University of Alberta

Rapid Naming Speed Components and Early Reading Acquisition

by

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To my grandmother Andriani
for her love and understanding

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CHAPTER 1

INTRODUCTION

Over the last three decades, it has been systematically shown that rapid automatized naming (RAN) speed, defined as how quickly children can name continuously presented and highly familiar visual stimuli, is a powerful predictor of both concurrent and future reading development in alphabetic (Ackerman & Dykman, 1993; Blachman, 1984; Bowers, 1995; Bowers, Steffy, & Swanson, 1986; Bowers & Wolf, 1993; Denckla & Rudel, 1976; Denckla & Cutting, 1999; Felton & Brown, 1990; Kirby & Parrila, 1999; Parrila, Kirby, & McQuarrie, 2004; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Sprugevica & Hoien, 2003; Wagner & Torgesen, 1987) as well as in non-alphabetic writing systems (Chan, Ho, Tsang, Lee, & Chung, 2003; Ho, Chan, Tsang, & Lee, 2000; Ho & Lai, 2000; McBride-Chang, Cho, Wagner, & Shu, 2004). An upsurge of interest in the use of rapid naming speed occurred after the pioneering studies by Denckla and Rudel (1974, 1976), which demonstrated that dyslexic children were not significantly different from normal readers in color naming accuracy, but were significantly less proficient in color naming speed.

Since that time, an accumulated body of evidence has indicated that fast performance on a RAN task is related to better reading ability and conversely that slow naming speed is associated with the presence of reading difficulties. RAN performance can distinguish average from poor readers during childhood (e.g., Badian, Duffy, Als, & McAnulty, 1991; Bowers & Swanson, 1991; Cornwall, 1992; Wolf, Bally, & Morris, 1986) and into adulthood (Felton, Naylor, & Wood, 1990; Korhonen, 1995). In addition, even after statistically controlling for IQ (Badian, 1993, Cornwall, 1992; Hulslander et al., 2004), reading experience (Badian, 1993; Parrila et al., 2004), attention deficit disorder (Ackerman & Dykman, 1993; Compton, Olson, DeFries, & Pennington, 2002), socioeconomic status (Felton et al., 1990; Swanson, Trainin, Necoechea, & Hammill, 2003), articulation rate (Parrila et al., 2004), and, most importantly, phonological awareness (e.g., Bowers, 1995; Bowers & Swanson, 1991; Cornwall, 1992; Kirby, Parrila, & Pfeiffer, 2003; Manis, Doi, & Bhadha, 2000), RAN has survived as a predictor of reading.

Despite the improved understanding of RAN and its relation to reading, Kirby et al. (2003) pointed out that studies vary greatly as to when predictors like phonological awareness and RAN are measured, what and how many predictors are used, what other predictors are included in the equations, whether the design of the study is cross-sectional or longitudinal, and whether covariates are included. In addition to methodological variations in the designs of RAN studies, issues that can be considered unresolved are the independence of phonological awareness and RAN, whether phonological awareness and RAN reliably predict different reading outcomes, whether RAN should be seen as a phonological construct, whether RAN should be measured with tasks involving school-learned content (such as letters or digits), and whether RAN should be conceptualized as a speed of processing measure.

Undoubtedly, the question that has intrigued the reading community is what does RAN measure and why it is related to reading. Bowers, Golden, Kennedy, and Young (1994) proposed that RAN performance reflects how rapidly and effortlessly individuals can access the names of common symbols (i.e., digits and letters), which then has a significant effect upon learning and retrieving orthographic patterns. In turn, this ability is indicative of how quickly the lexical representations of written words are accessed. Children who are slow in the RAN tasks are expected to have problems abstracting orthographic regularity from print, presumably due to slow access to letter codes (see e.g., Martens & de Jong, 2004). For example, if a child is slow in identifying individual letters, representations of single letters in a word will not be activated quickly enough to allow sensitivity to letter patterns that occur frequently in print. These children have difficulty forming memory representations of letter patterns in words and, therefore, poor sight vocabulary processing skills. Inevitably, if the sight vocabulary of these children is compromised, then it is expected that their spelling ability will be also poor.

Wile and Borowsky (2004) suggested an alternative account. According to them, RAN letters and RAN digits may reflect some form of sight vocabulary processing. Specifically, they assumed that single digits and letters could be thought of as learned symbols that, over time, become part of an individual's lexical representations, and thus should be accessed rapidly and effortlessly by skilled readers. How rapidly and effortlessly individuals can access the names of the common RAN symbols is then an indicator of how well and quickly the lexical representations of written words are accessed later in reading development.

Neuhaus, Foorman, Francis, and Carlson (2001a), in turn, provided evidence to support the view that reading ability is predicted by speed of processing associated with accessing the letter representations (measured by the pause time during the RAN task), and not by general processing speed (measured by articulation time during the RAN task). Neuhaus et al. (2001a) found that pause time in a Letter Naming task was the strongest predictor of word reading ability and reading comprehension. These examples make it clear that further research is needed before RAN's contribution to reading is fully delineated.

Purpose of the Proposed Research

Several studies with children varying in reading competence, age, and in languages other than English have accentuated the important role of RAN in the development of reading. The purpose of this study is to first examine how RAN performance develops from kindergarten to the end of grade 1. Second, I will examine how performance in different RAN tasks is related to reading ability at the beginning and the end of grade 1. Third, I will look at how RAN components, particularly the pause time and the articulation time, develop from kindergarten to the end of grade 1 and how they are related to different reading measures and to RAN total time. Finally, I will examine which RAN components differentiate best between poor and good readers. The main focus of this study is on the contribution RAN components have on reading as this question has not been examined thoroughly before.

CHAPTER 2

LITERATURE REVIEW

This literature review will first discuss the relationship between RAN and reading ability, focusing on several factors that affect this relationship, such as the characteristics of the sample studied and the type of RAN task used. Next, several theories that attempted to account for how RAN is related to reading will be reviewed. Finally, the literature on the main issue of interest in this thesis, the relationship of RAN components with reading, will be presented. After summarizing the literature, I will present the proposed model to be tested.

Relationship Between Rapid Naming Speed and Reading Ability

Several researchers have pointed out the importance of RAN in predicting reading ability (Bowers, 2001; Manis et al., 2000; Scarborough, 1998b; Torgesen et al., 1997; van den Bos, 1998; Wolf, 1991). RAN is considered relevant to reading because it is indicative of how readily children can gain access to a sound or a word meaning and efficiently process long, ordered strings of items. However, the magnitude of the relationship between RAN and reading measures varies greatly depending on the format of the RAN task (discrete or serial naming), the type of the stimuli presented in the RAN task (colors, objects, letters, or digits), the age of the students at the time when the RAN tasks are administered and the reading level of the students (poor readers, average readers, dyslexics). Although the cause of variability in children's naming speed is not fully understood, converging evidence suggests that a deficit in serial naming speed is a characteristic of reading difficulty from the early stages of reading to adulthood. In the following three parts of this literature review I will go through the RAN literature based on the effects of the RAN format, the type of the RAN stimuli, and the age and the reading ability of the students.

Effect of RAN Format

Early on in RAN research, methodological debate centered on whether or not RAN would still contribute to reading success if the items were presented in a discrete format rather than in the continuous format used in the traditional version of the task developed by Denckla and Rudel (1974, 1976). In the discrete format the items are presented individually and the naming latencies for the items are averaged, whereas in the continuous format all items (colors, objects, digits or letters) are presented simultaneously and the child's score is the total time to name all the items consecutively or the number of items named in a second. Advocates of a discrete-trial format have argued that it is a pure measure of naming speed since it eliminates those processes of sequential scanning, peripheral preprocessing of adjacent information, motoric requirements, and other extraneous sources of variance that are present in continuous trial formats (e.g., Fawcett & Nicolson, 1994). Advocates of continuous formats argue that it is exactly these various components that relate RAN with reading (Bowers & Swanson, 1991; Share, 1995; Torgesen, Wagner, Simmons, & Laughon, 1990; Walsh, Price, & Gillingham, 1988; Wolf & Bowers, 1999).

Results from several studies indicate that the correlation between RAN performance and reading is generally higher for serial (continuous) naming than for discrete naming (e.g., Hecht, Torgesen, Wagner, & Rashotte, 2001; Torgesen, Wagner, & Rashotte, 1994). Furthermore, there are conflicting research findings as to whether or not discrete trial RAN discriminates good and poor readers. Some researchers (e.g., Stanovich, 1981) have found that the discrete trial RAN does not discriminate good and poor readers, whereas others have found that it does (e.g., Bowers & Swanson, 1991; Fawcett & Nicolson, 1994). In contrast to discrete trial studies, studies using continuous format tasks have consistently found that RAN discriminates average from poor readers even among adults (Felton et al., 1990). In their 1991 study, Bowers and Swanson found that even after entering discrete trial naming speed first in the regression equation, the continuous format naming speed added uniquely to predicting reading ability.

Effect of Type of Stimuli

In addition to investigating differences between the different formats of RAN tasks, several studies turned their interest to questions regarding the relative predictive value of the various stimulus categories (letters, digits, colors, and objects) when using the serial RAN task. Two broad categories have been proposed: the alphanumeric or graphological, comprised of the letter and digit naming tasks, and the nonalphanumeric or nongraphological, which include the color and object naming tasks. Generally, it has been reported that performance on the alphanumeric tasks is more closely related to reading development than is performance on the serial naming of nonalphanumeric symbols (e.g., Cardoso-Martins & Pennington, 2004; Uhry, 2002; van den Bos, Zijlstra, & lutje Spelberg, 2002). The alphanumeric advantage as a predictor of reading skill likely develops only after children develop automatic processing of letters and numbers (Compton, 2003; Meyer, Wood, Hart, & Felton, 1998). Wolf et al. (1986) reported that naming speed for all stimulus categories in kindergarten was significantly related to future reading performance in second grade. However, only rapid naming of alphanumeric symbols concurrently predicted reading skill in second grade. It is also noteworthy that differences between good and poor readers tend to be larger for alphanumeric stimuli than for nonalphanumeric stimuli (Bowers, Steffy, & Tate, 1988; Felton & Brown, 1990; Murphy, Pollatsek, & Well, 1988; Wolf, 1999; Wolf et al., 1986).

Although the majority of research has shown that color naming and object naming are less powerful than letter naming and digit naming, some studies have suggested that there are no major differences in the predictive power between the two sets of predictors. Kirby et al. (2003) showed that color and object naming tasks administered in kindergarten could still account for significant variance in word reading in grade 5. Scarborough (1998b) found that RAN colors and RAN objects measured in grade 2 were predictive of grade 8 word identification scores, but only for impaired readers. Likewise, Meyer et al. (1998) found that performance on all four versions of the RAN task in grade 3 predicted equally well word identification scores in grade 5 and grade 8; but again, this was true only for the group of poor readers. Lastly, in Scarborough's (1998a) meta-analysis, the two sets of predictors were comparable (median $r = .39$ for Color and Object Naming, median $r = .38$ for Letter and Digit Naming).

Effects of Age and Reading Ability

Several studies have pointed out that the strength of the relation between RAN performance and reading may be affected by the age and the reading ability of the sample of children used in studies (e.g., McBride-Chang & Manis, 1996; Meyer et al., 1998; Scarborough, 1998b). Some researchers have argued that the relation between RAN and reading is stronger for readers of low skill, either young children in the early stages of reading development, or older impaired readers. For example, Blachman (1984) measured RAN performance in children of all levels of reading ability in kindergarten and grade 1 and found naming speed on the RAN task to be significantly correlated with word identification scores. Wagner et al. (1997) investigated the relative contribution of RAN and phoneme awareness to later reading ability in three developmental periods: from kindergarten to second grade, from first to third grade, and from second to fourth grade. After controlling for phoneme awareness, RAN predicted word reading significantly only in the first two developmental periods. These studies suggest that for young, inexperienced readers, RAN performance is related to reading across all levels of reading ability.

Cardoso-Martins and Pennington (2004) directly compared the effects of reading level and age in a longitudinal study that covered two developmental periods: kindergarten to grade 1 and grade 1 to grade 2. Two groups of children participated in their study: children of high and children of low familial risk for developmental dyslexia. Cardoso-Martins and Pennington hypothesized that RAN should be more strongly correlated with reading and spelling ability at the first than at the second developmental period and in high–risk than in low–risk children. In contrast, phoneme awareness should be a better predictor at the second developmental period and in low–risk than in high–risk children. The results from hierarchical regression analyses only partially supported their hypotheses. Indeed, RAN was more predictive of literacy outcomes in the high–risk than in the low–risk group. However, in the low–risk group the results did not vary with developmental period, and in the high–risk group the results were opposite to what was predicted as RAN had a larger effect in the second developmental period.

McBride-Chang and Manis (1996) examined the differential relation between RAN performance and reading ability in normally achieving and poor readers in grade 3 and 4. They found that for poor readers, the children with the slowest RAN scores were the children with the poorest reading scores. However, for the normally achieving readers, there was no relationship between RAN and reading ability. Other studies have also found little relation between RAN and reading ability in average or good readers. Scarborough (1998b) found that the RAN scores measured in grade 2 were predictive of grade 8 word identification scores only for poor readers. In the same vein, Meyer et al. (1998) found that grade 3 RAN scores were predictive of grade 5 and 8 word identification scores only for the poor readers in their sample. Surprisingly, Swanson et al. (2003) called into question the above findings by demonstrating in their meta-analysis that after correcting for sample size, restriction of range, and attenuation, the correlations between RAN and reading were substantially weaker for poor readers than for skilled readers.

With older children, the relationship between reading ability and RAN is less clear. Although it appears that across all ages, poor readers are slower on RAN tasks than are average or good readers (e.g., Bowers & Swanson, 1991; Felton et al., 1990; Meyer et al., 1998; Parrila, Corkett, & Georgiou, 2004; Scarborough, 1998b; Vukovic, Wilson, & Nash, 2004; Wolf, 1997), it has been argued that the predictive power of RAN diminishes for normally achieving children as they get older. For example, Vukovic et al. (2004) carried out two regression analyses to predict reading comprehension. Their sample consisted of 25 reading disabled university students and 28 control university students. To determine the predictive value of vocabulary, phoneme deletion, and naming speed, the variance of reading comprehension was partitioned using the Pratt Index method. Of the total of 38% of variance accounted for by the model, vocabulary accounted for 32.2%, phoneme deletion accounted for 7.2%, and RAN accounted for 60.4% of the explained variance. RAN was by far the most important independent variable in the model. However, in a second regression analysis, when reading rate and vocabulary were controlled, neither phoneme deletion nor RAN accounted for unique variance in reading comprehension.

van den Bos et al. (2002), in turn, reported that in their cross-sectional study the correlation between the alphanumeric factor and reading steadily increased with age. In their group of 82 Dutch adults without any reported reading problems (mean age 46 years old), the correlation between the alphanumeric factor and reading speed was .53. Taken together, these findings suggest that the relation between RAN and reading continues to exist in older readers, but more research is needed before we can say exactly which aspects of reading are correlated with RAN at different ages and which are not.

Summary

The focus of this part of the literature review has been on those factors that determine the strength of the relationship between RAN and reading. Converging research findings suggest that RAN performance is not only related to reading, but also a reliable predictor of future reading ability. The strength of the RAN – reading relationship appears to be affected by the format of the RAN task, the version of the

RAN task used, and the characteristics of the sample, such as age and reading competence. Generally, for younger and inexperienced children, RAN performance is related to reading for readers of all ability and with all versions of the RAN task. In contrast, for older readers, RAN performance is most robustly related to reading for less proficient readers and when either RAN-digits or RAN-letters are used. The next section examines the theories of the underlying mechanisms that drive the relationship between RAN and reading.

Theories of the RAN – Reading Link

Although RAN has been found to consistently account for unique variance in reading ability, the RAN - reading link remains the focus of ongoing debate. Various researchers have developed competing models to explain the relationship between RAN and reading performance in typically developing and reading-disabled individuals. On the one hand, Torgesen, Wagner, and their colleagues (see Torgesen et al., 1994; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Wagner & Torgesen, 1987; Wagner et al., 1997) have argued that RAN tasks assess the rate of access to and retrieval of stored phonologically based information from long-term memory, and therefore, they should be considered as phonological processing measures. On the other hand, Bowers, Wolf, and their colleagues (see Bowers, 1995; Bowers & Wolf, 1993; Wolf, 1991, 1999; Wolf, Bowers, & Biddle, 2000) have asserted that RAN's emphasis on skills such as processing speed and the integration of lower level visual processes with higher level cognitive and linguistic processes dictates that RAN be considered a separate cognitive processing skill related to reading. In the sections to follow I will attempt to describe in more depth the different theories and models that have been developed to link RAN performance to reading ability.

RAN and Phonological Processing

Although the relationship between RAN and reading is well established, it is unclear what underlying processes are driving this relationship. Torgesen, Wagner, and their colleagues (Torgesen et al., 1994; Torgesen et al., 1997; Wagner et al., 1997) subsumed RAN under the phonological processing family and maintained that RAN is an index of the ease and speed with which we access phonological information from the long term memory. It is not therefore surprising that at the term "phonological recoding in lexical access" has been used to represent rapid naming (see e.g., Wagner, 1986; Wagner & Torgesen, 1987).

Before reviewing the different studies conducted by Torgesen and Wagner's team it is crucial to provide a description of the basic constructs that dominate their research. They defined phonological processing as the ability to use phonological information – information about the sound structure of one's language – in processing oral and written language. As a construct, phonological processing was estimated by three broadly different but moderately related variables: phonological awareness, phonological recoding in lexical access, and phonetic recoding in working memory. Phonological awareness was defined as one's awareness of, and access to, the sound structure of oral language. Phonological recoding in lexical access (rapid naming) was considered to be the process of getting from a written word to its lexical referent by recoding the word into a sound based representational system. Phonetic recoding in working memory (phonological memory) was conceptualized as the process of recoding written symbols into a sound based representational system for efficient storage in working memory. Early on, Torgesen and Wagner (1987) expressed their concerns about the number of the latent phonological abilities. They argued that the phonological tasks commonly used to measure awareness, recoding in lexical access, and recoding in working memory might be measures of a general latent ability or, alternatively, that phonological awareness, phonological recoding in lexical access, and phonetic recoding in working memory might represent separate latent variables.

To shed some light on their concerns, Wagner et al. (1993) conducted a cross-sectional study of 184 kindergarten and 2nd grade students. The purpose of their study was to compare the degree to which five alternative models of the relationships among the phonological processing abilities fitted the data for the kindergarten and second-grade samples. The five models were (a) base (specific ability) model, according to which there are separate underlying abilities that account for individual differences in tasks that assess phonological awareness, phonological recoding in working memory, and retrieval of phonological codes from long-term memory; (b) general ability model, according to which there is a single underlying ability that is manifested in individual differences on each of the three kinds of phonological processing tasks; (c) awareness and use model, according to which there are two underlying abilities, the first being the conscious awareness of the phonological structure of the language and the second being the actual use of the phonological codes; (d) awareness/memory and code retrieval model, according to which there are two underlying abilities or funds of information, the first of which accounts for individual differences on both awareness and memory tasks, and the second of which accounts for performance in naming tasks; and (e) awareness/code retrieval and working memory model, according to which there are also two underlying abilities, the first of which accounts for individual differences on awareness tasks and naming tasks, and the second of which accounts for performance on memory span tasks.

Confirmatory factor analysis with a sample of kindergarten children revealed that the best-fitting model was a variant of the Awareness/Memory and Code Retrieval model. This model proposed a single underlying source of individual differences for analysis, which is the ability to segment larger units of speech into smaller units, and memory span tasks, with other correlated sources of individual differences for synthesis, that is the ability to blend smaller units of speech to form larger units, and the two kinds of naming speed (discrete and serial naming). In contrast to the best-fitting model for kindergarten, the best-fitting model for the second grade data supported separate but highly correlated latent abilities on analysis and memory tasks along with the synthesis and the two naming tasks.

From then on, five distinct latent variables (phonological analysis, phonological synthesis, working memory, isolated naming, and serial naming) were used in several studies (mainly longitudinal) conducted by Torgesen, Wagner, and their colleagues (see Torgesen et al., 1997, for a review). A general conclusion derived from these studies was that the effect of rapid naming, serial or discrete, on reading, was overshadowed by the effect of phonological analysis.

Of great importance to the influence of the phonological processing variables on reading was the inclusion of an autoregressor variable (reading achievement at an earlier point of development) in the prediction of later reading. The autoregression technique rules out both prior reading skill and growth in reading that is predictable from prior reading skill (expected growth). Therefore, the phonological processing measures are forced to enter into the regression equation with the hope of accounting for the remaining, unexpected growth in reading. If the criterion variables have stable individual differences, there may be very little unexpected growth and, hence, small contributions of the predictors are expected (see Manis et al., 1999, for a critique). For example, Torgesen et al. (1994) showed that when each of the phonological processing measures was examined individually, the path coefficient for RAN on reading was .37. However, when all the phonological processing measures were allowed to be simultaneous causes of variation in word reading, only phonological analysis was significant along with the autoregressor. Torgesen et al. (1994) concluded that the causal influences of different phonological processing skills on reading development are redundant. In a subsequent large scale longitudinal study, Torgesen et al. (1997) carried out regression analyses to investigate the relative contribution of phonological awareness and RAN on reading from grade 2 to 4, and from grade 3 to 5. In both analyses, each of these variables contributed unique variance to later reading. However, when autoregressor was included in the regression equation at the first step, only phonological awareness still accounted for additional variance.

Torgesen et al. (1997) defended the use of the autoregression technique maintaining that "unless the autoregressive effects of prior reading level are included in these kinds of predictive analyses, it is impossible to know whether rapid naming independently influenced growth in reading over the developmental period in question" (p. 165). In contrast, Wolf and Bowers (1999) argued that

> when a predictor is not significant in an autoregression analysis, the interpretation that the variable no longer has effects is only one possibility among several [...] the effects of naming speed may continue over time, affecting later word recognition in a manner indistinguishable from the effects on earlier reading. (p. 422)

Although it is important to keep in mind the different arguments in favor or against the use of the autoregression technique when conducting longitudinal research, there is still sufficient evidence to suggest that although performance on the RAN tasks shares some variance with performance on phonological tasks, it is not necessarily this shared variance that mediates the relationship between RAN and reading. Parrila et al. (2004) conducted commonality analyses with kindergarten phonological processing variables and grade 1 to grade 3 reading outcomes and showed that the elements common to RAN and phonological awareness were less important predictors of reading than the unique contributions of these tasks. They suggested that "what is unique to these tasks is more important in terms of prediction of reading variance than what they share" (p.16).

Similarly, RAN has been shown to account for unique variance in reading ability that is not accounted for by phonological awareness (Kirby et al., 2003; Swanson et al., 2003; Wolf & Bowers, 1999; Wolf et al., 2002). For example, Manis et al. (1999) examined whether RAN and phonological processing skills measured in grade 1 would predict unique variance in grade 2 reading skills. They found that RAN accounted for unique variance in word recognition separate from that accounted for by phonological awareness and that this relationship was present even after factoring out the earlier reading levels of the children. Moreover, studies that used methods like cluster analysis to search the naturally occurring subtypes of reading disability have found evidence for a subtype with impairments in both phonological awareness and naming speed and for subtypes with impairment only in phonological awareness or only on naming speed (Morris et al., 1998).

Additional evidence in support of a distinctive role of RAN in reading has been provided by studies pursued in languages with a transparent orthography (such as German, Finnish, and Dutch). Poor readers in these languages have been reported to have deficits in RAN, but to a lesser degree in phonological awareness tasks (e.g., de Jong & van der Leij, 1999; Korhonen, 1995; van den Bos, 1998; Wimmer, 1993). In languages with a transparent orthography phonological demands are more easily met than in English due to the higher regularity of grapheme-phoneme correspondences. Thus, even poor readers read remarkably accurately, although slowly. In addition, accuracy levels in word identification and word attack tasks are already high by grade 1 and in some reading populations (i.e. Finnish) exceed 90% (see Aro & Wimmer, 2003, for a comparison of reading skills across several European languages).

Working with Dutch-speaking children, de Jong and van der Leij (1999) demonstrated that when phonological awareness, verbal short-term memory, and naming speed were measured in kindergarten, only naming speed was a significant predictor of grade 1 and grade 2 reading outcomes. In a subsequent study, de Jong and van der Leij (2002) further indicated that when measured at the end of grade 1, both phonological awareness and naming speed made unique contributions to predicting grade 3 word decoding speed, after controlling for grade 1 word decoding speed and vocabulary. Wimmer, Mayringer, and Landerl (2000), in turn, found that German-speaking Austrian children classified as having a naming speed deficit upon school entry continued to be impaired in naming speed at the end of grade 3. These children also showed deficits in reading speed compared to children with no naming speed deficit.

Armed with several research findings indicating that RAN and phonological awareness represented independent processes, Wolf, Bowers, and their colleagues (Wolf & Bowers, 1999; Wolf, 1999; Wolf et al., 2000) begun to consider RAN as a complex ensemble of multiple processes that included, but were not limited to, phonological processes. In their 1999 review paper, Wolf and Bowers presented a cognitive model of visual naming. According to this model, at a basic level, naming requires (a) attention to the stimulus, (b) modality-specific information and its cumulative integration, (c) working memory and stored knowledge of the stimulus, (d) integration of conceptual information with stored lexical (i.e., phonological and semantic) information, (e) access and retrieval of the phonological label, (f) motoric activation leading to the articulation of the stimulus label, and (g) rapid rates of processing within and across all the individual subprocesses. External factors such as stimulus clarity, rate of presentation, word frequency, familiarity level, and age of the subjects were also included as influences on speed and accuracy of retrieval. With their model Wolf and Bowers (1999) made clear that phonological processes are only one set of processes among many and that with multiple subprocesses there can be different possible sources of slow naming speed.

Wolf and Bowers (1993, 1999) further proposed the *double-deficit hypothesis* of reading difficulties. According to the double-deficit hypothesis, it is possible to identify four categories under which children can be classified: a single naming speed deficit group, a single phonological awareness deficit group, a double deficit group (combined deficit in naming speed and phonological awareness), and a no-deficit or double-asset group. Several studies have found that RAN impaired readers are accurate but slow decoders, phonologically impaired readers are inaccurate decoders but faster than RAN impaired readers, and double-deficit readers are the poorest readers overall (see e.g., Lovett, Steinbach, & Frijters, 2000; Wolf, 1997, 1999; Wolf et al., 2002). Interestingly, Kirby et al. (2003) showed that children with weak phonological awareness and slow naming speed in kindergarten were most likely to develop reading difficulties by Grade 5 followed by children with naming speed deficit alone.

To summarize, four main lines of evidence indicate that RAN is a separate source of reading problems that is distinct from the phonological family. First, RAN tasks have consistently predicted reading beyond what was accounted for by phonological awareness. Second, research findings support the idea that deficits in phonological awareness are not in the root of reading problems in languages characterized by a transparent orthography. Although children in these languages are able to master successfully the phonological demands, they still manifest difficulties in reading fluency. There is abundant evidence that this fluency problem is predicted reliably by the performance on the RAN tasks. Third, studies that used methods like cluster analysis illustrated that among the reading disabled children there was a group with deficits only in rapid naming speed. Fourth, studies that have grouped children into different deficit subtypes have demonstrated that children with deficits in both phonological awareness and RAN have significantly lower scores on reading tasks than children with a deficit in only one of these skills.

RAN and Orthographic Knowledge

Compared to our knowledge of young children's phonological processing abilities, understanding of young children's orthographic knowledge is somewhat sketchy. Orthographic knowledge has been defined as the ability to "represent the unique array of letters that defines a printed word, as well as general attributes of the writing system such as sequential dependencies, structural redundancies, letter position frequencies and so forth" (Vellutino, Scanlon, & Tanzman, 1994, p. 282). Vellutino et al. argued that despite the prominence of the dual-route theory, which indicates that orthographic knowledge skills can be viewed as an alternative way of accessing the meaning of printed words, little agreement exists about the nature of orthographic knowledge skills and about suitable tasks to measure them.

Nevertheless, it has been repeatedly found that different orthographic knowledge tasks add a significant amount of unique variance to predicting reading ability after partitioning out phonological awareness tasks, thus supporting the idea that orthographic processing is likely separate from phonological awareness (Barker, Torgesen & Wagner, 1992; Cutting & Denckla, 2001). Phonological awareness unquestionably plays an important role in the initial phases of word reading, but its effect is expected to gradually diminish. As the readers mature and are exposed to more reading material, phonological recoding leads to the formation of orthographic images, and words can be identified with the help of orthographic knowledge. However, how factors such as orthographic knowledge are related to RAN and how RAN fits into this framework of relationship between orthographic knowledge and reading is not known.

Bowers and Ishaik (2003), in their review paper, stated their first hypothesis was that processes reflected in RAN underlie letter recognition speed. If letter recognition was proceeding too slowly, letter representations in words would not be activated in sufficiently close temporal proximity to induce sensitivity to commonly occurring orthographic patterns. Bowers et al. (1994) visualized orthographic knowledge to be the mediator of the relationship between RAN and reading. Bowers et al. (1994) suggested that "the reading disabled child's failure to abstract orthographic regularity after repeated print exposure and consequent difficulty acquiring automatic word reading may be due to slow access to letter codes" (p. 173).

Wolf and Bowers (1999) proposed that an inadequate development of the ability to form orthographic codes for commonly seen letter strings may be caused by slow retrieval of letter identities, which is reflected in the performance of the children on the RAN tasks. According to their hypothesis, processes underlying slow, visual naming speed may contribute to reading failure in three ways:

> (a) By impeding the appropriate amalgamation of connections between phonemes and orthographic patterns at sub–word and word levels of representation, (b) by limiting the quality of orthographic codes in memory, and (c) by increasing the amount of repeated practice needed to unitize codes before representations of adequate quality are achieved. (p. 426)

In line with these models, researchers have shown that performance on RAN tasks is significantly related to orthographic knowledge (e.g., Cardoso-Martins & Pennington, 2004; Manis et al., 1999; Manis et al., 2000; Uhry, 2002). For example, Manis et al. (2000) found that Letter Naming and Digit Naming predicted orthographic knowledge, accounting for a significant amount of the variance (6% and 17%, respectively) after controlling the effect of vocabulary knowledge and phonological awareness tasks. Uhry (2002) showed that RAN accounted for an additional variance in word-reading rate (5%) and spelling phonetically ambiguous *–ed* endings with arbitrary orthography (4%) after controlling for prior reading and oral vocabulary. The antithesis to the above findings was expressed by Torgesen et al. (1997) who found that when an autoregressor was taken into account, RAN performance in grade 2 and 3 did not predict orthographic knowledge in fourth and fifth grade.

To explore the hypothesized link between letter string processing, reading ability and RAN, Bowers (1996) developed the Quick Spelling Test (QST). The QST assesses the ability of a child to report the letters in four-letter words (e.g., *went*), pseudowords (e.g., *hool*), and nonwords (e.g., *ncdk*) presented in mixed order on a computer screen for 250 ms. There are 10 letter strings in each subtest and the number of strings correctly reported is scored. Bowers, Sunseth, and Golden (1999) found that RAN performance was significantly related with QST in grade 2 and 3 children. When they compared single- and double-deficit children on the subtests of QST, the most consistent discriminator of groups was performance on the illegal nonwords: the double-deficit group was particularly poor at reporting letters in these strings whereas no differences were detected between the groups for the real words or for the pseudowords. In a subsequent study, Sunseth and Bowers (2002) replicated these findings and showed that the double-deficit children were making more errors than single-deficit children in detecting words embedded in strings of consonant letters (e.g., *pjgirlwjwz*) even after controlling for their earlier reading performance. Rueffer (2000), in turn, devised a list of four-letter illegal nonwords that contained only frequent consonant bigrams (e.g., *blbs*; *chbt*) in distinction to the infrequent consonants bigrams presented in the original nonword condition (e.g., *ncdk*) of QST. Ruffer's sample consisted of 20 grade 4 children with reading disabilities, 10 chronological age control children, and 16 grade 2 reading level control children. She found that the presence of frequent bigrams in the nonwords was associated with more accurate processing of briefly exposed letter strings for each group of children. In addition, the chronological age control group identified significantly more of the low bigram frequency nonwords than either the reading disabled or the reading level control group, whereas the differences between the chronological age control group and the reading disabled group did not reach significance for the high bigram frequency nonwords or the pseudowords. It is therefore conceivable that increasing the orthographic structure of words raises the level of accuracy of poor readers more than it does for good readers.

Bowers (2001) argued that the enhanced perceptibility of letters due to knowledge of letter sequences does not affect the low bigram frequency strings, which are reflecting the contribution of lower level visual naming processes in letter string recognition. Correct identification increases with the enhanced perceptibility due to orthographic knowledge but the base level differences in lower level visual identification skill still contribute to the accurate recognition of the letter strings. Thus, it might be the case that RAN as well as recognition of letters in low bigram frequency strings mirrors the amount of featural information about a letter string that can be processed quickly and still support letter recognition (lower level visual identification process). Bowers (2001) was led to modify her initial suggestion that the effects of slow naming may be due partly to slow symbol recognition disrupting the ease building of links between letters that often co-occur. She suggested that "RAN may index processes that are reflected in baseline measures of identification of letter strings with low orthographic structure. It is upon this baseline that additive effects of knowledge of orthographic constraints may build" (p. 41).

To summarize, researchers examined possible indirect links between RAN and reading in order to understand the reasons why RAN is related to reading. One of those possible links was orthographic knowledge. Despite disagreements regarding the nature of orthographic knowledge skills and suitable tasks to measure them, unassailable empirical evidence suggests that orthographic knowledge is moderately related to RAN. Several researchers stressed that children who are slow to name printed symbols may not activate visual and phonological codes for printed letters in sufficiently close temporal proximity to allow encoding of the letter combinations that occur most frequently in print. Consequently, children who perform poorly on RAN do not acquire knowledge of orthographic patterns or form orthographic representations of words as quickly or easily as children with faster letter identification. Orthographic knowledge has been considered to be the mediator of the relationship between RAN and reading. Thus, RAN is expected to affect reading ability through the influence that orthographic knowledge exerts on reading.

RAN and Speed of Processing

An additional challenge in the RAN literature is whether RAN should be subsumed under a general processing speed construct. As Wolf et al. (2000) noted, embedded in this theoretical consideration is a highly complex issue of whether RAN represents the linguistic analogue of a larger, potentially domain-general processing speed deficit that goes beyond language.

Wolf and Bowers (1999) suggested that in addition to higher–level processes (i.e. access and retrieval of the phonological labels) multiple lower–level processing speed requirements contribute to RAN. They reasoned that because of the complex cognitive and temporal nature of RAN, precise timing is critical not only for the efficiency of operations within individual subprocesses but also for the integration of the operations across them as well. Therefore, a possible timing deficit would be particularly disruptive of the ability to name serially presented visual stimuli both accurately and quickly. They argued further that such a deficit could be specific to timing in verbal processing and not be observable in nonlinguistic tasks such as pressing a button when a light or a tone has occurred. Alternatively, they suggested that the deficit might be more general and affect motor, perceptual, and linguistic processing. They noted that whereas the presence of a single naming speed deficit in some poor readers was highlighting a specific timing deficit, numerous studies were suggesting that a timing deficit could be more general (e.g., Kail & Hall, 1994; Wolff, Michel, & Ovrut, 1990). In support of this argument, Wolf et al. (2000) reviewed a number of studies on reader group differences in timing at the behavioral level across visual, auditory, and motoric areas in which deficits in the rapid processing of perceptual, motoric, and auditory information in dyslexics were detected. In addition to differences at the behavioral level, several researchers also reported neurophysiological evidence. Findings by Galaburda, Menard, and Rosen (1994), and Chase (1996) converge on the following: If the magnocellular system in the thalamic visual areas is aberrant, then the processing of lower spatial frequencies will be slowed, potentially leading to slower visual discriminations, slower letter-pattern identification, and slower naming speed for serially presented visual stimuli.

Although a wealth of evidence points to a deficit in speed of processing in poor readers, it is still unclear if this deficit is actually causally related to RAN or if it is merely a manifestation of dyslexia or poor reading. Most researches have examined only one or two processing domains and have not included measures of phonological awareness and rapid naming in combination with measures of speed of processing. The inclusion of such tasks is of tremendous importance in determining whether the scope of the deficit in speed of processing is general or specific.

Recently, Catts, Gillispie, Leonard, Kail, and Miller (2002) found that grade 3 poor readers had a domain-general deficit in speed of information processing documented by their reaction times in 10 reaction time (RT) tasks across linguistic and nonlinguistic domains. Their sample consisted of 117 good and 66 poor readers. Poor readers, in turn, were segregated into two categories, those with normal IQ and those with low IQ. Catts et al. noticed significant differences between good and normal IQ-poor readers in motor, lexical, grammatical, and phonological RT tasks and between good readers and low IQ-poor readers in all of the RT tasks. Normal and low-IQ poor reader groups performed, respectively, 10% and 15% slower than good reader group across tasks. Furthermore, hierarchical multiple regression analysis demonstrated that rapid naming failed to explain significant variance in reading achievement after IQ and the RT tasks were entered into the equation. In contrast, RT tasks accounted for 8.3% of the variance in reading comprehension and 18.1% in word recognition when entered after IQ, and 2.4% and 5.5%, respectively, when entered after IQ and phonological awareness. Catts et al. (2002) concluded that RAN's association to reading ability might be "a reflection of a generalized deficit in speed of processing" (p.518). Nevertheless, the conclusions of this study are compromised by the sample used, which contained older readers and an over-representation of language delayed poor readers. The study also used only an object naming task to represent RAN.

Proponents of a processing speed deficit have drawn evidence from studies with children experiencing specific language impairment (SLI). Several studies have found that children with SLI process information more slowly than children with normal language development. For example, Johnston and Ellis-Weismer (1983) found that children with SLI mentally rotated unfamiliar shapes more slowly than children with normal language. Miller, Kail, Leonard, and Tomblin (2001) found that children with SLI were significantly slower than children with normally developing language skills in 10 different tasks (involving a total of 41 conditions), including nonlinguistic and linguistic activities. Based on evidence derived from the performance of SLI children, Kail (1994) proposed the generalized slowing hypothesis. According to this hypothesis, children with SLI respond more slowly than normally developing children on all types of tasks by a constant proportion. Applying this hypothesis, we would expect children with protracted rapid naming times to be consistently slower than children with normal naming times in all the rapid naming subprocesses – in the visual recognition of the presented stimulus, in the retrieval of the name of the stimulus, in the formulation of this name, and in the actual production of the name. To date, no research has been done to provide evidence in support of this assumption.

Kail and his colleagues (1991, 1994, 1999) extensively looked into the speed of processing hypothesis as an alternative explanation for the link between RAN and reading. They theorized that RAN-reading link reflects a global developmental change in processing speed. During childhood and adolescence, the speed of processing increases on a range of perceptual and cognitive tasks, a pattern which seems to indicate that a common, global mechanism is responsible for age-related change in processing speed (Kail, 1991). Access to name codes for digits, letters, colors, and objects may become more rapid with age simply because of age-related changes in the global retrieval speed, not because access to specific name codes becomes automatic. According to this view, the correlation between naming speed and reading reflects the fact that both are linked to age-related change in processing speed.

Kail and Hall (1994) emphasized two hypotheses:

1. If naming speed reflects an automatic process of lexical retrieval, and automaticity is achieved with practice, then age – synonymous with accumulated experience – should predict naming speed, and
2. If rapid naming is simply another manifestation of age-related change in processing speed, then measures of processing speed should predict rapid naming.

Indeed, Kail and Hall (1994) provided evidence from structural equation modeling suggesting that the link between RAN and reading is best explained by global changes in processing speed. In order to more accurately measure reading experience and avoid biases against the automaticity hypothesis, Kail, Hall, and Caskey (1999) used the title recognition and author recognition tests. In line with their previous results, Kail et al. showed that when print exposure was entered first in a stepwise multiple regression equation, the addition of processing speed accounted for a substantial increase in the explained variance in rapid naming. However, when processing time was entered first, print exposure did not increase the explained variance in rapid naming. Kail et al. interpreted their results as a clear indication that naming and reading are linked because skilled performance in both naming and reading depends, in part, on the rapid execution of the underlying processes.

A number of concerns, however, must be raised when interpreting the above findings. First, word reading was not included in the main set of predictors of naming speed although their sample consisted of 8-and 13-year-old children. Second, general speed of processing in Kail's studies was operationalized by the cross-out and visual matching tasks from Woodcock-Johnson Tests of Cognitive Ability (1989). An inspection of these tests shows that "cross-out" refers to circling or placing a line through identical figures (in the cross-out task) or numbers (in the visual matching task). van den Bos, Zijlstra, and van den Broeck (2003) argued that it can be assumed in both tasks that a visual matching operation is the central process whereas the more peripheral or output process is the cross-out action. They suggested that "the concept of general speed of processing is probably elusive and that it might be better to use the central process term (visual matching) instead" (p. 414).

The criticism that processing speed theory received as an explanation for the relation between RAN and reading didn't impede Cutting and Denckla (2001) from developing a model of word reading in which they incorporated processing speed as a distant factor. They demonstrated that processing speed contributed directly to RAN, memory span, and phonological awareness and also exerted an indirect effect on word reading via RAN and the rest of the cognitive processes. The latter finding was interpreted as a clear indication that beyond a certain basal level of processing speed, many other cognitive and linguistic processes would be influential in developing reading proficiency, and therefore processing speed could be considered a necessary but not a sufficient factor.

Despite the line of research indicating that RAN might be a product of a domain-general speed of processing mechanism there is also evidence showing that RAN is not associated with processing speed. For example, van den Bos et al. (2003) demonstrated that the correlations of the processing speed measures with the RAN tasks were only weak and on several occasions non-significant. Furthermore, van den Bos et al. found that the visual matching factor derived from a principal component analysis was shown to correlate significantly with one reading measure only and only at the age of 12 (correlations were non-significant at the ages of 8 and 10). Evidence in favor of a "domain specific" view of processing speed's association with reading was provided also by Wimmer and Mayringer (2001). They found that latency of response for visual discrimination tasks not involving familiar letters or numbers did not distinguish

German children with reading rate or accuracy and reading rate problems from normal reading controls. RAN tasks, on the other hand, discriminated both groups quite well.

In addition to experimental considerations, theoretical questions regarding the actual meaning of "speed" and how it is measured have been raised. Das (2003) argued that speed is not of one kind and that it is best to conceptualize speed in terms of distinct cognitive processes such as speed in planning and executing a response and in allocating attention. The construct of speed as operationalized in various tests of information processing (e.g., Visual Matching and Cross-Out tasks used by Kail and his colleagues) does not yield a unitary factor either. The speed of reading simple words and naming digits or letters, for example, loads on a separate factor from speed of visual search and trail making (joining numbers from 1 to 25 scattered on a page in serial order) (Das, 2003).

To summarize, Wolf and Bowers' (1999) theory on the different components of visual naming and the underlying precise timing requirements for efficient information processing yielded important theoretical considerations. Should naming speed deficit be considered a specific speed of processing problem or a product itself of more domain-general speed of processing deficits? The literature does not favor a unitary interpretation as several studies came up with conflicting results, perhaps mainly because of the tasks used and the age of the subjects in different studies. Nevertheless, the reviewed studies do offer some support for the idea that processing speed may contribute to or be related with RAN performance.

RAN Components and Reading Ability

For the last three decades most RAN studies have focused on delineating the relationship of RAN with reading in different ages, different reading ability groups, and in different languages. Several strategies have been employed in an attempt to unveil the mystery of the RAN-reading relationship (see e.g., Bowers, 1995; Bowers & Swanson, 1991; Scarborough & Domgaard, 1998; Sunseth & Bowers, 2002). These include varying the format of the test to explore effects on reading, using different versions of RAN tasks, and developing tasks that are supposed to tap hypothesized mediating links between RAN and reading. In one of those attempts, researchers have analyzed serial naming speed performance into the components of articulation time and pause time. The literature related to these components is reviewed below and constitutes the main focus of this thesis. Although there are inconsistencies in the results of the studies focusing on RAN components, the studies have provided us with better understanding of the parameters an eventual, coherent explanation of RAN-reading link will need to accommodate.

The Relationship Between Articulation Time, Pause Time, and Reading Ability

In spite of the consensus that RAN reliably predicts reading ability, researchers acknowledge that they have not yet understood completely *how* RAN influences reading and how its influence changes across time (e.g., Kirby et al., 2003). Interpretations of RAN are complicated particularly by its multicomponential nature (Wolf & Bowers, 1999; Wolf et al., 2000). Torgesen et al. (1997) suggested that "our understanding of rapid naming ability's relation to reading development will be enhanced to the extent that we make progress in dissecting the component skills involved in performance of rapid naming tasks" (p.183). In most previous research, RAN has been measured as a unitary construct by obtaining a single performance time for the entire test. In other words, the variable measured was the time it took the individual to name all the displayed stimuli starting with the uppermost left stimulus and proceeding row by row in a left-to-right fashion until the bottom-right stimulus is named (Denckla & Rudel, 1974). Neuhaus, Foorman, Francis, and Carlson (2001a) argued that measuring total performance time fails to provide the precision needed to adequately determine the nature of rapid naming speed tasks and that interest should be turned to intra-rapid naming speed components, such as the *pause time* between the named stimuli and the *articulation time* for each stimulus. According to this position, measurement of RAN components is fundamental to the attempt to illuminate *how* RAN is related to reading.

However, only a few studies have examined RAN components. Anderson, Podwall, and Jaffe (1984) triggered off the investigation of intra-rapid naming speed components in a study with six dyslexic and six control children matched on age, sex, and IQ. They found that both articulation time and pause time means were significantly longer for the dyslexic group on each of the four RAN subtests: letters, digits, colors, and objects. Obregon (1994) also measured articulation time, pause time, and the end-of-line scanning to compare the performance of six normal and six dyslexic readers. Pause time was found to differ significantly between reading groups. Despite the initiation of a new approach in treating the results of RAN tests and their relationship with reading ability, reasonable concerns emerge regarding the findings of these two studies because of their small sample size.

Neuhaus et al. (2001a) conducted a more comprehensive investigation with a group of 50 children. The participants in the study were drawn from grade 1 and grade 2, and the age range was 72 to 92 months. Neuhaus et al. (2001a) measured the articulation and pause times of RAN using tests with three types of stimuli: letters, digits, and objects. They found a significant relationship between pause times and reading ability for the letter naming and digit naming tests, but not for the object naming task. Furthermore, the consistency of the pause time in the letter naming task, a measure indicating variation between pause times, was also found to contribute significantly to the prediction of reading. Neuhaus et al. suggested that this may reflect differences in attention or executive functioning specific to the task of letter processing. Articulation time on all RAN tasks in both first and second grades was unrelated to any reading measure with the exception of the Basic Reading Cluster measured at the end of second grade. In contrast, Neuhaus and Swank (2002), in a study with 221 first-grade students, reported that articulation time was found to be related to the reading measures, although to a much lesser degree than the pause time. Thus, the early research on intra-rapid naming speed components indicates that pause times are probably the key in our attempts to understand RAN's relationship with reading.

A common feature of the aforementioned studies is that their participants were of an age at which some reading ability would be expected. It is possible that the skilled readers are more proficient in serial naming because their previous reading experiences had given them a wealth of opportunity to develop rapid naming skills. For example, good readers have more practice in scanning text and retrieving phonological codes from memory than poor readers. In order to eliminate the effect of reading experience on the performance of RAN, Cobbold, Passenger, and Terrell (2003) conducted a longitudinal study with 68 pre-readers (mean age 51.2 months at the first time of testing). Rapid naming speed was measured at three equidistant time points over a 12-month period. The children were only administered the object naming test from Dyslexia Early Screening Test (DEST) (Nicolson & Fawcett, 1996), which included twenty familiar pictures presented simultaneously without any repetition of items. At the end of the study, children's word-level reading ability was also assessed. Results suggested that children showed wide variability in rapid naming speed that was predominately attributable to the length of the pauses rather than to the length of the articulations. Moreover, only pause time component, when measured at the last administration of the object naming task, was related to word reading.

Researchers' interest has also turned to the relationship between the two RAN components. It appears that the relationship between pause time and articulation time depends on the type of rapid naming task used and the age of the children at the time of testing. In Neuhaus et al.'s (2001a) study, pause time and articulation time were not related in Grade 1 or 2 for either the letter naming task or the object naming task. However, pause and articulation times for the digit naming task were correlated significantly at both grades. A different pattern was identified in Neuhaus and Swank's (2002) results, where pause time and articulation time for RAN objects were reliably but negatively correlated. In a study with second, third and fourth grade students, Neuhaus, Carlson, Jeng, Post, and Swank (2001b) found a significant correlation between RAN letter pause and articulation time components in every grade level. Finally, Cobbold et al. (2003) didn't find any relation between pause and articulation time at any time of testing. Although researchers tend to agree that pause time and articulation time represent two different cognitive processes, the above findings suggest that further research is warranted in order to delineate what cognitive processes might underlie both articulation and pause times.

Development of Articulation Time and Pause Time

Because the number of longitudinal studies that examined the development of RAN components is not large, comments on the development of the RAN components can only be made with some caution. The researchers tend to agree that the changes occurring to pause time are greater in absolute numbers than the corresponding changes in the articulation time. For example, in Cobbold et al.'s (2003) study, the pause time mean at Time 1 (mean age = 50.7 months) was 20.2, at Time 2 (mean age = 56.9 months) 16.3, and at Time 3 (mean age = 63.1 months) 14.5. Articulation time means were 12.6, 11.9, and 11.2, respectively. At all the measurement points the standard deviation for the pause time was almost four times the standard deviation of the articulation time indicating greater variability in pause times. Using a repeated-measures analysis of variance procedure, Neuhaus et al. (2001a) revealed that pause time for all tasks (Letter, Digit, and Object Naming) significantly decreased from first to second grade. Mean articulation time for letters and digits also decreased significantly. However, mean articulation time for objects did not decrease significantly.

Finally, Neuhaus et al. (2001b), in an attempt to examine the reliability of a computerized sound analysis software, provided important information on the development of RAN components across two developmental periods, the first extending from kindergarten until grade 2 and the second from grade 2 until grade 4. Neuhaus et al.'s (2001b) sample consisted of 44 students in their first study and of 144 students in their second study. In Study 2, both articulation and pause time were faster than the times identified in Study 1; however, decrease for articulation time was only marginal, 19.53 versus 19.29 sec. On the other hand, decrease in pause time was large, 20.42 versus 11.21 sec. Neuhaus et al. (2001b) argued that "the differential reduction of articulation and pause may indicate that articulation represents a cognitive process that reaches an asymptotic level before the cognitive process or processes that are associated with pauses" (p. 501).

Interpretation of Articulation and Pause Time

One of the main problems, stemming primarily from the small number of studies that have investigated the RAN components, is the explanation of what these components represent. To date, studies that have drawn conclusions about articulation and pause time have used tasks other than the normal RAN ones. For example, articulation rate has been found in several studies to be associated with memory span (e.g., Das & Mishra, 1991; Rapala & Brady, 1990), phonological awareness (e.g., Ackerman et al., 1990; Cutting & Denckla, 2001), RAN (e.g., Parrila et al., 2004; Scarborough & Doomgaard, 1998), and letter recognition (e.g., Parrila et al., 2004). However, articulation rate in the above studies was measured either with a speech rate task, in which students repeat a set of three words (e.g., *cat*, *wall*, *key*) 10 times as fast as possible, or with a counting task, in which children count from 1 to 10 five times in a row as fast as possible. Consequently, interpretations about RAN articulation time are compromised by the fact that articulation time was derived from measures that possibly rely on different cognitive processes than RAN tasks.

On the basis of the above studies, articulation time has been shown to be influenced by stimulus familiarity (Balota & Abrams, 1995), natural speech (Shields & Balota, 1991), phonological similarity and complexity (Caplan, Rochon, & Waters, 1992; Mueller, Seymour, Kieras, & Meyer, 2003), neighborhood density (Vitevitch, 2002), and age (Parrila et al., 2004; Smith, 1992). Using a modified picture naming task, Vitevitch (2002) showed that words from dense neighborhoods (words with many similar sounding words) were articulated faster that words from sparse neighborhoods (words with few similar sounding words) even after controlling for possible effects of initial phonological segments, familiarity, word frequency, neighborhood frequency, and phonotactic probability of the stimuli. He concluded that multiple phonological representations are activated simultaneously and facilitate processing at word-form level during speech production. More importantly, Hulme, Roodenrys, Brown, and Mercer (1995) experimentally increased familiarization of both words and pseudowords, and articulation time reliably decreased. As articulation time has been reliably influenced by stimulus familiarity and degradation, articulation time can be conceptualized as an index of stimuli familiarity that may, in turn, reflect the integrity of the phonological representation to be recalled.

Although Post, Foorman, and Hiscock (1997) and Obregon (1994) did not empirically differentiate the level of vowel or letter knowledge between readers, if articulation time indexes stimulus familiarity, then their findings suggest that there was little variation in the student's level of vowel or letter familiarity since dyslexics were not significantly different from controls on articulation time. In contrast, Anderson et al. (1984) showed that vowel time differences between reading groups (dyslexic and adequate readers) accounted for nearly all of the differences in articulation time. On the letter naming subtest it was found that vowel duration alone achieved a perfect discrimination between the dyslexic and controls subjects.

Pause time's nature is even more obscured. The few studies that have attempted to explain what pause time means and what factors might influence it have been done primarily with memory tasks and therefore we must be cautious when drawing conclusions (see e.g., Hulme, Newton, Cowan, Stuart, & Brown, 1999). In terms of RAN tasks, Nauhaus et al. (2001) suggested that pause time for letters might reflect processing speed associated with letters and that pause time for objects might reflect a more general processing speed.

Das, Mok, and Mishra (1994) provided a different explanation of what pause time might reflect by analyzing and comparing the pause times of the different rows of a word naming task. According to them, there are at least three processes that constitute the pause time. The first is disengaging attention, the second is lexical access (finding a name for the next item), and the third is a combination of two subprocesses: assembling a pronunciation and a motor program for articulation. At the same time, Das et al. also hypothesized that variation in pause times might reflect blocks of involuntary rests produced by reactive inhibition during massed practice. Poor readers were slower in each of the six rows of the naming task, and they paused longer between the rows. Das et al.'s results imply that the reactive inhibition was dissipated faster by the average readers through shorter duration of pauses and that the performance of the average readers on the task remained superior to that of the poor readers.

Limitations of the Existing Studies

Whatever might be the function and the meaning of each of the RAN components, it is important to highlight that most of the existing studies that have longitudinally investigated the role of the RAN components are compromised by small sample size. Furthermore, information about RAN components and their contribution to reading ability is missing for a time period extending from kindergarten until the end of grade 1. Cobbold et al.'s (2003) work finished at the beginning of kindergarten and Neuhaus et al.'s (2001a) and Neuhaus and Swank's (2002) studies covered the time period from grade 1 to grade 2. It is also worth mentioning that to date no information is available on color naming pause and articulation time components since all the previous studies used letter, digit and object naming tasks, and that no study has included reading fluency measures that frequently are more strongly associated with RAN performance than reading accuracy measures.

In addition, methodological issues regarding the scoring of the pause and the articulation times arise as far as different processes have been employed by the researchers. Although Neuhaus et al. (2001b) presented their impressive results of the reliability and validity of a time-domain, amplitude-based automatic RAN scoring software program, they recognized its limited capacity to correctly identify articulations. They admitted that "the program mistakenly marked articulations because time and amplitude were the only parameters used to identify articulations" (p. 502), and maintained that future development of the automated measurement program should include a frequency-domain-based voice recognition module to address the identification limitation.

Finally, in the light of research findings indicating that different versions of the RAN task can account for different amounts of variance in reading ability (see Compton et al., 2003), it must be taken into account that researchers used different versions of the RAN tasks to extract the pause and articulation components. For example, Cobbold et al. (2003) used an object naming test comprised of 20 familiar objects from Dyslexia Early Screening Test. On the other hand, Neuhaus et al. (2001a) used the traditional format of RAN tasks comprised of 50 items. The interpretation of the differences in findings of these studies is further complicated by these task differences.

Summary of the Literature

A plethora of research has established the importance of phonological processing in early reading acquisition. Phonological abilities have been shown to be predictive of and causally related to reading (e.g., Blachman, 1984; de Jong & van der Leij, 1999; Kirby & Parrila, 1999; Torgesen et al., 1994; Uhry, 2002; Wagner et al., 1997). Additionally, training in phonological processing skills has been shown to systematically produce beneficial outcomes for children already diagnosed as reading-disabled or at-risk for developing reading difficulties (e.g., Levy, Abello, & Lysynchuk, 1997; Lovett et al., 2000; Torgesen & Davis, 1996). As a result, deficits in phonological processing have been identified as the core deficit in reading disability (e.g., Stanovich, 1988). However, the multifaceted nature of reading makes it apparent that deficits in other component skills may also contribute to problems in reading acquisition (Das, 1995; Share & Stanovich, 1995). Several researchers have proposed a second-core deficit indexed by rapid naming (e.g., Bowers & Swanson, 1991; Bowers & Newby-Clark, 2002; Denckla & Cutting, 1999; Kirby et al., 2003; Manis et al., 2000; Wolf &

Bowers, 1999; Wolf et al., 2002), whose effects appear to be independent and additive to those of phonological awareness.

In the light of research findings showing that deficits in both phonological awareness and RAN contribute independently to problems in reading, Wolf and Bowers (1999) proposed the double-deficit hypothesis. According to this hypothesis the poorest readers are the ones who experience difficulties in both phonological awareness and RAN. Early on, the steadily mounting interest in RAN was turned to research questions regarding what is hidden behind the relationship of RAN with reading, and what does RAN really measure. Interpretations of RAN were complicated particularly by its multicomponential nature (Bowers et al., 2000).

Several strategies have been employed in an attempt to unveil the mystery of RAN-reading relationship (see Scarborough & Domgaard, 1998). In one of the latest attempts, Neuhaus et al. (2001a) decomposed the total RAN time into its constituent components of pause time and articulation time. They reported that for first- and second-grade students, RAN pause time for numbers, letters and objects was differentially related to reading, while articulation time was rarely related to reading.

RAN has been hypothesized to reflect many different skills (Wolf & Bowers, 1999). Denckla and Cutting (1999) purported that slowing in RAN can arise from any one of the several key subprocesses that are interwoven in naming. Therefore, future directions of RAN research should aim to illuminate the different explanations that RAN receives by examining its components. It is likely that the unresolved nature of the naming-reading relation resides inside the naming task itself.

Proposed Model to Be Tested

Drawing on previous studies that have established the importance of RAN as a reliable predictor of reading ability (e.g., Blachman, 1984; Felton & Brown, 1990; Kirby & Parrila, 1999; Schatschneider et al., 2004; Wagner et al., 1997) the current study first aimed at investigating the relationship of RAN total times with early reading accuracy and reading fluency. In this first part of the study, performance on the RAN tasks was the independent variable, whereas performance on word accuracy and word fluency tasks represented the dependent variables. In the second part of the current study, articulation and pause time components were the independent variables, whereas word accuracy and word fluency represented the dependent variables. What follows is a more detail presentation of the different hypotheses regarding RAN total times and articulation and pause times, and their relationships with reading ability.

RAN Total Times and Reading Ability

RAN has been acknowledged as a second core deficit in reading disability (e.g., Manis et al., 2000; Wolf & Bowers, 1999; Wolf et al., 2002). Its effects have been shown to be independent of and additive to phonological awareness. On the basis of previous studies that have reported a moderate relationship between RAN and reading ability, I expected to find the same pattern of relationships in the current study. However, it was expected that the relationship between the RAN total times and reading fluency measures would be greater than the relationship between the RAN total times and reading accuracy measures. This hypothesis is based on previous research findings that have demonstrated RAN to be more related to word reading speed than to word reading accuracy (e.g., van den Bos et al., 2002). The latter has been found to be influenced mainly by phonological awareness.

Articulation Time, Pause Time, and Reading Ability

Wolf and Bowers (1999) argued that the relationship between the RAN total times and reading ability remains inconclusive, partly because of the multicomponential nature of RAN. Extending the initial attempts to partition RAN total time, this study examined how RAN components develop from kindergarten until the end of grade1, how they correlate with the RAN total times, and how they are related to the reading accuracy and reading fluency measures.

It was expected that both articulation and pause time components would change with development, but that the decrease would be greater for the pause time than for the articulation time. Becoming more familiar with the different symbols, the children will improve their time of retrieving the names of the symbols from their long-term memory. Consequently, the pause time was expected to decrease significantly from kindergarten to the end of Grade 1. Contrary to the decrease in pause time, articulation time was not expected to improve significantly. This hypothesis draws on previous findings, which showed that articulation time changes are smaller across time (see e.g., Cobbold et al., 2003; Neuhaus et al., 2001a). Furthermore, it was hypothesized that the faster the children are in retrieving phonological information from long-term memory (pause time), the better their reading accuracy would be. As RAN has been reported to be closely related with word reading speed (e.g., de Jong & van der Leij, 2002; Manis & Freedman, 2001; Wimmer, 1993; Wolf & Katzir-Cohen, 2001), faster pause times were expected to result in better reading fluency outcomes. Because both RAN and reading fluency measures have a time component in common, I expected that the relationship between pause time and reading fluency would be even greater than the relationship between pause time and reading accuracy.

Finally, articulation time was not expected to affect reading accuracy, and therefore longer articulation times should not impede the children from reading more words or pseudowords correctly. Nevertheless, articulation time was expected to be related with the reading fluency measures. This assumption is based on the fact that both articulation time and fluency measures share a time component. The shorter the articulation duration is, the faster the performance on the reading fluency measures is expected to be.

Significance of the Study

The present study aimed at providing answers to two important questions: What is the relationship between RAN and reading ability, and what do the RAN tasks really measure. Decomposing the RAN total times into the components of articulation time and pause time was expected to enhance our understanding with respect to what is driving the relationship between RAN and reading ability. For example, if contribution of articulation time to reading ability is minimal, then our interest must be turned to pause time and what it reflects. According to Wolf and Bowers' (1999) visual naming model there might be seven different cognitive processes that occur within pause time that have been stated earlier in this study. Thus, researchers will have to deal with a smaller amount of explanations of what RAN measures.

Being able to partition the RAN performance to multiple components and to examine which of these components contribute most to early reading acquisition will enable researchers to focus on the most significant components and skills they represent rather than on the general factor of rapid naming speed. By isolating the key components, both early diagnosis and intervention of reading difficulties could be enhanced. Finally, examining children longitudinally allowed me to examine if the RAN component skills are stable across the first years of schooling and whether the same components correlate significantly with reading in preliterate and early literate children. This information can also help in developing better early diagnosis and intervention methods.

CHAPTER 3

METHODS

Participants

Two hundred twenty-three children attending six kindergarten classes in schools in a suburban community in Alberta initially received a letter of information describing the study. One hundred sixty-one children were given permission to participate in the study. Seventy-seven children, 39 male and 38 female, of the 161 children were randomly selected to be part of the study. Fourteen kindergarten students, whose sound files in the RAN tasks were of a bad quality or were not recorded properly, were excluded from further analyses. Moreover, the data screening process identified one outlier in four different measures that was removed from the study. The final sample consisted of 62 students (mean age 66.8 months, $SD = 3.9$).

Materials

Naming Speed

Participants' RAN performance was assessed using four tasks: objects, colors, digits and letters. The last two tasks were administered only in the Fall and Spring term of grade 1. They were not administered in kindergarten, because children are generally more familiar with nongraphemic stimuli and in the absence of any formal instruction regarding the names of digits and letters this would likely provide a purer estimation of their automatized naming abilities.

Object Naming (ON). Object Naming from the CTOPP (Wagner, Torgesen, & Rashotte, 1999) was used. Participants were required to state as quickly as possible the names of six objects (pencil, boat, star, key, chair, and fish). On two separate sheets, objects were arranged randomly in four rows with nine objects in each row. Before naming the 36 objects, each participant was asked to name in a practice trial the objects to ensure familiarity. The two pages were timed separately. Wagner et al. (1999) reported test-retest reliability of .77 for Object Naming for children ages five to seven.

Color Naming (CN). This task required participants to state as quickly as possible the names of five colors (blue, black, green, red, and yellow). The colors were presented on a laptop computer screen and arranged randomly in five rows with ten colors per row on two separate pages. Prior to beginning the timed naming, each participant was asked to name in a practice trial the colors to ensure familiarity. The two pages were timed separately. Blachman (1984) reported test-retest reliability of .81 for Color Naming in kindergarten and .89 in grade 1.

Digit Naming (*DN*). This task was adopted from CTOPP (Wagner et al., 1999). This RAN task consists of a set of six digits (4, 7, 8, 5, 2, 3) that are displayed in random sequence six times for a total of 36 stimuli. Subjects are asked to name the digits from left to right as quickly as possible and the total time to complete the RAN task is recorded. Before naming the 36 digits, each participant was asked to name the digits in a practice trial. Wagner et al. (1999) reported test-retest reliability of .91 for Digit Naming for children ages five to seven.

Letter Naming (*LN*). This task was adopted from CTOPP (Wagner et al., 1999). Participants were asked to name as fast as possible the names of six letters (a, n, s, t, k, c). Letters were arranged randomly in four rows of nine letters in each row. As in the other naming speed tasks, children were asked to name the six letters in a practice trial before proceeding to the timed trials. The two pages were timed separately. Wagner et al. (1999) reported test-retest reliability of .97 for Letter Naming for children ages five to seven.

Word Reading

The Woodcock Reading Mastery Tests-Revised (WRMT-R) (Woodcock, 1998) was used to assess word reading in grade 1. Form H Word Identification test was used in the Fall and Spring term of grade 1. The test requires participants to read isolated words aloud. Words are graded in difficulty from pre-primer to adult level. Woodcock (1998) reports split-half reliabilities of .98 for grade 1.

Form H Word Attack test was used in the Fall and Spring term of grade 1 as a second measure of word reading. Participants are required to read nonwords presented on a laptop screen as if they are real English words. On both reading tasks, testing was discontinued after six consecutive errors. Participant's score was the number of items correct. Woodcock (1998) reports split-half reliabilities of .94 for grade 1.

Reading Fluency

Grey Oral Reading Test (GORT) (Wiederholt & Bryant, 2001). Form A of Part B was used to assess subjects' reading fluency. The participants were asked to read as fast and as accurately as possible a short story. The reading comprehension questions that follow the story were not administered because it was not the intention of this study to examine reading comprehension. Depending on the time it took the child to read the story, the experimenter converted this time into a value from 0 through 5 using a conversion table. The number of deviations from print was also recorded and converted to a 0-through 5-point accuracy score. The rate score and accuracy score were added together to get the Fluency Score. Wiederholt and Bryant (2001) reported test-retest reliability for fluency to be .93.

Test of Word Reading Efficiency (TOWRE) (Torgesen, Wagner, & Rashotte, 1999) is a timed measure of single word reading. The child is given a list of 104 words, divided into four columns of 26 words each, and asked to read them as fast as possible. A short, 8-word practice list is presented first. The number of words read correctly and the number of errors made within a 45-second time limit was recorded. The score was the number of words read correctly. Torgesen et al. (1999) reported test-retest reliability of .95 for ages six to nine.

Procedures

Participants were examined three times: in the Spring term of kindergarten, and in the Fall and Spring term of Grade 1. All participants were tested individually in their respective schools during school hours by trained experimenters. Testing was divided into two sessions lasting roughly 20 to 30 minutes.

Manipulation of Sound Files

RAN responses for each child in Color Naming and Letter Naming tasks were digitally recorded first on mini-CD disks with the help of a portable minidisk recorder (Sony MZ-N505). Second, separate audio wave files were created for each child in the Goldwave program by transferring the sound files from the mini-CDs to the computer. Only the sound files of the second page of the RAN tasks were analyzed. These files were expected to contain appropriate responses, extraneous remarks, and random background noise. The background noise was then removed using the hiss removal function of the program. Next, all sound files were set to the same root-mean-square (RMS) or average volume level. The new volume level was the mean of all the RMS levels of the sound files. This was done to match volumes across files and to diminish the effect of a possible extraneous variable (recording volume of the sound file or the volume of the child's speech).

Part of the data manipulation process was to extract the values of the RAN component elements. Both articulation and pause time were measured in milliseconds. In order to establish the onset and offset of articulation and pause time, a mean noise level of .15 of the absolute value of the sound file amplitude was imposed. Beginning of an articulation was defined as the point where meaningful acoustical energy exceeded the mean noise level threshold; conversely, offset was determined to be the point where the meaningful acoustical energy dropped below the .15 noise level. An automatic indication of the sound's duration between the threshold points was shown on the screen. Pause time was the time between the articulations and was estimated in the opposite manner to the articulation time. RAN total time was found by adding together the total articulation time and the total pause time prior to cleaning. This correlated .99 with the total time obtained in the traditional manner.

Four types of cleaning of RAN components took place. First, if there was an incorrect articulation, the preceding pause time, the incorrect articulation, and the following pause time were removed. Second, if there was a self-correction, then everything between the two correct articulations was removed. Third, if the child skipped a stimulus, then the pause time between the two correct articulations along with the articulation time that followed the skip were removed. Fourth, in the cases where there was off-task behavior (e.g., coughing, talking to the experimenter, self-encouragement) between two articulations, the specific pause time was removed.

Thus, articulation time represents the mean of those articulation times that were correctly verbalized and were not preceded by a skipped stimulus. The number of the cleaned articulation times might be 50 for the Color Naming task and 36 for the Letter naming task, which indicates that there were no naming mistakes, or less than 50 and 36, respectively, which indicates that one of the above cleaning instances took place. Pause Time is considered to be the mean of the pause times that occurred between two correctly articulated stimuli. The number of the cleaned pause times might be 49 for Color Naming, 35 for Letter Naming, or less if one of the cleaning instances was imposed. Only the cleaned Articulation and Pause Time measures were used in further analyses.

CHAPTER 4

RESULTS

RAN Total Time

Descriptive statistics of all the measures that were used in this study along with the *F* values from one-way repeated measures ANOVAs comparing the RAN performances at different measurement points are shown in Table 1.

Table 1

Descriptive Statistics of All the Measures in the Study and F values from One-Way Repeated Measures ANOVA Across the Three RAN Measurement Points

	Kindergarten		Grade 1 Fall		Grade 1 Spring		*F*
	M	SD	M	SD	M	SD	
CNT[a]	73.81	22.88	59.96	16.78	58.45	15.08	35.90***
ONT[a]	53.46	14.45	48.79	15.18	46.71	12.63	11.07***
LNT[a]			33.50	9.82	28.81	8.29	41.22***
DNT[a]			34.79	11.08	28.07	6.63	44.37***
WID			16.68	13.37	43.26	13.08	
WAT			6.68	6.49	17.32	8.87	
TOWRE					37.71	12.94	
GORT					7.35	2.31	

Note. CNT = Color Naming Total Time (50 stimuli); ONT = Object Naming Total Time (36 stimuli); LNT = Letter Naming Total Time (36 stimuli); DNT = Digit Naming Total Time (36 stimuli); WID = Word Identification; WAT = Word Attack; TOWRE = Test of Word Reading; GORT = Gray Oral Reading Test.
[a] The RAN latencies are in seconds; *** $p < .001$

A mean raw score and a standard deviation are provided for each measure. The analysis was completed in two steps, the first being the examination of the relationship between the total RAN time and reading ability and the second being the examination of the relationship between the RAN components (articulation time and pause time) and reading ability.

A closer look at the distributional properties of the measures included in this study revealed several problems for both kindergarten and grade 1. A participant who was an outlier in six different measures was removed from the study. Because the distributions of the RAN measures substantially deviated from normality, log transformations were first computed (Tabachnick & Fidell, 2001). After the log transformations, some of the measures were still affected by the presence of outliers. More precisely, Letter Naming in the Fall term of grade 1 (LNT-F1) and Letter Naming in the Spring term of grade 1 (LNT-S1) had respectively, three and one outliers, all located at the high end of the distributions. Digit Naming in the Spring term of grade 1 (DNT-S1) had two outliers, both located at the high end of the distribution. Object Naming in kindergarten (ONT-K) had two outliers, one at each end of the distribution. Further analyses with the transformed scores were performed in two ways: (a) excluding the outliers, and (b) including the outliers. The results of the second analyses are reported below only when a discrepancy was identified between the two analyses.

The reading outcome measures also presented some distributional property problems. Word Identification and Word Attack in the Fall term of grade 1 were moderately skewed and therefore a square root transformation was calculated for them.

The reading fluency measure, GORT, was negatively skewed. In the case of negatively skewed distributions, the best strategy is to reflect the variable by subtracting the actual score from X, where X was equal to the largest score +1 and then apply the appropriate transformation for positive skewness (Tabachnick & Fidell, 2001). A log transformation was applied achieving normality for the task. However, results with this task are corrected for direction to simplify their interpretation. Word Identification, Word Attack, and TOWRE in the Spring term of grade 1 were normally distributed.

An inspection of Table 1 shows that the mean times for Color Naming total time (CNT) and Object Naming total time (ONT) were larger than then corresponding mean total times for Letter Naming (LNT) and Digit Naming (DNT) in both Fall and Spring term of grade 1. Letter Naming total time (LNT) and Digit Naming total time (DNT) were very close at both testing times. It is important to note that Color Naming included 50 stimuli whereas the other RAN tasks included only 36 stimuli. When the mean time of CNT was adjusted to the length of the other RAN tasks, the new CNT mean times were 53.14 for kindergarten, 43.17 for the Fall term of grade 1, and 42.08 for the Spring term of grade 1. Thus, ONT appears to be the most time consuming task followed by CNT, LNT, and DNT. This result is in line with previous research findings (Wolf et al., 1986; van den Bos et al., 2002; van den Bos et al., 2003).

In order to examine whether the observed differences in the mean times across measurement points were significant, one-way repeated measures ANOVA was calculated across the three measurement points for CNT and ONT and across the two measurement points for LNT and DNT. Results indicated a significant main effect of time for CNT, $F(2, 118) = 35.90$, $p < .001$. Single-*df* comparisons showed that CNT-K was significantly different from CNT-F1, F (1, 59) = 37.53, $p < .001$, and from CNT-S1, F (1, 59) = 70.95, $p < .001$. CNT-F1 was not significantly different from CNT-S1, F (1, 59) = .62, *ns*. Significant main effect of time was also found for ONT, F (2,118) = 11.07, $p < .001$. Single-*df* comparisons showed that ONT-K was significantly different from ONT-F1, F (1, 59) = 13.63, $p < .001$, and from ONT-S1, F (1, 59) = 18.43, $p < .001$. ONT-F1 was not significantly different from ONT-S1, F (1, 61) = 1.67, *ns*. Finally, significant main effects of time were identified for LNT, F (1, 58) = 41.22, $p < .001$, and for DNT, F (1, 58) = 44.37, $p < .001$. In sum, CNT and ONT total times decreased significantly from kindergarten to Fall term of grade 1 but not between the two grade 1 measurement points. The total times on the two alphanumeric tasks, LNT and DNT, decreased significantly between the two measurement points in grade 1.

A relevant issue in a longitudinal study of RAN tasks is to evaluate their stability over time. The autocorrelations for all the RAN tasks are displayed in Table 2 in italics. The autocorrelations were significant for all the RAN tasks from kindergarten to the end of grade 1. The highest correlation (r = .74) was observed between Object Naming in the kindergarten (ONT-K) and Object Naming in the Fall term of grade 1 (ONT-F1). The lowest correlation (r = .58) was between ONT-K and Object Naming in the Spring term of grade 1 (ONT-S1). All other autocorrelations fell between these values. The magnitude of the autocorrelations suggests that there is an appreciably strong stability over time: children who were fast in completing the RAN tasks in kindergarten or in the Fall term of grade 1 remained fast at least until the end of grade 1, and children who were slow in kindergarten remained slow at least until the end of grade 1.

Table 2

Intercorrelations Between the RAN Tasks

		2.	3.	4.	5.	6.	7.	8.	9.	10.
1.	CNT-K	.59**	.71**	.75**	.70**	.57**	.60**	.36**	.57**	.36**
2.	CNT-F1		.68**	.59**	.66**	.52**	.64**	.58**	.75**	.50**
3.	CNT-S1			.59**	.73**	.72**	.70**	.62**	.66**	.52**
4.	ONT-K				.74**	.58**	.61**	.40**	.61**	.33**
5.	ONT-F1					.67**	.72**	.48**	.70**	.46**
6.	ONT-S1						.58**	.63**	.57**	.56**
7.	LNT-F1							.73**	.79**	.68**
8.	LNT-S1								.65**	.83**
9.	DNT-F1									.69**
10.	DNT-S1									

Note. CNT = Color Naming Total Time; ONT = Object Naming Total Time; LNT = Letter Naming Total Time; DNT = Digit Naming Total Time; K = Kindergarten; F1 = Fall term of grade 1; S1 = Spring term of grade 1; $N = 62$; ** $p < .01$.

Correlations between the different RAN tasks are also displayed in Table 2. As expected, the RAN tasks correlated highly with each other with correlations ranging from .52 (CNT-S1 with DNT-S1) to .83 (LNT-S1 with DNT-S1). Stronger correlations were generally observed between Color Naming and Object Naming and between Letter Naming and Digit Naming. To investigate whether a grouping of the RAN task into alphanumeric and non-alphanumeric could be implemented, a factor analysis was performed. In both Fall and Spring terms of grade 1, the initial principal component solution showed only one factor with eigenvalue larger than 1. When a second factor was extracted, it included only the Color Naming (Fall term of grade 1) or both Color Naming and Object Naming (Spring term of grade 1). Eigenvalues for the second factors were .42 and .65, respectively. Thus, for this sample of children, the distinction between alphanumeric and non-alphanumeric RAN tasks is only partially supported.

RAN Total Time and Reading Ability

One of the purposes of this study was to examine the relationship between the RAN tasks and the early reading development. Word Identification and Word Attack tasks were administered in kindergarten but showed significant floor effects and were subsequently excluded from further analyses. In the Fall term of grade 1, Word Identification and Word Attack tasks were used as the criterion variables. In the Spring Term of grade 1, reading fluency measures were added to the reading accuracy ones. Table 3 shows the correlations between RAN tasks and reading measures in grade 1.

As expected, RAN tasks correlated moderately with both reading accuracy and reading fluency measures. The correlations ranged between .25 and .53. Despite previous findings demonstrating that Color Naming and Object Naming could be efficiently used in kindergarten as predictors of later reading ability (see Parrila et al., 2004), the results for this sample revealed only weak correlations between CNT-K, ONT-K, and later reading ability. The correlations failed to reach significance levels when the analysis was performed including all the outliers' scores.

In the Fall term of grade 1, all four RAN measures correlated significantly with almost all of the reading measures (the exception being the non-significant correlation between ONT-F1 and WAT in the Spring term of grade 1). The strongest correlations were between the Digit Naming total time (DNT-F1) and the reading measures.

Table 3

Correlations Between the RAN Tasks and the Reading Measures

	Grade 1 Fall		Grade 1 Spring			
	WID	WAT	WID	WAT	TOWRE	GORT
CNT-K	-.24	-.27*	-.29*	-.03	-.19	-.20
CNT-F1	-.36**	-.47**	-.43**	-.26*	-.40**	-.39**
CNT-S1			-.26*	.00	-.29*	-.28*
ONT-K	-.30*	-.28*	-.32*	-.16	-.24	-.31*
ONT-F1	-.29*	-.30*	-.30*	-.10	-.33**	-.36**
ONT-S1			-.35**	-.28*	-.21	-.25*
LNT-F1	-.30*	-.29*	-.46**	-.24*	-.42**	-.45**
LNT-S1			-.42**	-.29*	-.36**	-.43**
DNT-F1	-.42**	-.40**	-.53**	-.37**	-.45**	-.47**
DNT-S1			-.41**	-.28*	-.32*	-.47**

Note. CNT = Color Naming Total Time; ONT = Object Naming Total Time; LNT = Letter Naming Total Time; DNT = Digit Naming Total Time; K = Kindergarten; F1 = Fall term of grade 1; S1 = Spring term of grade 1; WID = Word Identification; WAT = Word Attack; TOWRE = Test of Word Reading; GORT = Grey Oral Reading Test.
$N = 62$ * $p < .05$. ** $p < .01$.

Impressively, although CNT-K was only weakly correlated with later reading ability measures, substantial increases in the strength of the correlations were noticed for CNT-F1. The correlations between the RAN tasks and Word Attack were generally lower than the corresponding correlations with Word Identification. This result is in accordance with previous findings (Joseph, McCachran, & Naglieri, 2003; Wagner, Torgesen, & Rashotte, 1994). Significant correlations between the RAN tasks and the reading measures were identified also in the Spring term of grade 1. In general, higher correlations with the reading outcomes were achieved for LNT-S1 and DNT-S1 than for

CNT-S1 and ONT-S1. Again, when outliers' scores were included in the calculations, DNT-S1 and LNT-S1 correlations with the reading measures were in all the cases lower than when the outliers' scores were excluded from the analysis. Particularly, their correlation with Word Attack failed to reach significance.

RAN Components

The second main objective of this study was to examine the development of rapid naming components and their influence on reading ability. Consequently, for the RAN subtests of Color Naming and Letter Naming, the total time was partitioned into the constituent components of articulation time and pause time as explained above. Table 4 presents the descriptive statistics for the RAN components. A mean raw score and a standard deviation are provided for each measure. In addition, Table 4 presents the *F* values from one-way repeated measures ANOVA, which was used to examine changes in the RAN components across measurement points.

An examination of the distributional properties of the RAN components revealed some problems. All the measures were moderately skewed and therefore a log transformation was calculated. Despite the log transformations, CNAT in kindergarten had one outlier at the low end of the distribution, CNAT in the Spring term of grade 1 had three outliers at the high end of the distribution, and LNAT in the Spring term of grade 1 had one outlier at the high end of the distribution.

Table 4

Descriptive Statistics of the RAN Components and F values from One-Way Repeated Measures ANOVAs

	Kindergarten		Grade 1 Fall		Grade 1 Spring		*F*
	M	SD	M	SD	M	SD	
CNAT	.49	.09	.46	.07	.49	.06	4.48*
CNPT	.91	.41	.69	.27	.62	.22	28.00***
LNAT			.37	.07	.38	.07	.55
LNPT			.55	.31	.39	.18	35.49***

Note. CNAT = Color Naming Articulation Time; CNPT = Color Naming Pause Time; LNAT = Letter Naming Articulation Time; LNPT = Letter Naming Pause Time
$N = 62$ * $p < .05$ *** $p < .001$
[a] The latencies are in seconds.

Following the procedure which was employed for the analysis of the total times, further analyses with the transformed scores of the RAN components were performed both excluding and including the outliers' performances. In the tables to follow only the results of the analyses excluding the outliers' performance are reported. The results of the analyses with the outliers included are reported below only when a discrepancy was identified between the two analyses.

Performance time changes for both articulation and pause time components were examined for significance with one-way repeated measures ANOVA. CNAT was significantly different across time, $F\,(2, 114) = 4.48$, $p < .05$. Single-*df* comparisons showed that CNAT-K was significantly different from CNAT-F1, $F\,(1, 60) = 8.14$, $p < .05$, but not from CNAT-S1. CNAT-F1 was significantly different from CNAT-S1, *F* (1,

58) = 7.94, $p < .05$. A main effect of time was found for CNPT, F (2, 124) =28.00, $p <$ .001. Single-*df* comparisons showed that CNPT-K was significantly different from CNPT-F1, F (1, 62) = 25.26, $p < .001$, and significantly different from CNPT-S1, F (1, 62) = 56.98, $p < .001$. CNPT-F1 was not significantly different from CNPT-S1, F (1, 62) = 2.99, *ns*. Furthermore, no main effect of time was found for LNAT, F (1, 61) =.55, *ns*. However, LNPT–F1 was significantly different from LNPT-S1, F (1, 61) =35.49, $p < .001$. The above findings together with the result from the analysis for the total times suggest that the time decrease which was detected in LNT is attributable mainly to significant changes in Pause Time. Figure 2 compliments the numbers presented in Table 4 and provides the general pattern observed in the RAN components development.

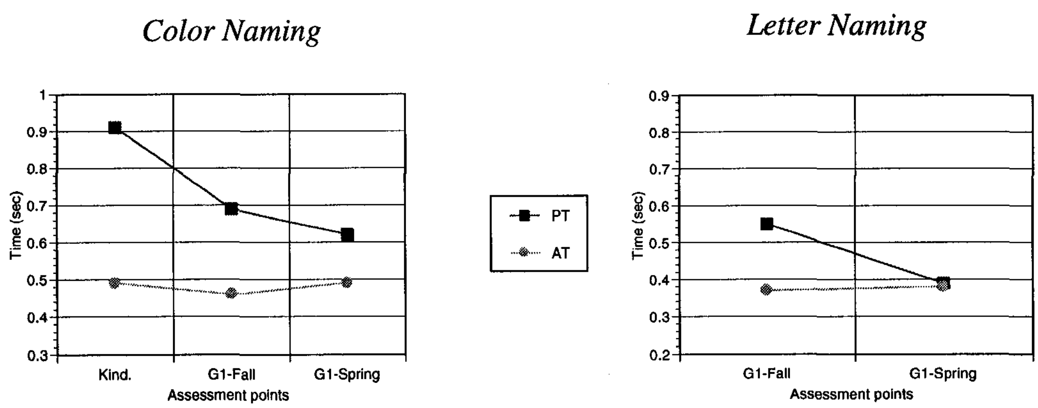

Figure 1. Development of articulation time (AT) and pause time (PT) for Color and Letter Naming.

Clearly, a decrease in the pause time across the assessment periods is shown for both Color Naming and Letter Naming. However, in the case of Color Naming articulation time there is a small decrease between Kindergarten and Fall term of grade 1 followed by a small increase at the end of grade 1. Letter Naming articulation time is essentially unchangeable across different measurement points. In order to examine if the differences observed in the mean articulation and pause time were significant across time, a two-way repeated measures ANOVA was calculated for Color and Letter Naming respectively. The results for Color Naming revealed a significant main effect of time, F (2, 112) = 35.46, $p < .001$, a significant main effect of component, F (1, 56) = 48.26, $p < .001$, and a significant main effect of interaction (Time X Component) F (2, 112) = 13.76, $p < .001$. The results for Letter Naming revealed a significant main effect of time, F (1, 60) = 4.73, $p < .05$, a significant main effect of component, F (1, 60) = 34.38, $p < .001$, and a significant main effect of interaction (Time X Component), F (1, 60) = 25.67, $p < .001$. The significant time by component interactions for both Color and Letter Naming reinforce the previously observed pattern that pause time and articulation time behave differently across time.

Table 5 shows the intercorrelations between the RAN components and the total times. The rationale behind this analysis is to examine the stability of the RAN components across time. Particularly high correlations were evident for the pause time component. The strongest correlation was observed between CNPT-K and CNPT-S1 (r = .63) and the lowest between CNPT-K and CNPT-F1 (r = .54). In terms of articulation time, only the correlations between CNAT-K and CNAT-F1, and between LNAT-F1 and LNAT-S1 were significant at .36 and .39, respectively. With the exception of a significant correlation between LNAT-S1 and LNPT-S1 (r = .43), all the other correlations between articulation time and pause time were not significant.

Table 5

Intercorrelations Between the RAN Components

	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
1. CNT-K	.08	.93**	.59**	.25*	.56**	.71**	.29*	.70**	.60**	.11	.58**	.36**	.09	.35**
2. CNAT-K		-.17	.13	.36**	.03	.18	.05	.13	-.05	.11	.01	.07	.01	.15
3. CNPT-K			.53**	.16	.54**	.63**	.30*	.63**	.56**	.09	.54**	.33**	.08	.29*
4. CNT-F1				.34**	.94**	.68**	.38**	.60**	.64**	.30*	.63**	.58**	.34**	.51**
5. CNAT-F1					.09	.30*	.23	.23	.23	.38**	.14	.27*	.06	.38**
6. CNPT-F1						.64**	.34**	.57**	.59**	.17	.62**	.54**	.39**	.44**
7. CNT-S1							.54**	.90**	.70**	.37**	.62**	.62**	.41**	.55**
8. CNAT-S1								.26*	.42**	.37**	.39**	.39**	.55**	.24
9. CNPT-S1									.64**	.20	.56**	.50**	.25	.48**
10. LNT-F1										.40**	.92**	.73**	.48**	.64**
11. LNAT-F1											.20	.45**	.39**	.49**
12. LNPT-F1												.68**	.48**	.59**
13. LNT-S1													.67**	.90**
14. LNAT-S1														.43**
15. LNPT-S1														

Note. CNT = Color Naming Total Time; CNAT = Color Naming Articulation Time; CNPT = Color Naming Pause Time; LNT = Letter Naming Total Time; LNAT = Letter Naming Articulation Time; LNPT = Letter Naming Pause Time; K = Kindergarten; F1 = Fall term of grade 1; S1 = Spring term of grade 1; $N = 62$ * $p < .05$. ** $p < .01$.

In addition, RAN total time and pause time were highly correlated with the correlations ranging between .90 and .94. Articulation time was only moderately correlated with the RAN total time with the correlations ranging between .08 and .68. Nevertheless, it must be noted that the correlations between articulation time and RAN total time steadily increased across measurement points. For example, the correlation in kindergarten between CNAT-K and CNT-K was .08, in the Fall term of grade 1 increased to .34, and in the Spring term of grade 1 it was .54.

In sum, pause time shows a remarkable stability from kindergarten until the end of grade 1, develops significantly as shown from the mean pause time decrease, and is mostly related to the RAN total time. On the other hand, articulation time is rather unstable, remains essentially unchangeable over time and is related to a lesser degree to the RAN total times.

RAN Components and Reading Ability

Table 6 presents the correlations between the RAN components and the reading measures. With the exception of a weak correlation between LNAT-S1 and GORT (r = .29), no other significant correlations between articulation time and reading measures were observed. The aforementioned correlation failed to reach significance when the analysis included the one outlier's performance. Pause time correlations with the reading measures replicated the pattern observed in the correlations between the RAN total times and the reading measures. In many instances, the magnitude of the correlation between the RAN pause time and the reading measures exceeded the corresponding correlation between the RAN total time and the reading measures. For example, although CNT in kindergarten was not significantly correlated with the reading fluency measures in the

Spring term of grade 1 (see Table 3), the CNPT-K was. Similarly, the correlations between LNPT-F1 and the reading measures were all higher than the correlations between LNT-F1 and the reading measures.

Table 6

Correlations Between the RAN Components and the Reading Measures

	Grade 1 Fall		Grade 1 Spring			
	WID	WAT	WID	WAT	TOWRE	GORT
CNAT-K	.14	.12	.13	.08	.09	-.13
CNPT-K	-.24	-.20	-.30*	-.02	-.26*	-.27*
CNAT-F1	-.09	-.21	-.12	-.14	.03	-.13
CNPT-F1	-.35**	-.43**	-.40**	-.19	-.42**	-.45**
CNAT-S1			-.17	-.09	-.21	-.19
CNPT-S1			-.24	.01	-.26*	-.25*
LNAT-F1	-.13	-.09	-.13	.01	-.14	-.16
LNPT-F1	-.45**	-.42**	-.56**	-.38**	-.45**	-.51**
LNAT-S1			-.23	-.19	-.20	-.29*
LNPT-S1			-.41**	-.23	-.30*	-.38**

Note. CNAT = Color Naming Articulation Time; CNPT = Color Naming Pause Time; LNAT = Letter Naming Articulation Time; LNPT = Letter Naming Pause Time; K = Kindergarten; F1 = Fall term of grade 1; S1 = Spring term of grade 1; WID = Word Identification; WAT = Word Attack; TOWRE = Test of Word Reading Efficiency; GORT = Gray Oral Reading Test.
$N = 62$. * $p < .05$. ** $p < .01$.

In sum, these results indicate that pause time is the key component in the relation between RAN and reading ability during the first year of school. Articulation time does not predict significantly any measure of reading ability.

Pause Time Components

Pause time itself has been suggested to reflect different processes (e.g., Wolf et al., 2000). For example, Neuhaus et al. (2001a) demonstrated that the consistency of the pause time predicted reading development after the pause time itself was controlled. For the purposes of this study consistency of the pause time was found by calculating the variance of the cleaned pause times across the whole task excluding the end-off-line pause times, variance of which was used as a separate measure of consistency. Mean of the end-off-line pause times was also used as a separate measure of intra-pause time. The different measures of pause time were obtained from Color Naming and Letter Naming pause time in the Fall term of grade 1. The decision to use only the Fall term's pause times was made based on the significant correlations between the CNPT-F1, LNPT-F1, and reading ability shown in Table 6. All the intra-pause time measures were moderately skewed and log transformations were executed. Only the transformed scores were used in further analyses. The correlation coefficients between the intra-pause time measures in the Fall term of grade 1 and the reading outcomes are shown in Table 7.

The consistency of the pause time was correlated with most of the reading measures (the exception is the non-significant correlation between the Letter Naming Pause Time Consistency (LNPTC-F1) and WAT in the Spring term of grade 1). End-off-line pause time consistency and end-off-line mean pause time were correlated with only a few of the reading measures.

Table 7

Intercorrelations Between the Different Pause Time Component Measures and the Reading Outcomes

	Grade 1 Fall		Grade 1 Spring			
	WID	WAT	WID	WAT	TOWRE	GORT
CNPTC-F1	-.38**	-.43**	-.37**	-.25*	-.40**	-.27*
CNELC-F1	-.06	-.10	-.13	.02	-.30*	-.37**
CNELM-F1	-.01	-.08	-.13	.03	-.20	-.40**
LNPTC-F1	-.31*	-.26*	-.37**	-.23	-.37**	-.42**
LNELC-F1	-.06	-.17	-.11	-.03	-.08	-.03
LNENM-F1	-.07	-.11	-.17	-.12	-.02	-.15

Note. CNPTC-F1 = Color Naming Pause Time Consistency; CNELC-F1 = Color Naming End-off-Line Consistency; CNELM-F1 = Color Naming End-off-Line Mean pause time; LNPTC-F1 = Letter Naming Pause Time Consistency; LNELC-F1 = Letter Naming End-off-Line Consistency; LNELM-F1 = Letter Naming End-off-Line Mean pause time; WID = Word Identification; WAT = Word Attack; TOWRE = Test of Word Reading Efficiency; GORT = Gray Oral Reading Test; F1 = Fall term of grade 1.
$N = 62$ * $p < .05$. ** $p < .01$.

Good and Poor Readers' Performance on RAN Components

An important question in the investigation of the influence of RAN components is whether they can be used to distinguish between good and poor readers. To examine this question, the participants at the bottom 25th percentile of the distribution of the reading scores (Fall term of grade 1: Word Identification raw score ≤ 7 and Word Attack raw score = 1; Spring term of grade 1: Word Identification raw score ≤ 33 and Word Attack raw score ≤ 10) were classified as poor readers. The 75th percentile of the distribution of the reading scores was used respectively as a cutoff point to specify the group of good readers (Fall term of grade 1: Word Identification raw score ≥ 24 and Word Attack raw score ≥ 11; Spring term of grade 1: Word Identification raw score ≥ 52 and Word Attack raw score ≥ 24).

Using these criteria, 17 out of 62 children were defined as poor readers in Word Identification in the Fall term of grade 1. Their number in the Spring Term of grade 1 was 14. The number of participants belonging to the top 25th percentile in Word Identification was 15 and 16 respectively. In Word Attack, 18 participants were identified as poor readers in the Fall term of grade 1 and 13 in the Spring term of grade 1. Thirteen children (20% of the sample) were identified as poor readers in both Word Identification and Word Attack in the Fall term of grade 1 whereas the corresponding number in the Spring term of grade 1 was 11 (17% of the sample). Eleven children (17% of the sample) scored on the top 25th percentile in Word Identification and Word Attack in both assessment times. *t*-test comparisons were calculated examining whether poor readers were performing significantly different than good readers in articulation time, pause time, and consistency of the pause time. The *t*-statistic along with the mean component times of the two groups is shown in Table 8.

Although poor readers appear to have longer articulation and pause times than good readers, only the pause time component distinguished between the two reading competence groups as shown by the significant *t*-values. In the Spring term of grade 1, none of the measures could differentiate between good and poor readers, when the criterion was their performance on Word Attack task. These results are in line with previous findings (see e.g., Obregon, 1994) and support the idea that poor readers may have deficiencies in pause time but not in articulation time or in consistency of the pause time.

Table 8

Comparisons Between Good and Poor Readers on the RAN Components

	Word Identification			Word Attack		
	Good	Poor	*t*	Good	Poor	*t*
			Fall term			
CNAT	461	478	.65	452	507	1.87
CNPT	563	777	2.59*	598	853	2.89**
CNCPT	385275	651391	1.85	424554	856025	1.95
LNAT	363	380	.67	380	390	.38
LNPT	447	733	2.48*	467	738	2.66*
LNCPT	452278	639722	.58	397421	503522	.48
			Spring term			
CNAT	477	521	1.22	512	539	.70
CNPT	550	727	2.48*	630	639	.15
CNCPT	472048	567644	.53	625081	468983	-.92
LNAT	377	409	.79	398	408	.25
LNPT	329	526	3.02**	396	483	1.18
LNCPT	138819	379478	1.82	198188	278189	.89

Note. CNAT = Color Naming Articulation Time; CNPT = Color Naming Pause Time; LNAT = Letter Naming Articulation Time; LNPT = Letter Naming Pause Time; CNCPT = Color Naming Consistency of Pause Time; LNCPT = Letter Naming Consistency of Pause Time.
* $p < .05$. ** $p < .01$.

In summation, the 25th and 75th percentile of the distribution of the scores in Word Identification and Word Attack were used respectively to identify the groups of poor and good readers. Only pause time component could distinguish poor readers from good readers. Although consistency of pause time and articulation time in poor readers were larger than in good readers, they didn't reach significance.

CHAPTER 5

Discussion

For the last three decades many studies have examined the role of phonological as well as extra-phonological factors in the development of reading acquisition. What stands out in all these studies is that phonological awareness is necessary for an effortless development of early reading skills. Although the phonological core deficit hypothesis has been able to account for the large majority of reading impairments, there remain individuals with adequate phonological skills but poor reading fluency skills. RAN, the ability to rapidly name visually presented, familiar symbols, has evolved as a promising second determinant of reading, accounting for a significant amount of variance over and above what is explained by phonological awareness. Despite improvement in our understanding of the relationship between RAN and reading ability, several issues remain unresolved such as what does RAN measure and why is related to reading. The present study attempted to address some of the unresolved issues examining the role of RAN in the development of reading from kindergarten until the end of grade 1 in a randomly selected sample. Sixty-two children were tested at the end of kindergarten, at the beginning of grade 1, and at the end of grade 1.

In the first part of the analyses, all four RAN total time measures were used to predict reading accuracy and reading fluency at the beginning and at the end of grade 1. Color Naming and Object Naming were administered in kindergarten and grade 1, whereas Letter Naming and Digit Naming were administered only in grade 1 since the children in kindergarten were not all familiar with the presented letters or digits. In the second part of the analysis the focus was on the RAN components of pause time and articulation time, derived from the sound files of the children's responses on Color and Letter Naming tasks. In particular, the analysis attempted to answer questions on how RAN components develop from kindergarten to the end of grade 1, how RAN components and RAN total time correlate, and which RAN components predict reading accuracy and fluency at the beginning and at the end of grade 1.

RAN Total Time and Reading Ability

As expected, the most time consuming RAN task was Object Naming followed by Color Naming, Letter Naming, and Digit Naming tasks. The naming time for the last two tasks was very similar. According to Theios and Amrhein (1989) prolonged naming of non-graphological stimuli is justified, because it demands two extra processing steps. Before being transferred to the linguistic output processor, mental representations of these stimuli must first pass through an abstract conceptual processor for meaning establishment, and next an internal code or label for the picture or color must be found and selected among a number of possible appropriate names in the mental lexicon of the linguistic system. Current models of picture naming (see e.g., Das, 2001; Glaser, 1992; Levelt, Roelofs, & Meyer, 1999) confirm this explanation.

The RAN performances also showed remarkable stability over time. The obtained autocorrelations were significant for all the RAN tasks from kindergarten to the end of grade 1 ranging from .58 to .74. Similarly, Torgesen and Burgess (1995) reported in their review paper that the stability between kindergarten and grade 1 latent variable of rapid naming was .84. These values are only slightly greater than those reported by Scarborough (1998a) for the 6-year interval between the second and eighth grades, and suggest that the stability of RAN tasks is observable over a period that stretches from before reading instruction begins until well beyond the initial stages of reading instruction.

Apart from investigating the stability of the RAN tasks, the present study also examined the development of the RAN tasks from kindergarten to the end of grade 1. Color and Object Naming total times decreased significantly from kindergarten to Fall term of grade 1 but not between the two grade 1 measurement points. The total times on Letter and Digit Naming decreased significantly during the two measurement points in grade 1. The finding that significant changes in naming time from the beginning until the end of grade 1 are detected mainly in the alphanumeric RAN tasks reinforces the unique association between reading and alphanumeric naming, which has been acknowledged by many researchers (e.g., Bowers & Swanson, 1991; Cardoso-Martins & Pennington, 2004; Compton, 2003; Wagner et al., 1997; Wolf & Bowers, 1999). Although this study did not examine causal relationships between RAN and reading ability, it still provides support for Compton's (2003) findings for a bidirectional facilitation effect of RAN and reading. In Compton's study, a reciprocal relationship between RAN Digits and decoding skills was supported, with RAN performance prior to the acquisition of decoding skill predictive of future decoding skill and with increased growth in RAN facilitated by acquisition of decoding skill. This pattern was not replicated with Color Naming. Similarly in this study, with the initiation of formal reading instruction at the beginning of grade 1, a significant decrease in naming time was observed only for Letter and Digit Naming, but not for Color or Object Naming.

In line with previous research findings (see e.g., Felton & Brown, 1990; Kirby et al., 2003; Parrila et al., 2004; Torgesen et al., 1997), RAN tasks were moderately related to both reading accuracy and reading fluency. The obtained correlations between Letter Naming, Digit Naming and reading measures were higher than the corresponding correlations for Color and Object Naming. In contrast to previously expressed arguments that Color and Object Naming could be used efficiently in kindergarten to account for significant variance in reading at the end of grade 1 (see e.g., Blachman, 1984; de Jong & van der Leij, 1999; Parrila et al., 2004), this study showed that the non-alphanumeric tasks – measured in kindergarten – were only weakly correlated with some of the reading measures both at the beginning and at the end of grade 1. Furthermore, it is noteworthy that the correlations between the RAN tasks and the reading measures were generally higher for reading fluency than for reading accuracy, verifying the hypothesis expressed in the introduction of this thesis.

RAN Components and Reading Ability

RAN total time was partitioned into the components of articulation time and pause time. In this way, the multidimensional nature of RAN was further illuminated and a more precise identification of the parts of the complex assemble of processes that are related to reading was enhanced. Previous studies converge on that pause time was significantly correlated with reading ability, but this association was depending on the RAN task used and on the age of the participants (e.g., Cobbold et al., 2003; Neuhaus et al., 2001a; Neuhaus & Swank, 2002). In contrast, articulation time was not associated with reading at any point of time.

Before discussing the results of this study on the RAN components it is important to note that children with incorrect articulations were not excluded from the analysis. This was done for three statistical and theoretical reasons: first, children with some wrong articulations still had a large number of correct articulations and pauses between the correct articulations. Thus, the analysis of the RAN components could be performed with the remaining, correct articulations and pauses. Second, by excluding subjects the study loses statistical power (see Cohen, 1988). Third, it is important for the researchers to know what the performance of children who make mistakes is. By excluding this sample from further analysis, a restriction of range in RAN performance might occur and deflated or misleading correlations might result.

As predicted, this study showed that while both Color Naming and Letter Naming pause time developed significantly, articulation time did not. Despite a significant decrease in articulation time from kindergarten to Fall term of grade 1, Spring term's articulation time is essentially the same as the one observed in kindergarten. The increase in articulation time from the Fall to the Spring term of grade 1 may reflect a change of strategy in naming the stimuli. Whereas children at an earlier point of time were making more articulation errors, later on, they may have invested more attention in correctly articulating the names of the stimuli and this, in turn, minimized the articulation errors but increased the articulation time.

RAN pause time was highly stable across the measurement points whereas articulation time was considerably less stable. This finding has also been reported by Cobbold et al. (2003) for a period of time that overlaps with the start point of this study. Most correlations between articulation time and pause time were not significant. This result reinforces the suggestion put forward by Neuhaus et al. (2001a) that the cognitive processes influencing the speed of articulation and the lengths of the pauses are independent. RAN total time and pause time were highly correlated. The correlations between RAN total time and articulation time were moderate at best. Pause time was the best predictor of both reading accuracy and fluency measures. Articulation time was only weakly correlated with the reading measures. It is remarkable that none of the correlations between reading accuracy measures and articulation time reached significance. The magnitude of the pause time correlations with the reading measures was approximately the same as the magnitude of the corresponding correlations observed for the RAN total time and reading measures. Taken together this observation attests to the fact that the variability of RAN total time is mainly attributable to the pause time. Finally, consistency of the pause time, a measure supposed to reflect sustained attention towards the whole RAN task was moderately correlated with the majority of the reading measures. In contrast, the mean of the end-off-line pause times and their consistency were only weakly and in most occasions non-significantly correlated with the reading measures.

If articulation time reflects stimulus familiarity as suggested by previous studies (see Balota & Abrams, 1995; Neuhaus et al., 2001a) and pause time reflects the retrieval process of the verbal labels for the stimuli, then it is conceivable that the subjects in this study had little variation in their stimuli knowledge and had more variability in the retrieval time of this knowledge. Therefore, it can be inferred that color or letter name knowledge and the ability to retrieve this knowledge are separable and develop at different rates.

This result argues against the generalized slowing hypothesis according to which it would be expected that poor readers would be slow in the retrieval of the verbal label and in the actual production of the name by a constant factor. In other words, if Total

Time = Articulation Time + Pause Time, then poor readers' RAN performance would equal to X (Articulation Time) + X (Pause Time), where X equals a constant number. However, in this study, component comparisons between poor and good readers revealed that significant differences were apparent only for pause time, but not for articulation time. Thus, the generalized slowing hypothesis is not supported by the findings of this study.

The question that unavoidably emerges is what pause time reflects. Wolf and Bowers (1999) commenting Obregon's (1994) findings suggested that pause time reflects "the extra time taken by dyslexic participants to relinquish processing the previous stimulus and to move on to processing the next one" (p. 418). A different position was expressed by Neuhaus et al. (2001a) who considered pause time for letters a measure of processing speed associated with letters and pause time for objects a measure reflecting a more general verbal processing speed. Das et al. (1994) hypothesized that variation in pause time might reflect blocks of involuntary rests produced by reactive inhibition during massed practice. However, this study provided evidence that poor readers and good readers were not differentiated based on the consistency of the pause time across the whole RAN tasks. This implies that poor readers and good readers dissipated reactive inhibition similarly at least across the whole RAN task. Nevertheless, differences between good readers and poor readers have been reported by Neuhaus et al. (2001a) when processing consistency was measured by the row variance.

Due to the multicomponential nature of RAN, we would expect that each one of the subprocesses could be deemed as a potential explanation linking RAN to reading ability. Adopting Wolf and Bowers' (1999) organization of visual naming subprocesses, it is plausible that pause time subsumes processes like inhibition of response towards the previous stimuli, perception of the next stimulus, direction of the access and retrieval of a label, engagement of attention onto the next stimulus, and motor programming. Which of these processes can be linked to reading is a topic for future research.

Limitations of the Study

Some limitations of the present study are worth mentioning. First, it must be made clear that the results of this study are restricted only for the developmental span and population that has been examined, that is from kindergarten until the end of grade 1, and therefore the findings do not apply to later grades or to specific reading populations. Second, only RAN tasks were used along with the reading measures. This decision was made based on the main focus of this study, which was the investigation of the relationships between the RAN components and reading. Therefore, it is expected that the observed correlations between the RAN tasks and the reading measures or between the RAN components and the reading measures would be different if the effect of other variables was controlled. These variables could be any other measure subsumed under the phonological family, such as phonological awareness or phonological memory, or any other measure of orthographic knowledge. In addition, no external factors that may affect early reading acquisition have been incorporated in the proposed model (e.g., verbal intelligence, educational level of the parents, print exposure, SES).

Third, although some pause times were relatively long possibly indicating off-task behavior, they could not be cleared because they were accompanied by silence. This may reflect that the children were either using this time thinking or that they were distracted from their target activity without any audible sign. If the second assumption is true, then the inclusion of these pauses resulted in an increase of both the mean pause time and the variance of the pause time for the wrong reasons.

Fourth, characteristics of the language's orthography may have impacted the relative contributions of pause time and articulation time on reading ability. For example, Wimmer (1993) provided evidence suggesting that, as a language's orthography becomes more transparent (relations between letters and sounds more predictable), individual differences in phonological awareness may become less important in explaining reading ability, whereas differences in rapid naming ability become more important. The orthography of English is rather opaque, thus rendering phonological awareness more powerful and rapid naming less central. The current results cannot be generalized to languages with transparent orthography.

Future Directions

In the light of research findings that phonological awareness, rapid naming, and letter knowledge comprise the best set of predictors of reading acquisition (e.g., Catts, 1996; League & Bishop, 2004; Schatschneider et al., 2004), any examination of the links between RAN and reading is not only relevant, but also *sine qua non* for the design of more comprehensive diagnostic batteries. In this way, children experiencing rapid naming difficulties will no longer slip through the screening measures, because of their adequate phonological awareness skills. The results of this study certainly have implications for future intervention programs. If articulation time is only weakly related to reading, then it makes sense to suggest that remediation should not target articulation, but the processes involved during the pause time. If Lovett et al.'s (2000) remediation program failed to improve naming speed in the single-naming deficit group, this might suggest that the phonologically-based intervention along with the teaching of metacognitive skills does not sufficiently address the cognitive processes involved in the pause time.

In future research it would be beneficial to investigate other variables such as phonological awareness and orthographic knowledge that may show a relationship with the pause time and articulation time. Such research could help understanding of the cognitive processes that are taking place during the serial naming. It would also be of value to carry out further research with children during later grades, where it is expected, according to Parrila et al. (2004), that naming speed exceeds the importance of phonological awareness as a predictor of reading ability. If the cognitive processes that underlie pause time become more automatic with the passing of time, and pause time decreases approaching the levels of articulation time, would the relationships between these RAN components and reading be different?

Cross-linguistic studies would also be informative regarding the relationship between the RAN components and reading ability. Would pause time be the same in children of the same age but speaking a different language or would longer articulations in one of the languages cause the increase in the corresponding pause time and distort the associations with reading?

This intra-rapid naming study succeeded in partitioning the RAN total time into the distinct and identifiable components of articulation time and pause time. Keeping in mind the ultimate goal of delineating why RAN is related to reading, future research should ponder on further dissecting the pause time and provide a more thorough explanation as to what is the process or combination of processes that links RAN to reading and what is responsible for slow naming. Creative integration of information derived from several sources such as *f*MRI, ERP, or eye movement studies would be of great help. Unless an amalgamation of information derived from different research domains is accomplished, the nature of the relationship between RAN and reading will continue to be highly speculative and unresolved.

Conclusions

Once again, it has been found that RAN tasks are related to reading ability. Generally, Letter and Digit Naming correlations with the reading measures at the beginning and at the end of grade 1 were higher than the corresponding correlations between Color Naming, Object Naming, and reading measures. Color Naming and Letter Naming total times were further partitioned into the constituent components of articulation time and pause time. The results indicated that pause time was highly stable from kindergarten to the end of grade 1, developed significantly, and was highly correlated with the reading measures administered at the beginning and at the end of grade 1. Articulation time was less stable, did not develop, and was only weakly correlated with the reading measures. In addition, the lack of association between the pause time and the articulation time suggests that the cognitive processes that underlie the two RAN components are independent of each other. The results are comparable to previous findings and suggest that pause time is the key component in the relation of RAN with reading. Further understanding of the relation between RAN and reading likely depends on understanding the cognitive processes taking place during the pause time.

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