.22	-.04
7.	Elision							—	-.11
8.	RAN-Letters								—

**p<0.01 (2-tailed), *p<0.05 (2-tailed)

Model 1 a

Prediction of Word Attack with Elision Entered First Into the Equation

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.10	0.10	7.50	0.01
Vocabulary	0.00	0.10	0.10	0.75
Elision	0.26	0.36	26.18	0.01
RAN-Letters	0.11	0.46	12.50	0.01

Model 1 b

Prediction of Word Attack with RAN-Letters Entered First Into the Equation

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.10	0.10	7.50	0.01
Vocabulary	0.00	0.10	0.10	0.75
RAN-Letters	0.12	0.22	9.98	0.01
Elision	0.24	0.46	29.03	0.01

Model 2 a

Prediction of Word Identification with Elision Entered First Into the Equation

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.19	0.19	16.07	0.01
Vocabulary	0.01	0.20	0.44	0.51
Elision	0.10	0.30	9.09	0.01
RAN-Letters	0.16	0.46	18.49	0.01

Model 2 b

Prediction of Word Identification with RAN-Letters Entered First Into the Equation

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.19	0.19	16.07	0.01
Vocabulary	0.01	0.20	0.44	0.51
RAN-Letters	0.17	0.37	17.31	0.01
Elision	0.09	0.46	10.25	0.01

Model 3 a

Prediction of Reading Fluency with Elision Entered First Into the Equation

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.24	0.24	21.00	0.01
Vocabulary	0.01	0.25	0.85	0.36
Elision	0.01	0.26	1.12	0.30
RAN-Letters	0.21	0.47	24.88	0.01

Model 3 b

Prediction of Reading Fluency with RAN-Letters Entered First Into the Equation

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.24	0.24	21.00	0.01
Vocabulary	0.01	0.25	0.85	0.36
RAN-Letters	0.21	0.46	25.37	0.01
Elision	0.01	0.47	1.02	0.32

Model 4 a

Prediction of Passage Comprehension with Elision Entered First Into the Equation

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.24	0.24	21.39	0.01
Vocabulary	0.08	0.32	7.56	0.01
Elision	0.03	0.35	2.73	0.10
RAN-Letters	0.13	0.48	16.03	0.01

Model 4 b

Prediction of Passage Comprehension with RAN-Letters Entered First Into the Equation

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.24	0.24	21.39	0.01
Vocabulary	0.08	0.32	7.56	0.01
RAN-Letters	0.14	0.46	16.23	0.01
Elision	0.02	0.48	2.74	0.10

Model 5 a

Prediction of Passage Comprehension with Reading Fluency Entered First Into the Equation Followed by Elision and then RAN-Letters

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.24	0.24	21.39	0.01
Vocabulary	0.08	0.32	7.56	0.01
Reading Fluency	0.34	0.66	64.03	0.01
Elision	0.01	0.67	1.59	0.21
RAN-Letters	0.01	0.67	1.06	0.31

Model 5 b

Prediction of Passage Comprehension with Reading Fluency Entered First Into the Equation Followed by RAN-Letters and then Elision

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.24	0.24	21.39	0.01
Vocabulary	0.08	0.32	7.56	0.01
Reading Fluency	0.34	0.66	64.03	0.01
RAN-Letters	0.01	0.66	0.97	0.33
Elision	0.01	0.67	1.66	0.20

Model 5 c

Prediction of Passage Comprehension with Elision Entered First Into the Equation Followed by RAN-Letters and then Reading Fluency

Step	Partial R^2	Model R^2	*F* Change	Probability
Age	0.24	0.24	21.39	0.01
Vocabulary	0.08	0.32	7.56	0.01
Elision	0.03	0.35	2.73	0.10
RAN-Letters	0.13	0.48	16.03	0.01
Reading Fluency	0.19	0.67	37.00	0.01

Model 5 d

Prediction of Passage Comprehension with RAN-Letters Entered First Into the Equation Followed by Elision and then Reading Fluency

Step	Partial R^2	Model R^2	*F* Change	Probability
Age	0.24	0.24	21.39	0.01
Vocabulary	0.08	0.32	7.56	0.01
RAN-Letters	0.14	0.46	16.23	0.01
Elision	0.02	0.48	2.74	0.10
Reading Fluency	0.19	0.67	37.00	0.01

Model 5 e

Prediction of Passage Comprehension with RAN-Letters Entered First Into the Equation Followed by Reading Fluency

Step	Partial R^2	Model R^2	*F* Change	Probability
Age	0.24	0.24	21.39	0.01
Vocabulary	0.08	0.32	7.56	0.01
RAN-Letters	0.14	0.46	16.23	0.01
Reading Fluency	0.21	0.66	39.21	0.01

Model 5 f

Prediction of Passage Comprehension with Word Identification Entered First Into the Equation Followed by RAN-Letters and then Reading Fluency

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.24	0.24	21.39	0.01
Vocabulary	0.08	0.32	7.56	0.01
Word ID	0.29	0.61	47.38	0.01
RAN-Letters	0.02	0.63	3.28	0.08
Reading Fluency	0.05	0.68	10.19	0.01

Model 5 g

Prediction of Passage Comprehension with RAN-Letters Entered First Into the Equation Followed by Word Identification and then Reading Fluency

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.24	0.24	21.39	0.01
Vocabulary	0.08	0.32	7.56	0.01
RAN-Letters	0.14	0.46	16.23	0.01
Word ID	0.17	0.63	29.09	0.01
Reading Fluency	0.05	0.68	10.19	0.01

Model 5 h

Prediction of Passage Comprehension with Reading Fluency Entered First Into the Equation Followed by Word Identification and then RAN-Letters

Step	Partial R^2	Model R^2	F Change	Probability
Age	0.24	0.24	21.39	0.01
Vocabulary	0.08	0.32	7.56	0.01
Reading Fluency	0.34	0.66	64.03	0.01
Word ID	0.02	0.67	3.30	0.07
RAN-Letters	0.00	0.68	0.73	0.40