University of Alberta

Why is Rapid Naming Speed Related to Reading? Examining Different Theoretical Accounts

by

Georgios Kyriacou Georgiou ©

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Abstract

This thesis consists of three separate papers. The first paper examined: (a) how rapid automatized naming (RAN) speed components – articulation time and pause time – predict reading accuracy and reading fluency in grades 2 and 3; and (b) how RAN components are related to measures of phonological awareness, orthographic knowledge, and speed of processing. Forty-eight children were administered RAN tasks in grades 1, 2, and 3. Results indicated that pause time was highly correlated with both reading accuracy and reading fluency measures and shared more of its predictive variance with orthographic knowledge than with phonological awareness or speed of processing. In contrast, articulation time was only weakly correlated with the reading measures and was rather independent of any processing skill at any point of measurement.

The second paper examined how RAN is related to reading ability across languages that vary in orthographic consistency. Forty English-speaking Canadian children, 40 Greek-speaking Cypriot children, and 40 Chinese-speaking Taiwanese children were administered RAN, reading accuracy, and reading fluency tasks in grade 4. The results revealed that across languages there were no statistically significant differences in the correlations between RAN and reading. However, a subsequent analysis of the RAN components – articulation and pause time – revealed that different RAN components may be responsible for the RAN-reading relationship across languages. The article concludes with implications for existing theories relating RAN to reading.

The third paper reports on a cross-linguistic longitudinal study that examined the predictors of word decoding and reading fluency in children learning to read an orthographically inconsistent language (English) and children learning to read an orthographically consistent language (Greek). One-hundred-ten English-speaking Canadian children and 70 Greek-speaking Cypriot children attending grade 1 were examined on measures of RAN, phonological awareness, phonological memory, orthographic knowledge, word decoding, and reading fluency. The same children were reassessed on word decoding and reading fluency measures when they were in grade 2. Results indicated that both phonological and orthographic processing measures contributed uniquely to reading ability in grades 1 and 2. However, the importance of these predictors was different in the two languages particularly with respect to their effect on word decoding.

Co-authorship Statement

The three empirical studies presented in this dissertation jointly attempt to provide some insights into why RAN is related to reading. In all three papers I am the first author. Study I is in press in *Scientific Studies of Reading*. It is a coauthored paper with Dr. R. Parrila, Dr. J. Kirby, and Mrs. K. Stephenson. Dr. Parrila supervised all the steps for the completion of the study, Dr. Kirby contributed in the design and development of some of the tests and Mrs. Stephenson contributed in tests' development, participants' selection, and data collection. Study II is in press in *Reading and Writing: An Interdisciplinary Journal.* It is a coauthored paper with Dr. R. Parrila, and Dr. C.-H. Liao. Dr. Parrila supervised all the steps for the completion of the study and Dr. Liao was the site coordinator in Taiwan, where the data for the Chinese-speaking children were collected. She also selected and designed the assessment tools for the Chinese-speaking children. Finally, study III has been submitted for publication. It is a coauthored paper with Dr. R. Parrila and Dr. T. Papadopoulos. Dr. Parrila supervised all the steps for the completion of the study and Dr. Papadopoulos was the site coordinator in Cyprus, where the data for the Greek-speaking children were collected. Dr. Papadopoulos designed also some of the tests. Finally, data analysis and manuscript preparation for all three papers was completed by me.

Dedicated

to

my parents, Angela and Kyriaco
for their continuous support and understanding

and to

Jessica Nahirney
for joining me in this beautiful journey with love and sincerity

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I. INTRODUCTION

More than three decades of research has established that rapid automatized naming (RAN) speed, defined as how quickly children can name continuously-presented and highly-familiar visual stimuli, such as letters, digits, colors, and objects, is a strong concurrent and longitudinal predictor of reading development (e.g., Blachman, 1984; Bowers, 1995; Bowers, Steffy, & Swanson, 1986; Bowers & Wolf, 1993; Denckla & Rudel, 1976; Kirby, Parrila, & Pfeiffer, 2003; Manis, Doi, & Bhadha, 2000; Parrila, Kirby, & McQuarrie, 2004; Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007; Scarborough, 1998; Wolf, Bally, & Morris, 1986). Despite the acknowledged importance of RAN in predicting reading, there are significant unresolved issues, such as what RAN tasks measure and, most importantly, why RAN is related to reading.

This dissertation consists of three separate studies that examine different theoretical accounts of the RAN-reading relationship by utilizing three approaches. The first, and commonly used, approach is to examine the unique contribution of RAN to reading accuracy and fluency over and beyond measures of other cognitive processing skills. In Study I, the contribution of RAN to reading was examined in relation to measures of phonological awareness, orthographic processing, and speed of processing. Similarly, in Study III, the contribution of RAN to reading was examined in relation to measures of phonological awareness, phonological short-term memory, and orthographic knowledge. The second approach is a more recent addition to RAN research and examines the effect of RAN components – articulation time and pause time – on reading in English (Study I) and across languages that vary widely in orthographic consistency (Study II). Finally, the third approach examines the effects of orthographic consistency on RAN-reading relationship. Specifically, in Study II the effect of orthographic consistency is examined by comparing Chinese, English, and Greek grade 4 children, and in Study III it is examined by following children learning to read in English and Greek from grade 1 until grade 2. In the rest of this introduction, I first review the most prominent RAN-reading theories and then briefly the literature on (a) RAN in relation to other cognitive processing skills, (b) RAN components, and (c) RAN and orthographic consistency. At the end of the introduction, I briefly describe the three empirical studies that are described in detail in Chapters II, III, and IV.

RAN-Reading Theories

Various researchers have attempted to explain why RAN is related to reading. Research reported in this dissertation was guided primarily by four competing theoretical explanations regarding the nature of the RAN-reading relationship in typically developing and reading-disabled individuals: (a) Torgesen, Wagner, and their colleagues' hypothesis that RAN should be considered as another manifestation of phonological processing, (b) Bowers, Wolf, and their colleagues' hypothesis that RAN is an index of the quality of orthographic representations, (c) Manis and his colleagues' hypothesis that RAN reflects how fast arbitrary sound-symbol associations are established, and finally (b) Kail and his colleagues' hypothesis that RAN and reading are related because they both rely on speed of processing. Theories relating RAN to cerebellum deficits (e.g., Nicolson, Fawcett, & Dean, 2001), working memory (e.g., Amtmann, Abbott, & Berninger, 2007), or modalities synchronization (e.g., Breznitz, 2005) will not be examined in this dissertation and, therefore, are not reviewed below.

RAN as an Index of Phonological Processing

Torgesen, Wagner, and their colleagues (e.g., Torgesen, Wagner, & Rashotte, 1994; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Wagner & Torgesen, 1987) subsumed RAN under the phonological processing family and maintained that RAN is an index of the speed with which we access phonological information from the long term memory. It is therefore not surprising that in their initial published work on this topic the term "phonological recoding in lexical access" was used to represent rapid naming (e.g., Wagner & Torgesen, 1987). Furthermore, Torgesen et al. (1994) reported the results of a latent variable analysis showing that phonological processing measures, including RAN and phonological short-term memory, were redundant with each other as predictors of reading.

Recently, Bowey, McGuigan, and Ruschena (2005) provided support for Torgesen, Wagner, and their colleagues' theoretical account by demonstrating that phonological processing, measured with a phoneme deletion and a nonword repetition task, was mediating the relationship between alphanumeric RAN and word reading in an unselected group of grade 4 children. More specifically, Bowey et al. (2005) showed that of the 21% of the variance shared by alphanumeric RAN and word reading, only 2% was independent of phonological processing ability.

However, there is also a wealth of studies that have called into question the mediating role of phonological processing by demonstrating that RAN has an independent role to play in predicting reading ability over and beyond the contribution of phonological awareness (e.g., Bowers, 1995; Compton, DeFries, & Olson, 2001; Cronin & Carver, 1998; Parrila et al., 2004; Manis et al., 2000; Powell et al., 2007; Savage & Frederickson, 2005). First, there is evidence to suggest that although performance on the RAN tasks shares some variance with performance on phonological tasks, probably because of the need to access the sound representations and to articulate the names of the symbols in both tasks, it is not necessarily this shared variance that is responsible for the relationship between RAN and reading. Parrila and his colleagues (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).

Second, several studies have shown that RAN and phonological awareness account for variance in different types of reading tasks (e.g., Bowers, 1995; Young & Bowers, 1995; Savage & Frederickson, 2005). RAN appears to be more strongly related to tasks that require reading fluency, such as in reading a short story as fast as possible, whereas phonological awareness appears to be more strongly related to tasks that require word decoding abilities, such as Word Identification and Word Attack tasks. Third, studies conducted in languages with a transparent orthography (such as German, Finnish, and Dutch) have shown that poor readers in these languages have deficits in RAN, but to a lesser degree in phonological awareness tasks (e.g., Brizzolara et al., 2006; Korhonen, 1995; van den Bos, 1998; Wimmer, 1993) because phonological demands are more easily met in these languages due to the higher regularity of grapheme-phoneme correspondences. Finally, deficits in both phonological awareness and RAN appear to have an additive negative effect on reading. Wolf and Bowers (1999) proposed the *double-deficit hypothesis*, according to which it is possible to identify four categories under which children can be classified: a single naming deficit group, a single phonological 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 can be accurate but slow decoders, that phonologically impaired readers are inaccurate decoders but faster than RAN-impaired readers, and that double-deficit readers are the poorest readers overall (e.g., Escribano, 2007; Lovett, Steinbach, & Frijters, 2000; Manis et al., 2000; Powell et al., 2007; Wolf, O'Rourke, Gidney, Lovett, Cirino, & Morris, 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.

RAN as an Index of Orthographic Processing

In response to the plethora of evidence showing that RAN is likely independent from phonological processing, Bowers and Wolf (1993) proposed a competing theoretical account according to which processes reflected in RAN underlie letter recognition speed. If letter recognition is proceeding too slowly, letter representations in words will not be activated in sufficiently close temporal proximity to induce sensitivity to commonly occurring orthographic patterns. Bowers, Golden, Kennedy, and Young (1994) conceptualized orthographic processing, defined as the ability to use visual-orthographic information in processing words, as a 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).

In line with this theoretical account, researchers have shown that performance on RAN tasks is related to orthographic knowledge (e.g., Cardoso-Martins & Pennington, 2004; Cutting & Denckla, 2001; Holland, McIntosh, & Huffman, 2004; Manis et al., 2000) and that children with slow RAN performance have deficits in orthographic knowledge compared to their peers with unimpaired RAN performance (e.g., Bowers, Sunseth, & Golden, 1999; Conrad & Levy, 2007; Sunseth & Bowers, 2002).

However, there is also evidence to challenge the orthographic processing hypothesis. For example, Bowers and her colleagues (1999) developed the Quick Spelling Test (QST) that required children to report the letters in four-letter words (e.g., *went*), pseudowords (e.g., *hool*), and nonwords (e.g., *ncdk*) presented in random order on a computer screen for 250 ms. They expected that children with RAN deficits would be less accurate on all letter strings, but they would still show some benefit in reporting letters from real words and pseudowords compared to nonwords. On the other hand, it was expected that children with typical RAN performance and consequently more orthographic knowledge, should benefit from the orthographic structure in words and pseudowords compared to nonwords. The results indicated that performance on the RAN tasks was related only to the number of letters reported in the nonword condition. The groups did not differ from each other on reporting letters from real words or pseudowords. Thus, it is conceivable that children with a RAN deficit were actually using orthographic knowledge to facilitate letter processing.

A variation of Bowers and Wolf's (1993) theoretical account was proposed by Manis, Seidenberg, and Doi (1999). They argued that the critical property of RAN is that the visual stimuli in the task have to be mapped rapidly to their names, and that these mappings are arbitrary. For example, seeing the digit "5" does not equip the participant with the phonological information needed to say the word "five." In the same way, producing the correct pronunciation for an exception word (i.e., *yacht*) requires the retrieval of partially arbitrary item-specific knowledge. In support of this theory, Manis et al. (1999) as well as other researchers (e.g., Clarke, Hulme, & Snowling, 2005; Uhry, 2002) showed that RAN was more strongly related to exception word reading compared to regular or nonword reading.

RAN as an Index of Speed of Processing

The equivocal results presented in the aforementioned studies propelled a fourth theoretical proposition regarding the RAN-reading relationship. Rather than being causal in nature, the relationship between RAN and reading may be driven by a third "common cause" factor. Kail and his colleagues (e.g., Kail & Hall, 1994; Kail, Hall, & Caskey, 1999) have argued that speed of processing may be an alternative explanation for the link between RAN and reading. They theorized that the 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. More specifically, Kail et al. (1999) maintained 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" (p. 312).

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 related to speed of processing. For example, van den Bos, Zijlstra, and van den Broek (2003) demonstrated that the correlations of the speed of processing measures with the RAN tasks were weak and on several occasions non-significant. Furthermore, van den Bos et al. found that the visual matching speed 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).

To summarize, several theoretical accounts have been proposed to account for the relationship between RAN and reading. Consistent with the phonological core deficit in development dyslexia, Torgesen and his collaborators (e.g., Torgesen et al., 1994, 1997) have suggested that RAN is an index of the speed of access to and retrieval of phonological representations from the long term memory. In contrast, Bowers and Wolf (1993) 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. Manis et al. (1999) further pointed out that this is particularly useful when the associations between sounds and symbols are arbitrary. Finally, Kail and his collaborators (Kail & Hall, 1994; Kail et al., 1999) have theorized that RAN and reading may be linked because of an underlying speed of processing factor.

RAN as a Unique Predictor of Reading

Since the pioneering study of Denckla and Rudel (1976) showing that speed of naming colors or objects and not accuracy per se was related to reading performance, numerous studies have demonstrated that RAN is a reliable predictor of reading (see e.g., Bowers & Ishaik, 2003; Wolf & Bowers, 1999; Wolf, Bowers, & Biddle, 2000, for a review of the RAN studies; and Scarborough, 1998; Swanson, Trainin, Necoechea, & Hammill, 2003, for meta-analyses using RAN). Generally, the studies converge on the conclusion that RAN accounts for unique variance in reading even after statistically controlling for verbal and non-verbal cognitive ability (Badian, 1993; Cornwall, 1992), visual skills (McBride-Chang & Zhong, 2003), speed of processing (Bowey et al., 2005), discrete naming (Bowers & Swanson, 1991), articulation rate (Parrila et al., 2004), letter knowledge (Kirby et al., 2003), and, most importantly, phonological awareness (e.g., Bowers, 1995; Cornwall, 1992; Kirby et al., 2003; Manis et al., 2000). For example, in one of the most frequently cited studies, de Jong and van der Leij (1999) demonstrated that when phonological awareness, verbal short-term memory, and RAN were measured in kindergarten, only RAN 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 RAN made unique contributions to predicting grade 3 word decoding speed after controlling for grade 1 word decoding speed and vocabulary. The independent contribution of RAN to reading over and beyond phonological awareness challenges the view that RAN's effects on reading are redundant to phonological awareness and phonological short-term memory and that RAN should be subsumed under the rubric of phonological processing. At the same time, this line of research cannot rule out the possibility that RAN's effects on reading are mediated through resulting variability in orthographic processing.

Studies that have examined RAN in relation to both phonological awareness and orthographic processing are scarce and have reported contradictory findings (e.g., Cutting & Denckla, 2001; Holland et al., 2004; Liao, Georgiou, & Parrila, in press). For example, Cutting and Denckla (2001) found that RAN, phonological awareness, and orthographic processing all had direct effects on reading and that RAN had no direct effects on either phonological awareness or orthographic processing. In turn, Holland et al. (2004) showed that the best fitting model was one in which RAN predicted reading indirectly through the effects of phonological awareness and orthographic processing. Finally, working with Chinese-speaking children, Liao and her colleagues (in press) showed that RAN tasks accounted for unique variance in reading fluency in grades 2 and 4 after controlling for short-term memory, phonological awareness, and orthographic processing. Their results also indicated that RAN tasks shared part of their predictive variance in reading fluency with phonological awareness in grade 2, and with phonological awareness and orthographic processing in grade 4. Despite the importance of these findings, they underline the necessity for a more thorough examination of RAN along with measures of phonological and orthographic processing.

RAN Components and Reading

Several researchers have argued that measuring RAN 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 *articulation time* and *pause time* (e.g., Cobbold, Passenger, & Terrell, 2003; Neuhaus, Foorman, Francis, & Carlson, 2001). Articulation time has been defined as the sum of the times of all correctly articulated items that correspond to the displayed RAN stimuli, and pause time as the sum of the length of pauses that are the intervals between the correctly sequenced articulations.

Recently, Georgiou, Parrila, and Kirby (2006) examined the development of RAN components and their relationship to reading from kindergarten until the end of grade 1. They showed that pause time was highly stable from kindergarten to the end of grade 1, developed significantly, and was highly correlated with both reading accuracy and reading fluency measures. Articulation time was less stable, did not develop, and was only weakly correlated with the reading measures. Although breaking down the RAN total time into its components can enhance our understanding of how RAN performance is associated with reading, the components need to be examined along with other cognitive processing skills, such as phonological awareness, orthographic knowledge, and speed of processing, if we want to make arguments pertinent to the different theoretical explanations of the RAN-reading relationship. To date, only one study has done so and to a limited extent (Clarke et al., 2005). More specifically, Clarke et al. (2005) examined the relationship between RAN components and phoneme deletion. They reported that phoneme deletion was significantly related to RAN Digits articulation time but not to RAN Letters articulation time. Similarly, phoneme deletion was significantly related to RAN Letters pause time but not to RAN Digits pause time. Interestingly, when RAN components were entered in hierarchical regression analyses to predict reading, neither articulation time nor pause time survived the statistical control of age and phoneme deletion.

Although this finding may appear to provide support for Torgesen and his colleagues' theoretical account, it should be viewed with some caution. First, not enough information is provided with respect to how the RAN components were derived other than that they were estimated with the aid of a computer software. Previous studies that have used an amplitude-based RAN scoring software program have recognized the software's limited capacity to correctly identify articulations and, in addition, any extraneous sounds such as coughing or task-irrelevant speech have been marked by the software operator as being part of pause times (e.g., Neuhaus et al., 2001; Neuhaus & Swank, 2002). Second, Clarke et al. used non-traditional RAN measures that may compromise generalizability of their findings. They used digit and letter naming tasks which contained 48 items and utilized 10 different digits (for digit naming) and 25 different letters (for letter naming). Although the relatively small differences in the length of the RAN tasks are likely not critical to the strength of the relationship with reading, the set size of items to be retrieved from long term memory may be. As pointed out by Scarborough and Domgaard (1998), increasing the number of items to be accessed in RAN tasks (e.g., from 5 in Denckla and Rudel's to 10 or 25 in Clarke et al.'s study) results in increased phonological encoding. Hence, the increased phonological encoding alone may explain why controlling for phoneme deletion in the Clarke et al.'s (2005) study resulted in a non-significant contribution of pause time in word reading.

RAN and Orthographic Consistency

Written languages can be put on a continuum from transparent, or shallow, orthographies to opaque, or deep, orthographies according to the degree of consistency with which graphemes correspond to phonemes (e.g., Seymour, Aro, & Erskine, 2003). A plethora of studies has examined the role of RAN in reading in several different languages (e.g., *Chinese*: Ho & Lai, 1997; *Dutch*: de Jong & van der Leij, 1999; *English*: Kirby et al., 2003; Parrila et al., 2004; *Finnish*: Lepola, Poskiparta, Laakkonen, & Niemi, 2005; *German*: Wimmer, 1993; *Greek*: Nikolopoulos, Goulandris, Hulme, & Snowling, 2006). However, there is a paucity of cross-linguistic studies examining if the strength of this relationship is the same across languages and types of reading outcomes, and, most importantly, whether RAN is related to reading for the same reason(s) across languages. For example, it is possible that the same RAN components predict reading across languages, and to the same degree; that the same RAN components predict reading across languages, but to a different degree; or that different RAN components predict reading across languages.

Examining the contribution of RAN to reading across languages that vary in orthographic consistency provides an elegant way of testing different theoretical accounts of why RAN is related to reading. For example, if Torgesen, Wagner, and their colleagues' hypothesis that RAN assesses the rate of access to and retrieval of stored phonological information in long-term memory is correct and if phonological processing is more important for reading in English than in Chinese or in consistent orthographies (i.e., Finnish, German, or Greek), as suggested by many researchers (e.g., Mann & Wimmer, 2002; Mayringer, Wimmer, & Landerl, 1998; McBride-Chang et al., 2005; Wimmer & Mayringer, 2001), then RAN should exert a much stronger effect on reading in English than in Chinese or in consistent orthographies. Note that this prediction runs counter to the findings of single-language studies (e.g., Di Filippo et al., 2005; Lepola et al., 2005; Nikolopoulos et al., 2006; Protopapas, Sideridis, Mouzaki, & Simos, 2007) showing that RAN is strongly related to reading in consistent orthographies.

Likewise, if Bowers, Wolf, and their colleagues' hypothesis that RAN may be a marker of difficulties in orthographic rather than phonological processing is correct and if orthographic processing is important for reading irrespective of the characteristics of the orthography (e.g., *Chinese*: Ho, Chan, Chung, Lee, & Tsang, 2007; *English*: Badian, 2001; Barker, Torgesen, & Wagner, 1992; *Norwegian*: Bjaalid, Hoien, & Lundberg, 1996), then RAN would be expected to predict reading equally well across languages. At the same time, we should observe greater correlations for alphanumeric RAN (Digits or Letters) compared to non-alphanumeric RAN (Colors or Objects) in all alphabetic writing systems, because letters and digits carry more orthographic information than colors and objects.

Finally, if Manis et al.'s (1999) hypothesis is correct, we should observe higher correlations between RAN and reading in Chinese than in English and, in turn, higher correlations in English than in more consistent alphabetic orthographies. Although identifying consistencies in the sounds made by phonetic radicals in Chinese characters is helpful in learning to pronounce new characters (e.g., Cheung, McBride-Chang, & Chow, 2006), they do not guarantee success in the way that learning grapheme-phoneme correspondences does in transparent orthographies. Manis et al.'s (1999) hypothesis, however, seems to be in conflict with existing evidence showing that RAN is more important for reading in orthographically consistent languages than in orthographically inconsistent ones (e.g., Mann & Wimmer, 2002).

Overview of the Present Dissertation

Chapters II, III, and IV present three empirical studies aimed at examining RAN-reading relationship. The purpose of Study I (Chapter II) was to examine how RAN components – articulation time and pause time – relate to measures of phonological awareness, orthographic processing, and speed of processing, and predict reading accuracy and reading fluency in the early school years. On the basis of previous studies (e.g., Georgiou et al., 2006; Neuhaus et al., 2001; Neuhaus & Swank, 2002), it was expected that pause time, and to a lesser degree articulation time, will predict reading acquisition and that despite significant shared variance with phonological awareness, orthographic processing, and/or speed of processing, pause time will continue to account for unique variance in reading.

The second study (Chapter III) examined how RAN components predict reading accuracy and fluency in Chinese, English, and Greek. The languages were selected so that they represent different points in the orthographic consistency continuum (Seymour et al., 2003). Chinese is considered to represent the one extreme end of orthographic consistency (opaque orthography), Greek is considered to represent the other extreme end of orthographic consistency (transparent orthography), and English is considered to represent the "mid-point" on the orthographic consistency continuum (more transparent than Chinese but less transparent than Greek). Because this is the first time that the effects of RAN components are examined in languages other than English, no predictions were made given also the fact that there is such a great variation in the findings of single-language studies with respect to the contribution of RAN total time on reading.

Finally, Study III (Chapter IV) aimed to examine the effects of RAN in relation to phonological awareness, phonological short-term memory, and orthographic processing on word decoding and reading fluency in English and Greek. The contribution of RAN was viewed in the context of *psycholinguistic grain size theory* (PGST) and of the most prominent RAN-reading theories. It was hypothesized that if RAN measures the ability to access and retrieve phonological representations from long term memory, then it should be more strongly related to reading in Greek, because the phonological representation of each single grapheme should be retrieved quickly enough for the grapheme-phoneme recoding strategy to be effective. In contrast, it was hypothesized that if RAN measures the ability to form orthographic representations, then it should be more important for reading in English, because for the larger grain-size unit strategies to succeed the orthographic information of those units must be developed.

The dissertation concludes with a discussion of the main findings and limitations of the presented studies. In addition, implications and some ideas for future research are presented in Chapter V.

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II. RAN COMPONENTS AND THEIR RELATIONSHIP TO OTHER COGNITIVE PROCESSING SKILLS AND READING

More than thirty years of research has demonstrated that rapid automatized naming (RAN) speed, defined as how quickly children can name continuously presented and highly familiar visual stimuli, is a strong concurrent and longitudinal predictor of reading development (Blachman, 1984; Bowers, 1995; Bowers & Swanson, 1991; Cutting & Denckla, 2001; de Jong & van der Leij, 1999; Denckla & Rudel, 1974; Felton & Brown, 1990; Kirby, Parrila, & Pfeiffer, 2003; Scarborough, 1998; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; van den Bos, Zijlstra, & Spelberg, 2002). In addition, a substantial body of evidence suggests that RAN is not only related to normal reading acquisition but also to reading disabilities irrespective of the language in which children learn to read (e.g., Bishop & League, 2006; Christodoulou & Alivisatos, 2004; de Jong & van der Leij, 2003; Di Filippo et al., 2006; Ho & Lai, 1999; Korhonen, 1995; Lyytinen, Erskine, Tolvanen, Torppa, Poikkeus, & Lyytinen, 2006; McBride-Chang & Manis, 1996; Shu, McBride-Chang, Wu, & Liu, 2006; Wimmer, 1993).

RAN has survived as a significant predictor of reading even after controlling statistically for verbal and non-verbal IQ (Badian, 1993; Bowers, Steffy, & Tate, 1988), prior reading ability (Badian, 1993), short-term memory (Parrila, Kirby, & McQuarrie, 2004), articulation rate (Parrila et al., 2004), speed of processing (Bowey, McGuigan, & Ruschena, 2005; Cutting & Denckla, 2001), letter knowledge (Kirby et al., 2003; Lepola, Poskiparta, Laakkonen, & Niemi, 2005), and, most importantly, phonological awareness (Bowers, 1995; Kirby et al., 2003; Manis, Doi, & Bhadha, 2000). Nevertheless, the relationship between RAN and reading appears to vary as a function of the type of RAN tasks used (alphanumeric versus non-alphanumeric) and the type of reading outcomes (reading accuracy versus reading fluency) (e.g., Katzir et al., 2006; Parrila & Georgiou, 2006; Savage & Frederickson, 2005; Schatschneider et al., 2004). For example, Savage and Frederickson (2005) demonstrated that the relationship between RAN and reading was significantly higher when Digit Naming, as opposed to Object Naming, was used as a measure of RAN, and when text-reading speed, as opposed to word reading accuracy, was used as a measure of reading ability.

Despite the acknowledged importance of RAN in predicting reading, there is still no consensus as to what cognitive process or processes are driving the relationship between RAN and reading and how RAN's influence changes across time (e.g., Kirby et al., 2003; Närhi et al., 2005; Scarborough & Domgaard, 1998). Torgesen, Wagner, and their colleagues (e.g., Torgesen, Wagner, & Rashotte, 1994; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Wagner & Torgesen, 1987) have argued that RAN tasks primarily assess the rate of access to and retrieval of stored phonological information in long-term memory (or speed of lexical access). Therefore, RAN should be part of the phonological processing construct along with phonological awareness and phonological memory. On the other hand, Bowers, Wolf, and their colleagues (e.g., Bowers & Wolf, 1993; Bowers, Golden, Kennedy, & Young, 1994; Wolf, Bowers, & Biddle, 2000) proposed that RAN may be a marker of difficulties in orthographic, rather than phonological, processing. If letter identification proceeds too slowly, letter representations in words will not be activated in sufficiently close temporal proximity to induce sensitivity to commonly occurring orthographic patterns.

In essence, Bowers, Wolf, and their colleagues predicted that the variance in RAN associated with reading would be mediated through resulting variability in orthographic processing. Similarly, Manis, Seidenberg, and Doi (1999) emphasized the role of orthographic processing but suggested that instead of timing, the critical property of the RAN tasks is that the relationship between the symbol and its name is arbitrary. Accordingly, they predicted that RAN – reading relationship should be stronger if reading tasks involve more arbitrary orthography-to-phonology mappings, as in reading exception words versus reading regular words. Finally, Kail and his colleagues (e.g., Kail & Hall, 1994; Kail, Hall, & Caskey, 1999) maintained that the association between RAN and reading reflects general cognitive 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. 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.

The relationship between RAN and reading appears to also change developmentally (e.g., de Jong & van der Leij, 1999; 2000; Kirby et al., 2003; Parrila et al., 2004; Torgesen et al., 1997; Wagner et al., 1997). For example, Wagner et al. (1997) examined the 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. RAN contributed independent variation to word reading ability in the first two developmental periods, but not in the third.

Thus, it is plausible that the process or processes responsible for the association between RAN and reading may vary across time. Recently, Bowey et al. (2005) proposed that at the beginning of reading development both over-learned letter knowledge and phonological processing ability mediate the relationship between RAN and reading while at later levels of reading development it is primarily phonological processing ability that mediates the relationship between RAN and reading. Finally, they suggested that, at all levels of reading development, speed of processing also plays some role in the RAN-reading relationship. If this hypothesis is correct, it may explain why in later grades RAN is no longer a strong predictor of reading among samples of average readers. Based on theories of reading development (e.g., Ehri, 1992; Seymour, 2006), we would expect that as children's reading skills develop they rely more on whole-word recognition than on phonological recoding to read. In support of this argument, Badian (2001) demonstrated that although phonological awareness predicted unique variance in reading at the early grades, orthographic knowledge was more important in later grades. Taken together, if RAN is related to reading because of phonological processing (as suggested by Bowey and her colleagues) and phonological processing itself is less important for reading in later grades, then this explains why RAN is important only in the first few years of reading development but not later.

However, based on existing evidence showing that RAN is significantly related to orthographic knowledge (see e.g., Cutting & Denckla, 2001; Manis et al., 1999, 2000; Sunseth & Bowers, 2002; Torgesen et al., 1997), we would expect that RAN remains a strong predictor of reading even in later grades when the role of orthographic knowledge increases. Perhaps the contradiction can be explained if we examine orthographic knowledge's contribution to different types of reading outcomes. Because orthographic knowledge enables instant recognition of letter chunks or whole word units, it should explain more variance in measures that emphasize speed than in measures that simply require accurate identification. For example, Barker, Torgesen, and Wagner (1992) found that orthographic knowledge, measured with the Orthographic Choice and Homophone Choice tasks, accounted for 5% and 7% of variance in word decoding and word identification, but 20% and 15% of variance in oral reading rate and silent reading rate, respectively, after controlling for general cognitive ability, age, and a composite measure of phonological skills. Taken together, these findings suggest that RAN's stronger contribution to reading fluency may be mediated by orthographic knowledge rather than phonological processing or speed of processing.

RAN Components

In most previous research, RAN has been measured as a unitary construct by obtaining a single performance time for the entire test. Neuhaus, Foorman, Francis, and Carlson (2001) 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 *articulation time* and *pause time*. They defined articulation time as the sum of all correctly articulated times that correspond to the displayed RAN stimuli, and pause time as the sum of the length of pauses that are the intervals between the correctly sequenced articulations.

To date, only a few studies have focused on RAN components in relation to reading. The first studies to examine RAN components compared children with dyslexia and normally reading children (Anderson, Podwall, & Jaffe, 1984; Obregon, 1994; Snyder & Downey, 1995). Briefly, these early studies concurred that pause time reliably differentiates dyslexic and normally developing readers, whereas the results for articulation time were contradictory (see Georgiou, Parrila, & Kirby, 2006, for a review).

Neuhaus and her colleagues (2001) were the first to examine RAN components and reading with an unselected sample of 50 grade 1 and grade 2 students. Neuhaus et al. used three RAN tests (letters, digits, and objects) and found that the letter naming pause time and the consistency of the letter naming pause time – defined as the variance of the mean pause times of the five rows of stimuli – were the only measures that consistently predicted decoding and reading comprehension. Letter naming pause time was a significant predictor of reading even after controlling for the object naming pause time. This prompted Neuhaus et al. to suggest that pause time for letters predicts reading because of the unique speed of processing demands associated with retrieving letter knowledge rather than more general verbal processing speed demands as reflected in object naming pause time. Neuhaus and Swank (2002), in turn, reported that letter naming pause time, consistency of pause time, and articulation time were all significantly associated with reading in a larger ($N = 221$) sample of grade 1 students, as was the object naming pause time but not the object naming articulation time.

Subsequent studies have reported contradictory findings. Georgiou et al. (2006) demonstrated that only pause time (both in Color and Letter Naming) was significantly related to grade 1 word reading and reading fluency measures. However, Clarke, Hulme, and Snowling (2005), in a study with older children, showed that for digit naming, only articulation time was significantly related to exception word and nonword reading, whereas for letter naming, both articulation and pause time were related to exception word reading but not to nonword reading. Interestingly, when RAN components were entered in hierarchical regression analyses to predict reading, neither articulation time nor pause time survived the statistical control of age and phoneme deletion.

Thus, the previous research on RAN components with unselected samples has provided conflicting findings on the effects of RAN components on reading. Most studies suggest a larger relationship between pause time and reading than between articulation time and reading. However, age of participants and type of RAN tasks used appear to affect which RAN components are related to reading and when they exert their predictive power.

Limitations of the Existing Studies

The discrepancies in existing studies may reflect limitations in the methods used to analyze the RAN components. For example, Neuhaus and colleagues (2001, 2002) used an amplitude-based RAN scoring software program to estimate the mean pause and articulation time, but, at the same time, recognized the software's limited capacity to correctly identify articulations. In addition, extraneous sounds such as coughing or task-irrelevant speech were marked by the software operator as being part of pause times. It is conceivable that if extraneous sounds were marked as part of the pause time, then not only pause time's estimation was affected but also the consistency of the pause time may have been distorted.

Furthermore, researchers have used different versions of the RAN tasks to extract the RAN components. This is potentially problematic in the light of research indicating that different versions of the RAN task can account for different amounts of variance in reading ability (Compton, Olson, DeFries, & Pennington, 2002). For example, Cobbold, Passenger, and Terrell, (2003) used an object naming test comprised of 20 different objects from the Dyslexia Early Screening Test. Neuhaus et al. (2001) used the traditional format RAN tasks (Denckla & Rudel, 1976) consisting of 5 items repeated 10 times each, and Georgiou et al. (2006) used the traditional format for color naming but chose letter naming task from CTOPP (Wagner et al., 1999), which consists of 6 items repeated 6 times each. Finally, Clarke et al. (2005) used digit and letter naming tasks that contained 48 items and that utilized 10 different digits (for digit naming) and 25 different letters (for letter naming).

Although the relatively small differences in the length of the RAN tasks are likely not critical to the strength of the relationship with reading, the set size of items to be retrieved from long term memory may be. As pointed out by Scarborough and Domgaard (1998), increasing the number of items to be accessed in RAN tasks (e.g., from 5 in Denckla and Rudel's to 10 or 25 in Clarke et al.'s study) results in increased phonological encoding. Hence, it stands to reason that the increased phonological encoding alone might explain why controlling for phoneme deletion in the Clarke et al.'s (2005) study resulted in a non-significant contribution of pause time in exception word reading.

Overview of the Present Study

The present study is a follow-up of our previous work on RAN components in which we examined the development of and relationship between RAN components and reading from kindergarten until the end of grade 1 (Georgiou et al., 2006). Two important additions have been made in this follow-up. First, we added a third RAN task in our battery, RAN Digits, which has been shown repeatedly to be a strong predictor of reading (e.g., Bowers & Swanson, 1991; Katzir et al., 2006; Manis et al., 2000; Savage & Frederickson, 2005). Second, we added measures of phonological awareness, orthographic knowledge, and speed of processing in order to estimate their relationship with the RAN components.

The objectives of this study were to examine: (a) how RAN components – articulation time and pause time – in grades 1 to 3 predict word and nonword reading accuracy, and word- and text-reading fluency in grades 2 and 3; and (b) how RAN components are related to measures of phonological awareness, orthographic knowledge, and speed of processing.

Based on previously reported results (e.g., Georgiou et al., 2006; Neuhaus et al., 2001), we expected that pause times, and to a lesser degree articulation times, will be correlated to both reading accuracy and fluency measures. Because both RAN and reading fluency measures have a time component in common, we expected that the relationship between RAN components and reading fluency will be greater than the relationship between RAN components and reading accuracy. Finally, we expected that RAN pause time, but not RAN articulation time, will be significantly related to measures of phonological awareness and orthographic knowledge. The relationship with phonological awareness was expected to be stronger in grade 1 than later on, whereas the relationship with orthographic knowledge was expected to be stronger in later grades (perhaps grade 2 onwards) than earlier. However, both RAN components were expected to be significantly related to speed of processing.

To our knowledge, the current study is the first to examine the relationship between RAN components and measures of phonological awareness, orthographic knowledge, and speed of processing. Clarke and her colleagues' (2005) initiated this line of research by examining the relationship between RAN components and phoneme deletion. They reported that phoneme deletion was significantly related to RAN Digits articulation time but not to RAN Letters articulation time. Similarly, phoneme deletion was significantly related to RAN Letters pause time but not to RAN Digits pause time. These results are difficult to reconcile with any of the theoretical models of RAN-reading relationship and highlight the importance of a study that includes not only measures of phonological processing but also measures representing a wider range of processes, such as orthographic knowledge and speed of processing.

Method

Participants

Sixty-two English-speaking Canadian children (33 girls and 29 boys, mean age = 79.32 months, *SD* = 3.98, at the end of grade 1) were followed from the end of grade 1 until grade 3. The children came from middle-to-upper-middle SES families and none had previously been diagnosed with emotional, behavioural, or sensory deficits. By grade 3 the sample consisted of 48 children (27 girls and 21 boys). Fourteen children withdrew from the study (9 in grade 2 and 5 more in grade 3). In order to examine if the performance of the children who withdrew from the study differed significantly from the rest of the children, we performed *t* tests on their grade 1 RAN components performance. None of the *t* tests reached significance (all *p*s > .10). Written permission from the parents was obtained prior to each testing.

Materials

Naming Speed

RAN-Colors (RAN-C). 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 semi-randomly in five rows with ten colors per row. Prior to beginning the timed naming, each participant was asked to name the colors in a practice trial to ensure familiarity. Wolf and Denckla (2005) reported test-retest reliability for Color Naming to be .90.

RAN-Letters (*RAN-L).* This task was adopted from the Comprehensive Test of Phonological Processing (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 semi-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 trial. Wagner et al. (1999) reported test-retest reliability of .97 for Letter Naming for children ages five to seven.

RAN-Digits (*RAN-D*). This task was adopted from CTOPP (Wagner et al., 1999). Participants were asked to name as fast as possible the names of six digits (4, 7, 8, 5, 2, 3). Digits were arranged semi-randomly in four rows of nine digits in each row. Subjects were asked to name the digits from left to right as quickly as possible and the total time to complete the RAN task was 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.

Phonological Awareness

Phonological awareness was assessed with Phoneme Elision, which was adapted from Comprehensive Test of Phonological Processing (CTOPP) (Wagner et al., 1999) by adding six test items, four two-syllable words and two words that required the participant to say the word without saying a designated sound in the word, to make a total of 29 items. Items were recorded digitally with Canadian pronunciations onto a laptop computer and presented through separate speakers. Testing was discontinued after three consecutive errors. A participant's score was the number of correct items. Split-half reliability coefficients in our sample were .87, .89, and .89 for grades 1, 2, and 3, respectively.

Orthographic Knowledge

Wide Range Achievement Test III- Spelling (WRAT3-S; Wilkinson, 1993) was used as a measure of orthographic knowledge. In this task the participant is required to write on a form with numbered spaces a word that is dictated to him/her. The examiner first reads the word aloud, then reads a sentence in which the target word is embedded, and then repeats the target word. The task consists of 40 items. A cut-off rule of 10 consecutive mistakes was applied. Cronbach's alpha reliability coefficients in our sample were .89, .87, and .87 for grades 1, 2, and 3, respectively.

Speed of Processing

The Cross-Out task was used as a measure of speed of processing. In this task the children were asked to cross-out identical numbers dispersed in 10 rows of 10 numbers in each row. Each one of the 10 rows in the task consists of a number at the left end of a row and 10 numbers to the right, three of which are identical (e.g., 1 8 9 5 6 2 9 7 4 9). The child crosses-out the 3 numbers of the 10 that are identical to the one at the left. Prior to beginning the timed task, each participant was asked to cross-out the identical numbers in two practice trials to ensure familiarity. The child's score is the number of correctly crossed-out numbers in 30 seconds.

Word- and Nonword-Reading Accuracy

Two tests of word reading accuracy were administered. First, the Form H Word Identification test from Woodcock Reading Mastery Tests-Revised (WRMT-R; Woodcock, 1998) was used to assess word reading. The test requires participants to read isolated words aloud. Words are graded in difficulty from pre-primer to adult level. The participant's score was the number of correctly read words. A cut-off rule of six consecutive mistakes was applied. Split-half reliability coefficients in our sample were .94 for grade 2 and .92 for grade 3. Second, the children were also asked to read a list of 28 irregular words. Some of the words were adopted from Castles and Coltheart (1993). A cut-off rule of six consecutive mistakes was applied. Split-half reliability coefficient in our sample was .94 for grade 2 and .93 for grade 3.

The Form H Word Attack test from Woodcock Reading Mastery Tests-Revised (WRMT-R; Woodcock, 1998) was used as a third measure of basic reading skills. Participants are required to pronounce nonwords presented on a laptop screen. Again, testing was discontinued after six consecutive errors. The participant's score was the number of items correct. Split-half reliability coefficients in our sample were .94, for grade 2 and .93, for grade 3.

Word- and Text-Reading Fluency

Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999) was used as a measure of word-reading fluency. 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.

Gray Oral Reading Test (GORT; Wiederholt & Bryant, 2001) was used to assess subjects' text-reading fluency. The participants were asked to read as fast and as accurately as possible two short texts. The texts were selected so that one would be well within the reading ability of almost all children, and one a bit more challenging; all participants read the same two texts. The individual's score was the time to read both stories. The reading comprehension questions that follow the stories were not administered. Wiederholt and Bryant (2001) reported test-retest reliability for fluency to be .93.

Procedure

Participants were examined three times: April/May of grade 1, January/February of grade 2, and January/February of grade 3. All participants were tested individually in their respective schools during school hours by trained experimenters. Testing was completed in two sessions lasting roughly 30 minutes each. In the first session the children were administered the RAN Colors task, and all the word and nonword reading tasks. In the second session the children were administered the RAN Digits and RAN Letters tasks, and all the reading fluency tasks. Speed of processing task was administered only in grade 3 as part of the second session.

Manipulation of Sound Files

The sound files containing the color naming, digit naming, and letter naming responses for each participant were analyzed using GoldWave v.4.26 (GoldWave Inc. 2002). Data extraction for each child was completed following the procedure described in detail in Georgiou et al. (2006). Both articulation and pause times were measured in milliseconds. In order to establish the onset and offset of articulation time, pause time, and number of pauses, a volume level of .15 of the absolute value of the sound file amplitude was used as a cutoff.

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 and the articulation time that followed the skip were removed. Fourth, in cases in which off-task behavior (e.g., coughing, talking to the experimenter, self-encouragement) was observed between two articulations, the specific pause time was removed.

Articulation time in this study represents the mean of those articulation times that were correctly verbalized and were not preceded by a skipped stimulus. The maximum possible number of cleaned articulation times was 50 for the RAN-C and 36 for the RAN-L and RAN-D naming tasks, indicating that there were no naming errors; smaller numbers of cleaned articulation times indicate that one of the above cleaning procedures took place. Across all the possible articulation times for RAN-C (3100 in grade 1, 2650 in grade 2, and 2400 in grade 3), 29 instances of cleaning took place in grade 1, 23 in grade 2, and 12 in grade 3. Across all possible articulation times for RAN-L (2232 in grade 1, 1908 in grade 2, and 1828 in grade 3), 25 instances of cleaning took place in grade 1, 16 in grade 2, and 14 in grade 3, respectively. For RAN-L (with the same numbers of times as RAN-D), 9 instances of cleaning took place in grade 1, 14 in grade 2, and 7 in grade 3, respectively.

Pause time in this study is the mean of the pause times that occurred between two correctly articulated stimuli. The maximum possible number of cleaned pause times was 49 for RAN-C and 35 for RAN-L and RAN-D; smaller numbers indicate that one of the cleaning procedures was imposed. Across all possible RAN-C pause times at each grade (3038 in grade 1, 2597 in grade 2, and 2352 in grade 3), there were 120, 99, and 65 instances of pause time cleaning, respectively. For RAN-L, across all possible pause times (2170 in grade 1, 1855 in grade 2, and 1680 in grade 3), 93 instances of pause time cleaning took place in grade 1, 64 in grade 2, and 54 in grade 3. Finally, for RAN-D, 37 instances of pause time cleaning took place in grade 1, 25 in grade 2, and 12 in grade 3. Only the cleaned articulation and pause time measures were used in further analyses.

Results

Preliminary Data Analysis

Table 2-1 presents the descriptive statistics for all the measures across time.

Table 2-1

Descriptive Statistics of the Measures Used in the Study

	Grade 1 (n = 62)		Grade 2 (n = 53)		Grade 3 (n = 48)	
	M	SD	M	SD	M	SD
RAN-C Total[1]	58.30	14.68	56.87	14.93	43.50	8.29
RAN-C Articulation	502.51	76.45	489.72	96.06	473.75	70.40
RAN-C Pause	625.94	221.08	606.64	232.53	373.27	143.53
RAN-L Total[1]	28.69	7.29	25.15	6.69	20.12	3.20
RAN-L Articulation	386.35	75.30	360.76	52.04	347.48	42.62
RAN-L Pause	385.26	170.07	303.55	113.90	194.21	71.14
RAN-D Total[1]	28.58	7.19	23.76	5.79	18.45	3.77
RAN-D Articulation	454.37	64.05	423.25	70.86	376.16	56.05
RAN-D Pause	295.26	153.52	236.99	123.76	134.34	65.26
Phoneme Elision	16.48	4.90	18.53	5.01	22.81	5.39
WRAT3-S	7.71	2.64	8.85	2.76	13.06	3.07
Speed of Processing					19.31	4.13
Word Identification			54.62	13.30	67.33	10.25
Word Attack			22.02	8.08	28.56	6.57
IWR			18.32	5.95	24.31	3.12
TOWRE			48.74	14.05	63.81	8.98
GORT[1]			38.09	18.38	26.60	7.69

Note. The descriptive statistics are based on the unwinsorized data.
RAN-C = Rapid Automatized Naming-Colors; RAN-L = Rapid Automatized Naming-Letters; RAN-D = Rapid Automatized Naming-Digits; WRAT3-S = Wide Reading Achievement Test III– Spelling; IWR = Irregular Word Reading; TOWRE = Test of Word Reading Efficiency; GORT = Gray Oral Reading Test.
[1] Measured in seconds.

An examination of the distributional properties of the RAN components indicated that all of the measures were positively skewed. In order to normalize the distributions, the responses of outliers whose scores were ± 2 SD or more from the group mean were replaced by a value equal to the next highest non-outlier-score plus one unit of measurement (Tabachnick & Fidell, 2001). This process is known as winsorization and it preserves the rank of the outlier's score within the distribution without disturbing the distribution either by deleting the score or by retaining it in its original form. The winsorized data were used in all subsequent analyses.

Correlations Between RAN Components and Reading Ability

Table 2-2 presents the correlations of the RAN total times and the RAN components with the different reading measures. First, RAN-C total times and components measured in grades 2 and 3 (in contrast to grade 1) are only weakly, and in most instances non-significantly, correlated with the reading measures. On the other hand, the majority of the correlations between the RAN-L and RAN-D total times and components with the reading measures are significant. The lowest correlations were those between the RAN total times and components with Word Attack and the highest those between RAN total times and components with TOWRE and GORT. Second, pause time (particularly for RAN-L and RAN-D) was in most instances significantly correlated with the reading measures. In contrast, fewer correlations between articulation time and reading measures reached significance. None of the correlations between Word Attack or Irregular Word Reading and articulation time was significant.

Table 2-2

Correlations Between the RAN Components and the Reading Measures

	Grade 2					Grade 3				
	WID	WAT	IWR	TOWRE	GORT	WID	WAT	IWR	TOWRE	GORT
RAN-C Grade 1 Spring										
Total Time	-.27*	-.16	-.22	-.41**	.25	-.21	-.14	-.23	-.39**	.45**
Articulation Time	-.20	-.07	-.10	-.25	.13	-.23	-.15	-.19	-.31*	.36*
Pause Time	-.29*	-.22	-.25	-.39**	.29*	-.19	-.13	-.27	-.34*	.39**
RAN-C Grade2 Fall										
Total Time	-.18	-.11	-.08	-.26	.12	-.09	-.09	-.13	-.24	.19
Articulation Time	.01	-.03	.06	-.13	-.04	.03	.05	.17	-.11	.19
Pause Time	-.24	-.18	-.18	-.26	.20	-.18	-.17	-.26	-.33*	.22
RAN-C Grade3 Fall										
Total Time						-.11	-.07	-.19	-.30*	.20
Articulation Time						-.02	-.05	-.13	-.25	.18
Pause Time						-.15	-.11	-.16	-.26	.18
RAN-L Grade1 Spring										
Total Time	-.47**	-.36**	-.39**	-.47**	.53**	-.35*	-.28	-.43**	-.61**	.64**
Articulation Time	-.16	-.11	-.05	-.14	.22	-.24	-.15	-.13	-.43**	.44**
Pause Time	-.50**	-.38**	-.48**	-.50**	.60**	-.36*	-.31*	-.50**	-.61**	.64**
RAN-L Grade2 Fall										
Total Time	-.29*	-.13	-.30*	-.35*	.44**	-.32*	-.06	-.33*	-.49**	.50**
Articulation Time	-.15	-.01	.00	-.08	.15	-.21	-.04	-.11	-.22	.25
Pause Time	-.30*	-.15	-.35*	-.38**	.49**	-.28	-.09	-.36*	-.46**	.51**
RAN-L Grade 3 Fall										
Total Time						-.14	-.04	-.21	-.41**	-.39**
Articulation Time						-.16	-.09	-.14	-.35*	.35*
Pause Time						-.15	-.04	-.24	-.37**	.37**

Table 2-2 *(continued)*

RAN-D Grade1 Spring										
Total Time	-.39**	-.23	-.30*	-.44**	.47**	-.23	-.06	-.37*	-.47**	.46**
Articulation Time	-.09	-.06	-.03	-.29*	.18	-.15	-.05	-.05	-.30*	.30*
Pause Time	-.37**	-.25	-.33*	-.41**	.35*	-.17	-.07	-.34*	-.28	.22
RAN-D Grade2 Fall										
Total Time	-.40**	-.27	-.28*	-.39**	.39**	-.36*	-.18	-.40**	-.43**	.45**
Articulation Time	-.31*	-.20	-.21	-.31*	.31*	-.35*	-.13	-.17	-.34*	.39**
Pause Time	-.39**	-.29*	-.29*	-.37**	-.39**	-.31*	-.19	-.45**	-.43**	.43**
RAN-D Grade 3 Fall										
Total Time						-.21	-.11	-.17	-.49**	.35*
Articulation Time						-.14	-.05	-.07	-.44**	.28
Pause Time						-.16	-.10	-.16	-.36*	.31*

Note. RAN-C = Rapid Automatized Naming-Colors; RAN-L = Rapid Automatized Naming-Letters; RAN-D = Rapid Automatized Naming-Digits; WID = Word Identification; WAT = Word Attack; IWR = Irregular Word Reading; TOWRE = Word Reading Efficiency; GORT = Gray Oral Reading Test.

$^a N = 53$. $^b N = 48$.

$^* p < .05$. $^{**} p < .01$.

Next, we examined if the correlations between the RAN components and Word Attack were significantly smaller than the correlations between RAN components and Irregular Word Reading using Hotelling's *t* test for differences between two dependent correlation coefficients (Glass & Hopkins, 1984). The analysis was performed to examine Manis et al.'s (1999) hypothesis that RAN should be more strongly related to exception word reading than to decoding. Because of the large number of possible pairwise comparisons ($N = 45$), we decided to keep only those pairs in which (a) both correlations in the pair were significant, or (b) one correlation in the pair was significant but the other one was not. Thus, the final number of pairwise comparisons was 16. The results showed that six pairwise comparisons were significant ($p < .05$), all in favor of Irregular Word Reading. Two of them involved grade 2 RAN-L total and pause time predicting grade 3 reading outcomes, two involved grade 1 RAN-D total and pause time predicting grade 3 reading outcomes, one involved grade 2 RAN-L pause time predicting grade 2 outcomes and the last one grade 2 RAN-D pause time predicting grade 3 reading outcomes. Therefore, our findings provide some support for Manis et al.'s (1999) hypothesis.

To summarize, the correlations between RAN-C components and reading were mostly non-significant. In contrast, RAN-L and RAN-D components continued to be significantly correlated with the reading measures until grade 3, although the correlations tend to decrease after grade 2. Generally, the highest correlations were observed between pause time and reading fluency and the lowest between articulation time and reading accuracy.

Correlations Between RAN Components and Measures of Phonological Awareness, Orthographic Knowledge, and Speed of Processing

Table 2-3 presents the correlations between RAN components and measures of phonological awareness, orthographic processing, and speed of processing. RAN-C components were eliminated from these analyses because they were not significantly correlated with any reading outcome when measured beyond grade 1, and RAN-D and RAN-L components were combined to provide composite scores for articulation time (the average of the summed *z* scores for RAN-D and RAN-L articulation time) and pause time (the average of the summed *z* scores for RAN-D and RAN-L pause time). This was done to reduce the volume of data presented and the interpretation of the findings. Phonological awareness (Elision) and orthographic knowledge (WRAT3-S) were assessed at all measurement points whereas speed of processing was assessed only in grade 3. Generally, the correlations were modest with the highest correlation being between RAN total time in grade 2 and orthographic knowledge in grade 3 ($r = .46, p < .01$). Articulation time was not significantly related to any measure at any time of measurement. In contrast, pause time was significantly correlated to phonological awareness in grade 1 and to orthographic knowledge in all grades. The concurrent correlations between RAN components and orthographic knowledge tended to increase across time, whereas the concurrent correlations between RAN components and phonological awareness tended to decrease across time. Notably, the concurrent correlations between RAN components and speed of processing in grade 3 were not significant; a finding that reinforces the argument that speed of processing alone cannot explain the RAN-reading relationship.

Table 2-3

Correlations Between RAN Components and Measures of Phonological Awareness, Orthographic Knowledge, and Speed of Processing

	Grade 1		Grade 2		Grade 3		
	Elision	WRAT-S	Elision	WRAT-S	Elision	WRAT-S	SOP
RAN Grade 1 Spring							
Total Time	-.31*	-.30*	-.26	-.40**	-.25	-.43**	-.29*
Articulation Time	-.07	-.07	-.09	-.18	-.23	-.25	-.23
Pause Time	-.31*	-.34**	-.28*	-.43**	-.20	-.39**	-.30*
RAN Grade 2 Fall							
Total Time			-.24	-.35**	-.30*	-.46**	-.26
Articulation Time			-.13	-.18	-.23	-.28	-.22
Pause Time			-.25	-.38**	-.29*	-.43**	-.22
RAN Grade 3 Fall							
Total Time					-.07	-.37**	-.21
Articulation Time					-.13	-.27	-.22
Pause Time					-.11	-.40**	-.16

Note. WRAT3-S = Wide Reading Achievement Test III– Spelling; SOP = Speed of Processing.
* $p < .05$. ** $p < .01$.

In order to examine if RAN components share their predictive variance on reading with phonological awareness, orthographic knowledge, and speed of processing, a series of hierarchical multiple regression analyses was conducted next. For grades 1 and 2, each one of the RAN components was first entered in the regression equation alone in order to estimate its contribution to the reading outcomes. Next, the RAN components were entered in the regression equation following either phonological awareness or orthographic knowledge. Finally, the RAN components were entered in the regression equation following both phonological awareness and orthographic knowledge (entered as a block at step 1). For grade 3, the first regression analysis was the same as in the previous grades. In the second, the RAN components were entered in the regression equation following phonological awareness, or orthographic knowledge, or speed of processing (entered interchangeably at step 1). In the third, RAN components' contribution to reading was estimated after controlling for phonological awareness, orthographic knowledge, and speed of processing (entered as a block at step 1). Word Identification, Irregular Word Reading, TOWRE, and GORT were the dependent variables. Word Attack was not used in these analyses because RAN components were only weakly related to this variable (see Table 2-3). Table 2-4 presents the results with grade 1 RAN components, Table 2-5 presents the results with grade 2 RAN components, and Table 2-6 presents the results with grade 3 RAN components. R^2 changes and level of significance are presented in all tables.

Table 2-4

R^2 Changes and Significance Levels in Hierarchical Regression Analyses With Grade 1 RAN Components

		Grade 2				Grade 3			
Step	Variable	WID	IWR	TOWRE	GORT	WID	IWR	TOWRE	GORT
1.	RAN_AT	.02	.00	.06	.05	.05	.01	.17**	.18**
1.	RAN_PT	.23***	.20***	.26***	.27***	.09*	.21***	.24***	.22***
1.	Elision	.27***	.29***	.14**	.13**	.23***	.17**	.19**	.17**
2.	RAN_AT	.01	.00	.05	.04	.04	.01	.16**	.16**
2.	RAN_PT	.11**	.08*	.17***	.19***	.02	.13**	.14**	.13**
1.	WRAT3-S	.57***	.46***	.30***	.27***	.39***	.33**	.28***	.14**
2.	RAN_AT	.01	.00	.05	.04	.04	.01	.17**	.17**
2.	RAN_PT	.05*	.05*	.11**	.13**	.01	.08*	.11**	.13**
1.	Elision WRAT3-S	.57***	.48***	.30***	.27***	.41***	.34***	.30***	.20**
2.	RAN_AT	.01	.00	.05	.04	.04	.01	.16**	.16**
2.	RAN_PT	.05*	.04*	.11**	.13**	.01	.08*	.11**	.10**

Note. WID = Word Identification; IWR = Irregular Word Reading; TOWRE = Word Reading Efficiency; GORT = Gray Oral Reading Test; WRAT3-S = Wide Reading Achievement Test III– Spelling; AT = Articulation Time; PT = Pause Time.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 2-5

R^2 Changes and Significance Levels in Hierarchical Regression Analyses With Grade 2 RAN Components

		Grade 2				Grade 3			
Step	Variable	WID	IWR	TOWRE	GORT	WID	IWR	TOWRE	GORT
1.	RAN_AT	.06	.01	.05	.06	.09*	.03	.09*	.13*
1.	RAN_PT	.16**	.14**	.20***	.27***	.13*	.24***	.29***	.32***
1.	Elision	.35***	.33***	.13**	.12**	.32***	.17**	.13**	.18**
2.	RAN_AT	.03	.00	.03	.04	.07*	.01	.08*	.10*
2.	RAN_PT	.07*	.06*	.13**	.20***	.06*	.17***	.22***	.24***
1.	WRAT3-S	.62***	.55***	.39***	.39***	.53***	.41***	.28***	.22***
2.	RAN_AT	.01	.01	.01	.02	.05*	.01	.06	.09*
2.	RAN_PT	.01	.01	.05*	.09**	.01	.08**	.15***	.19***
1.	Elision WRAT3-S	.64***	.58***	.39***	.39***	.57***	.42***	.28***	.26***
2.	RAN_AT	.01	.00	.01	.02	.05*	.00	.06	.09*
2.	RAN_PT	.01	.01	.05*	.09**	.01	.08**	.15**	.18***

Note. WID = Word Identification; IWR = Irregular Word Reading; TOWRE = Word Reading Efficiency; GORT = Gray Oral Reading Test; WRAT3-S = Wide Reading Achievement Test III– Spelling; AT = Articulation Time; PT = Pause Time.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 2-6

R^2 Changes and Significance Levels in Hierarchical Regression Analyses With Grade 3 RAN Components

		Grade 3			
Step	Variable	WID	IWR	TOWRE	GORT
1.	RAN_AT	.03	.01	.20***	.13*
1.	RAN_PT	.03	.05	.17**	.15**
1.	Elision	.23***	.22***	.13*	.18**
2.	RAN_AT	.01	.00	.16**	.09*
2.	RAN_PT	.02	.03	.15**	.12**
1.	WRAT3-S	.65***	.47***	.46***	.33***
2.	RAN_AT	.00	.00	.09**	.06*
2.	RAN_PT	.02	.00	.03	.03
1.	SOP	.05	.03	.16**	.10*
2.	RAN_AT	.02	.01	.13**	.09*
2.	RAN_PT	.02	.04	.13**	.12*
1.	SOP Elision WRAT3-S	.70***	.52***	.55***	.42***
2.	RAN_AT	.00	.00	.06*	.04
2.	RAN_PT	.02	.00	.02	.03

Note. WID = Word Identification; IWR = Irregular Word Reading; TOWRE = Word Reading Efficiency; GORT = Gray Oral Reading Test; WRAT3-S = Wide Reading Achievement Test III– Spelling; AT = Articulation Time; PT = Pause Time.
$* p < .05$. $** p < .01$. $*** p < .001$.

The results of the hierarchical regression analyses revealed first that articulation time explained unique variance only in grade 3 reading fluency measures. This contribution was independent of phonological awareness or orthographic knowledge as the shared predictive variance with these two cognitive processing skills was very small (0 to 2%) in grades 1 and 2. In grade 3, articulation time shared 1 to 4% of predictive variance with phonological awareness, 1 to 11% of predictive variance with orthographic knowledge, and 4 to 7% of predictive variance with speed of processing. Articulation time in grade 3 continued to explain unique variance in TOWRE even after controlling for speed of processing, phonological awareness, and orthographic knowledge, indicating that articulation time is partly independent from these cognitive processes.

Second, pause time measured in grades 1 and 2 accounted for unique variance in both reading accuracy and reading fluency measures. However, in grade 3, its contribution was limited only to reading fluency measures. In contrast to articulation time, pause time shared a substantial proportion of predictive variance with phonological awareness and orthographic knowledge across measurement points. More specifically, pause time shared 7 to 12% of predictive variance with phonological awareness in grade 1, 7 to 9% in grade 2, and 1 to 3% in grade 3. Pause time also shared 8 to 18% of predictive variance with orthographic knowledge in grade 1, 12 to 18% in grade 2, and 1 to 14% in grade 3. Finally, pause time shared 3 to 4% of predictive variance with speed of processing. It is noteworthy that when grade 3 orthographic knowledge was controlled, pause time's contribution to reading fluency measures dropped to a non-significant level, indicating that the variance in reading fluency accounted for by pause time was shared with orthographic knowledge. Third, although the shared predictive variance between pause time and orthographic knowledge remained essentially unchanged across time, the shared predictive variance with phonological awareness decreased across time. This was particularly evident in grade 3, when, as mentioned above, the shared predictive variance with phonological awareness dropped to 2 – 3% whereas the shared predictive variance with orthographic knowledge was 1 – 14%. This finding suggests that early on in reading development RAN reflects both phonological processing and orthographic processing. However, later on in reading development RAN reflects primarily orthographic processing.

To summarize, the results of the correlational and the regression analyses indicated that articulation time was rather independent from speed of processing, phonological awareness, and orthographic knowledge. On the other hand, pause time shared a substantial proportion of variance with both phonological and orthographic processing at grade 1 and with orthographic processing at grade 3. The small proportion of shared variance between pause time and speed of processing can be considered as evidence against the argument that RAN is related to reading because of the effects of speed of processing.

Discussion

Despite the plethora of studies showing that RAN is a strong concurrent and longitudinal predictor of reading ability (e.g., Badian, 1993; Cutting & Denckla, 2001; de Jong & van der Leij, 1999; Georgiou et al., 2006; Katzir et al., 2006; Kirby et al., 2003; Manis et al., 2000; Parrila et al., 2004; Scarborough, 1998; Wolf & Bowers, 1999) and the argument that RAN is a necessary screening tool for reading difficulties along with phonological awareness and letter knowledge (e.g., Bishop, 2003; Bishop & League, 2006; Schatschneider et al., 2004), little is known about the mechanisms that are responsible for the RAN-reading relationship.

Partitioning RAN total time into its components has been characterized as critical both for theoretical and practical reasons (Neuhaus et al., 2001; Torgesen et al., 1997; Wolf & Bowers, 1999; Wolf et al., 2000). In terms of theory, we need to gain a better understanding of what processes develop within RAN, what processes different RAN tasks share, and what accounts for RAN's relationship with reading measures. From the practical point of view, more elaborate RAN-specific information can help to improve the existing intervention programs (de Jong & Vrielink, 2004; Wolf, Miller, & Donnelly, 2000).

The first objective of this study was to examine how RAN components in grades 1 to 3 predict word and nonword reading and word- and text-reading fluency in grades 2 and 3. For RAN-C, not much can be said beyond its contribution in grade 1. Only a few of the RAN-C components in grades 2 and 3 were significantly related to reading outcomes. For RAN-L and RAN-D, pause time was the best predictor of both word reading accuracy and reading fluency. In turn, pause time's relationship with nonword reading was weaker and correlations were, in most instances, non-significant. Previous studies have converged on the conclusion that pause time is significantly correlated with reading accuracy measures (e.g., Cobbold et al., 2003; Neuhaus et al., 2001; Neuhaus & Swank, 2002), but they have not included fluency measures that arguably should be more related to RAN than the accuracy measures (e.g., de Jong & van der Leij, 1999, Katzir et al., 2006; van den Bos et al., 2002). Although the concurrent correlations between word reading accuracy and pause time tended to decrease across time, the concurrent correlations between word- and text-reading fluency and pause time did not, pointing to an issue that deserves our attention when arguments are made regarding the declining effect of RAN in the early years of reading development (Torgesen et al., 1997; Wagner et al., 1997).

Finally, we examined the relationship between the RAN components and measures of phonological awareness, orthographic knowledge, and speed of processing. Articulation time was not significantly related to any measure at any time of measurement. In contrast, pause time was more strongly related to orthographic knowledge than to phonological awareness or speed of processing. Notably, the concurrent correlations between RAN components and orthographic knowledge tended to increase across time whereas the concurrent correlations between RAN components and phonological awareness tended to decrease across time. The follow-up hierarchical regression analyses verified that pause time shared more predictive variance with orthographic knowledge than with phonological processing or speed of processing.

The question that unavoidably emerges is what exactly does pause time measure. Our findings do not provide a clearcut answer, but suggest that maybe it is time to move beyond dichotic propositions of the past (e.g., Bowers & Wolf, 1993; Torgesen et al., 1997). We believe that pause time reflects two-level processes. At a baseline level, pause time reflects the effects of sequential naming requirements and of speed of processing. In their review paper, Wolf and Bowers (1999) emphasized that rapid naming may operate as a *lexical midpoint* in a cascading system of processing speed effects and that the addition of rapid rate and seriation to processing speed requirements make naming speed a different cognitive task from phonological processing tasks. In support of this argument, the results of our study indicated that controlling for speed of processing reduces both articulation and pause times' contributions to reading fluency measures. Nevertheless, sequential naming and speed of processing requirements are not a sufficient explanation for two reasons. First, if RAN-L, RAN-D, and RAN-C pause times are measuring the same thing, then they should be correlated to the same extent with the reading outcomes. However, RAN-C was not significantly correlated with the reading outcomes when measured in grades 2 and 3. Second, the results of the regression analyses indicated that even after controlling for speed of processing, pause time still accounted for 13% of unique variance in TOWRE and 12% of unique variance in GORT.

Beyond this baseline level of effects in rapid naming, we argue that alphanumeric RAN pause time reflects both the speed of access to phonological information in long-term memory and the ease of building up high-quality orthographic representations that facilitate fluent reading. However, the degree of association with phonological and/or orthographic processing changes across time, such that RAN pause time is more strongly related to phonological processing in earlier years than later and to orthographic processing in later grades than earlier (see correlations in Table 2-3). The stronger relationship between RAN pause time and phonological awareness at the beginning of reading development could indicate that both cognitive processes rely upon the quality of sound representations (e.g., Perfetti & Hart, 2002). If the sound representations of the accessed stimuli are not well specified ("poor" quality), this will slow down RAN and impede sound isolation and blending. In line with this suggestion, Compton (2003) demonstrated in a study with grade 1 children that increased phonological confusion in a Letter Naming task was associated with greater unique variance in word identification than was increased visual-orthographic confusion. When the sound representations become better specified, they no longer disrupt RAN performance and, as a result, RAN loses its power as a predictor of reading accuracy.

If letter identification is not fast enough, the quality of the orthographic representations will also be compromised, which, in turn, will contribute to slow and inaccurate reading (Bowers & Wolf, 1993). In support of this argument we have shown that RAN pause time was significantly related to orthographic knowledge across the developmental span covered in this study and that RAN pause time was more strongly related to reading fluency that arguably depends more on quick access to large orthographic units than reading accuracy. However, this is only part of the story as we found that some of the correlations between RAN pause time and irregular word reading tended to be stronger than the correlations between RAN pause time and word decoding, a result that provides support to Manis and his colleagues' (1999) hypothesis. It should be noted though that the difference in the relationship between RAN components and irregular word reading as opposed to word decoding, although consistent with Manis and his colleagues' hypothesis, is also consistent with Bowers and Wolf's hypothesis. Certainly, the reading of irregular words calls upon orthographic knowledge, which is not entirely or even mainly arbitrary.

Although RAN pause time's relationship to orthographic knowledge increased across time, the correlations between RAN pause time and word identification decreased. RAN pause time – measured in grade 3 – did not predict reading accuracy, even when no other processing skills were controlled. This finding is in line with McBride-Chang and Manis' (1996) argument that in groups of average or above-average students, variability in rapid naming is not related to variability in their reading accuracy scores. Perhaps being “fast” enough, as indexed by performance on RAN tasks, means that the child can relatively easily learn the orthographic patterns in words or detect these orthographic patterns in lists of words (e.g., Levy, 2001; Levy, Bourassa, & Horn, 1999). And perhaps being able to join the recognition of visual-orthographic units to a pronunciation quickly and easily enough is only important for reading fluency, but not for reading accuracy.

For the most part, our results agree with the earlier studies that have examined RAN components. We extended these findings in three important manners. First, the current study used an unselected sample of children and children who made articulation errors were not excluded from the analyses (e.g., Neuhaus et al., 2001). Children with some incorrect 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, the current study included word- and text-reading fluency measures in addition to reading accuracy measures used in previous studies. Our findings suggest that the RAN-reading relationship is not as “time-limited” for fluency measures as it is for accuracy measures. However, even among the reading accuracy measures, RAN appears to be more strongly related to irregular word reading than to pseudoword reading, a finding that provides some support for Manis and his colleagues’ (1999) hypothesis regarding RAN-reading relationship. Finally, we examined the relationship between RAN components and measures of phonological awareness, orthographic processing, and speed of processing. Pause time appears to be related to both phonological awareness and orthographic knowledge at the beginning of reading development, but it is more strongly related to orthographic knowledge later on.

Some limitations of the present study are worth mentioning. First, the results of this study are restricted for the developmental span and population examined, from the end of grade 1 until grade 3, and therefore the findings may not apply to later grades or to specific reading disability populations. Second, because of the longitudinal design of the study, there was some attrition that compromised the final sample size. Certainly, future studies should attempt to replicate these findings with a larger sample size and with reading-disabled participants. Third, a measure of speed of processing was available only in grade 3. This did not allow us to examine its effects early on in reading development and how it may have impacted RAN components. Finally, WRAT3-S was used as a measure of orthographic knowledge. Although WRAT3-S is a spelling-to-dictation task, certainly one needs item-specific orthographic knowledge to perform well on the task. However, this knowledge is at the lexical and not at the sub-lexical level (e.g., Hagiliassis, Pratt, & Johnston, 2006), which is expected to be facilitated by quick letter naming (Bowers & Wolf, 1993).

Future research should include measures of sub-lexical orthographic knowledge and also be carried out with children of different reading ability levels in order to examine which RAN components are responsible for the differential relationship between RAN and reading in groups of poor and good readers (McBride-Chang & Manis, 1996). Finally, cross-linguistic studies of RAN components would be informative regarding the relationship between RAN and reading in different languages.

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III. RAN AND READING ACROSS LANGUAGES VARYING IN ORTHOGRAPHIC CONSISTENCY

Recently, there has been a substantial increase in cross-linguistic research on children's reading acquisition (e.g., Harris & Hatano, 1999; Joshi & Aaron, 2006). The studies converge on the conclusion that the progress of children learning to read in orthographically consistent languages, such as Finnish, German, or Greek, is generally faster than that of children learning to read in orthographically inconsistent languages, such as English or Danish (e.g., Aro & Wimmer, 2003; Ellis et al., 2004; Seymour, Aro, & Erskine, 2003; Wimmer & Goswami, 1994). In an orthographically consistent language, letters or letter clusters map consistently onto sounds. Conversely, in an orthographically inconsistent language, the relation between letters and sounds is often equivocal. If the consistency of the orthography is an important determinant of the rate of reading acquisition, the next question is naturally to what extent reading depends on the same underlying cognitive skills across these languages. Thus, the purpose of this study was to examine how rapid automatized naming (RAN) speed, the often called second core deficit in reading disabilities, is related to reading across languages.

RAN, defined as the ability to name as fast as possible highly familiar visual stimuli, such as digits, letters, colors, and objects, has been shown to be a strong concurrent and longitudinal predictor of reading ability in several consistent (see e.g., *Dutch*: de Jong & van der Leij, 1999; van den Bos, Zijlstra, & Spelberg, 2002; *Finnish*: Holopainen, Ahonen, & Lyytinen, 2001; Lepola, Poskiparta, Laakkonen, & Niemi, 2005; *German*: Mayringer, Wimmer, & Landerl, 1998; Wimmer, 1993; *Greek*:

Nikolopoulos, Goulandris, Hulme, & Snowling, 2006; *Italian*: Di Filippo et al., 2005) as well as in inconsistent orthographies (e.g., *English*: Blachman, 1984; Bowers, 1995; Compton, 2003; Kirby, Parrila, & Pfeiffer, 2003; Manis, Doi, & Bhadha, 2000; McBride-Chang & Manis, 1996; Parrila, Kirby, & McQuarrie, 2004; Savage & Frederickson, 2005; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; *French*: Plaza & Cohen, 2003), including non-alphabetic languages, such as Chinese (e.g., Cheung, McBride-Chang, & Chow, 2006; Chow, McBride-Chang, & Burgess, 2006; Ho & Bryant, 1997; Ho & Lai, 1997; Hu & Catts, 1998; Liao, Georgiou, & Parrila, in press; McBride-Chang & Ho, 2005), and Japanese (e.g., Kobayashi, Haynes, Macaruso, Hook, & Kato, 2005).

Several researchers have argued that RAN is a stronger predictor of reading in orthographically consistent languages than in orthographically inconsistent languages (e.g., de Jong & van der Leij, 1999; Di Filippo et al., 2005; Georgiou, Parrila, & Papadopoulos, 2005; Landerl & Wimmer, 2000; Mann & Wimmer, 2002; Mayringer et al., 1998; van den Bos et al., 2002). For example, Mann and Wimmer (2002) showed that, when considered along with phonological awareness and digit span, RAN was the only significant predictor of reading speed in German, whereas phonological awareness was the only significant predictor of reading speed in English. However, results from studies in Chinese – located at the extreme end of the orthographic consistency continuum – are difficult to accommodate with the position that RAN is more important for reading in orthographically consistent languages. Several recent studies have shown that RAN predicts character recognition, even after controlling for other known correlates of reading, such as verbal and nonverbal intelligence (Chow et al., 2006; McBride-Chang et al., 2003), visual memory (Hu & Catts, 1998), speed of processing (McBride-Chang et al., 2003), phonological sensitivity (Liao et al., in press; McBride-Chang et al., 2003; McBride-Chang & Zhong, 2003), or orthographic processing (Liao et al., in press). Some of the correlations obtained between RAN and reading in Chinese are similar to or even larger than what has been reported in orthographically consistent languages for children of the same age with comparable RAN tasks. Likewise, some of the correlation coefficients reported in Chinese studies (e.g., Hu & Catts, 1998; Liao et al., in press; McBride-Chang & Zhong, 2003) are larger than the median correlation coefficient reported in Scarborough's (1998) meta-analysis (Median $r = .39$ for non-alphanumeric RAN and Median $r = .38$ for alphanumeric RAN) for studies with English-speaking participants. Despite this conflicting evidence, no cross-linguistic study has examined the relative contribution of RAN on reading in Chinese, English, and in a more orthographically consistent language, such as Finnish, Italian, or Greek.

Examining the contribution of RAN to reading across languages that vary in orthographic consistency has implications for the theoretical models that have been proposed to explain the RAN-reading relationship. For example, Torgesen, Wagner, and their colleagues (e.g., Torgesen, Wagner, & Rashotte, 1994; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Wagner & Torgesen, 1987) have argued that RAN assesses the rate of access to and retrieval of stored phonological information in long-term memory. Initially, RAN was called "phonological recoding in lexical access" and was considered as part of the phonological processing family along with phonological awareness and phonological memory (e.g., Wagner & Torgesen, 1987). If phonological processing is more important for reading in English than in Chinese or in consistent orthographies (i.e. Finnish, German, or Greek), as suggested by many researchers (e.g., Georgiou et al., 2005; Mann & Wimmer, 2002; Mayringer et al., 1998; McBride-Chang et al., 2005; Wimmer & Mayringer, 2001), then RAN should exert a much stronger effect on reading in English than in Chinese or in consistent orthographies, a prediction that does not seem to match with results from single-language studies reviewed above.

Bowers, Wolf, and their colleagues (e.g., Bowers & Wolf, 1993; Bowers, Golden, Kennedy, & Young, 1994; Wolf, Bowers, & Biddle, 2000) proposed that RAN may be a marker of difficulties in orthographic rather than phonological processing. If letter identification proceeds too slowly, letter representations in words will not be activated in sufficiently close temporal proximity to induce sensitivity to commonly occurring orthographic patterns. In essence, Bowers, Wolf, and their colleagues predicted that the variance in RAN associated with reading would be mediated through resulting variability in orthographic processing. Although there is a paucity of cross-linguistic studies examining the effect of orthographic processing on reading, the evidence from single-language studies suggests that orthographic processing is important for reading irrespective of the characteristics of the orthography (e.g., Badian, 2001; Barker, Torgesen, & Wagner, 1992; Bjaalid, Hoien, & Lundberg, 1996; Cutting & Denckla, 2001; Ho, Chan, Chung, Lee, & Tsang, 2007; Liao et al., in press; Rahbari, Sénéchal, & Arab-Mohdaddam, 2007; Torgesen et al., 1997). Thus, although we cannot explicitly state a directional hypothesis regarding the role of RAN in reading across languages, we would expect it to be significantly related to reading in all of them if its relationship is mediated through resulting variability in orthographic processing. At the same time, across languages we should observe greater correlations for alphanumeric RAN (Digits or Letters) compared to non-alphanumeric RAN (Colors or Objects) because letters and digits carry more orthographic information than colors or objects.

An alternative hypothesis regarding orthographic processing and RAN's relationship to reading has been proposed by Manis, Seidenberg, and Doi (1999). They argued that the critical property of RAN is that the visual stimuli in the task have to be mapped rapidly to their names, and that these mappings are arbitrary. For example, seeing the digit "5" does not equip the participant with the phonological information needed to say the word "five." In the same way, producing the correct pronunciation for an exception word (i.e., *yacht*) requires the retrieval of partially arbitrary item-specific knowledge. Viewed under a cross-linguistic perspective, if Manis et al.'s (1999) hypothesis is correct, then we should observe higher correlations between RAN and reading in Chinese than in English and, in turn, higher correlations in English than in more consistent alphabetic orthographies. Although identifying consistencies in the sounds made by phonetic radicals in Chinese characters is helpful in learning to pronounce new characters (e.g., Cheung et al., 2006), they do not guarantee success in the way that learning grapheme-phoneme correspondences does in transparent orthographies. Manis et al.'s (1999) hypothesis, however, seems to be in conflict with existing evidence showing that RAN is more important for reading in orthographically consistent languages than in orthographically inconsistent ones (e.g., Mann & Wimmer, 2002).

Discrepancies betweeen the findings of single-language studies have often been ascribed to methodological differences (e.g., Patel, Snowling, & de Jong, 2004). For example, a possible explanation for the seemingly stronger relation between RAN and reading in consistent orthographies may have to do with shared method variance. Because reading accuracy in orthographically consistent languages can reach an asymptote after only a few months of reading instruction, researchers have favored reading fluency measures (e.g., de Jong & van der Leij, 1999; van den Bos et al., 2002). However, reading fluency and RAN share a time component which, in turn, may have inflated their relationship. Recently, Patel and her colleagues (2004) demonstrated that when comparable reading measures were used in English and Dutch, RAN was similarly related to reading in the two languages.

In addition, RAN has been measured as a unitary construct by obtaining a single performance time for the entire test. According to Neuhaus, Foorman, Francis, and Carlson (2001), measuring total performance time fails to provide the precision needed to adequately determine the nature of RAN tasks and the interest should be turned to intra-RAN components, such as *articulation time* and *pause time*. They defined articulation time as the sum of all individual articulation times for correctly articulated stimuli in a RAN display, and pause time as the sum of the pauses of time that are the intervals between the correct articulations. Most previous studies on RAN components – all conducted with English-speaking children – have reported that pause time is significantly related to reading (e.g., Georgiou, Parrila, & Kirby, 2006; Neuhaus et al., 2001; Neuhaus & Swank, 2002), whereas results with articulation time have been varied. If pause time is indeed the key component in the RAN-reading relationship, and RAN is more strongly related to reading in orthographically consistent languages than in English (e.g., Landerl & Wimmer, 2000; Mann & Wimmer, 2002), then pause time should be more strongly related to reading in German or Greek than in English.

The purpose of the current study was to examine the contribution of RAN in three languages that were purposively selected to represent different points in the orthographic consistency continuum. Chinese was selected to represent the one extreme end of orthographic consistency (opaque orthography), Greek was selected to represent the other extreme end of orthographic consistency (transparent orthography), and English was selected to represent the "mid-point" on the orthographic consistency continuum (more transparent than Chinese but less transparent than Greek).

The first objective of the present study was to compare the strength of the relationship between RAN and reading accuracy and reading fluency in Chinese, English, and Greek. The majority of existing cross-linguistic studies that have included RAN (e.g., Mann & Wimmer, 2002; McBride-Chang & Kail, 2002) have focused on young readers. Although there is some evidence suggesting that RAN's contribution to reading accuracy diminishes over time for English speaking children (e.g., Torgesen et al., 1997; but also see Kirby et al., 2003, for a different pattern of relationships), the same is likely not true for reading fluency (e.g., Torgesen et al., 1997), and we have studies suggesting that RAN's contribution to reading fluency may increase rather than decrease as children get older both in Chinese (Liao et al., in press; Tan, Spinks, Eden, Perfetti, & Siok, 2005) and in orthographically consistent languages (Nikolopoulos et al., 2006; van den Bos et al., 2002). Thus, we wanted to examine both accuracy and fluency measures with a sample of grade 4 children.

Second, we sought to examine if RAN is related to reading for the same reasons across languages by decomposing RAN into its constituent components of articulation and pause time and examining how these components are related to reading across languages. We hypothesized that some of the inconsistencies between current models and results from single-language studies may have to do with the unit of analysis being RAN total time rather than its components, whose importance may vary across languages.

Method

Participants

Forty English-speaking Canadian children (19 girls and 21 boys, mean age = 119.70 months, *SD* = 4.24), 40 Greek-speaking Cypriot children (23 girls and 17 boys, mean age = 119.42 months, *SD* = 4.64), and 40 Chinese-speaking Taiwanese children (23 girls and 17 boys, mean age = 119.85 months, *SD* = 3.98) attending grade 4 in their respective countries participated in this study. The participants were coming from predominantly middle-to-upper-middle SES families and were monolingual with no documented cognitive, sensory, or behavioural difficulties. The English- and the Greek-speaking children had approximately 5 years of formal education whereas the Chinese-speaking children had approximately 7 years of formal education. General cognitive ability, measured with Block Design in English and Greek (WISC III; Wechsler, 1991), and with Matrices in Chinese (CAS; Naglieri & Das, 1997), was within average range (Chinese: *M* standard score = 10.60, *SD* = 2.49; English: *M* standard score = 11.70, *SD* = 3.95; Greek: *M* standard score = 10.80, *SD* = 2.54). Written permission from the parents was obtained prior to testing.

Materials

Naming Speed

RAN Colors. This task was adopted from Wolf and Denckla (2005) and 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 10 colors per row. Prior to beginning the timed naming, each participant was asked to name in a practice trial the colors to ensure familiarity. Wolf and Denckla (2005) reported test-retest reliability of Color Naming to be .90. Color Naming in Greek and in Chinese was the same as in English and was also administered in the same way. The corresponding names of colors in Greek are [*mble*] for blue, [*mavro*] for black, [*prasino*] for green, [*kokkino*] for red, and [*kitrino*] for yellow. In Chinese, the names of the colors are [*lan*]2 for blue, [*hai*]1 for black, [*lui*]4 for green, [*hong*]2 for red, and [*huang*]2 for yellow. The mean phoneme length of the stimuli was 3.6 for English, 5.6 for Greek, and 3.4 for Chinese.

RAN Digits. This task was adopted from Wolf and Denckla (2005) and required participants to name as quickly as possible the names of five digits (2, 7, 4, 9, 5). The digits were presented on a laptop computer screen and arranged semi-randomly in five rows with 10 digits per row. Prior to beginning the timed naming, each participant was asked to name the digits in a practice trial to ensure familiarity. Wolf and Denckla (2005) reported test-retest reliability of .92 across ages. The test was administered in the same format and with the same items in Greek. The corresponding names of digits in Greek are [*dio*] for two, [*epta*] for seven, [*tessera*] for four, [eŋia] for nine, and [*pende*] for five. In Chinese, the format of the task was the same as in English and Greek, but the children were asked to name a different set of five digits (1, 4, 5, 7, 8). The corresponding names of digits in Chinese are [*yi*]1 for one, [*si*]4 for four, [*wu*]3 for five, [*qi*]1 for seven, and [*ba*]1 for eight. The mean phoneme length of the stimuli was 3.6 for English, 4.8 for Greek, and 1.6 for Chinese.

Word Reading

In English, the Form H Word Identification test from Woodcock Reading Mastery Tests-Revised (WRMT-R; Woodcock, 1998) was used as a measure of word reading accuracy. The test requires participants to read isolated words aloud. Words are graded in difficulty from pre-primer to adult level. The participant's score was the number of correctly read words. A cut-off rule of six consecutive mistakes was applied. Split-half reliability coefficient in our sample was .93.

In Greek, the children were asked to read a list of 60 words drawn from their language textbooks. The words varied in length from one syllable to five syllables and in frequency of appearance within the Hellenic National Corpus (Hatzigeorgiou et al., 2000; hnc.ilsp.gr), a corpus of approximately 47 million lexical units compiled from a wide selection of texts. The participant's score was the number of correctly read words. A cut-off rule of six consecutive mistakes was applied. Split-half reliability coefficient in our sample was .72.

In Taiwan, the Graded Chinese Character Recognition Test (Character Recognition; Huang, 2001) was used to assess reading accuracy. This is a standardized group administered reading measure with 200 single-syllable characters graded in difficulty. Participants were asked to write down the name of the character next to it using Zhu-Yin-Fu-Hao, which is an auxiliary phonetic system used in Taiwan in which each symbol represents a phonological segment of Chinese syllables. The score of the test was the number of characters answered correctly in 30 minutes. Huang (2001) reported test-retest reliability of .89 for grade 4.

Reading Fluency

In English, Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999) was used to assess word-reading fluency. 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.

In Greek, we used an adaptation of TOWRE (Georgiou et al., 2005). It consists of 104 words beginning with one syllable words and ending with three syllable words. However, in Greek the words were relatively longer than in English. Georgiou et al. (2005) reported test-retest reliability of .96 for grade 4.

In Taiwan, the One-Minute Reading test was used to assess reading fluency. One-Minute Reading, a subtest of the Hong Kong Test of Specific Learning

Difficulties in Reading and Writing (HKT-SpLD; Ho, Chan, Tsang, & Lee, 2000), contains 90 simple Chinese two-character words. Children were asked to read the characters as fast and accurately as possible for one minute. The score was the number of characters read correctly within one minute. The test was administered individually. Ho et al. (2000) reported split-half reliability of .99 for grade 4.

Procedure

Participants were examined in April/May of grade 4 in each of the countries. All participants were tested individually in their respective schools during school hours by trained experimenters. The order of the tests was fixed within each country and across countries such that the children did first the general cognitive ability task followed by Color Naming, the reading accuracy task, Digit Naming, and finally the reading fluency task. Testing was completed in one session lasting roughly 30-40 minutes.

Manipulation of Sound Files

The sound files containing the Color Naming and the Digit Naming responses for each participant were analyzed using GoldWave v.4.26 (GoldWave Inc. 2002). Data extraction for each child was completed following the procedure described in detail in Georgiou et al. (2006). Both articulation and pause times were measured in milliseconds. Before the calculation of the mean RAN components' times, 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 and the articulation time that followed the skip were removed. Fourth, in cases in which off-task behavior (e.g., coughing, talking to the experimenter, self-encouragement) was observed between two articulations, the specific pause time was removed.

Articulation time represents the mean of those articulation times that were correctly verbalized and were not preceded by a skipped stimulus. The maximum possible number of cleaned articulation times for each participant was 50 for both RAN tasks, indicating that there were no naming errors; smaller numbers of cleaned articulation times indicate that one of the above cleaning procedures took place. Across all the possible articulation times for RAN Digits, 4 instances of cleaning took place in English, 6 in Chinese, and 3 in Greek, respectively. For RAN Colors, 9 instances of cleaning took place in English, 27 in Chinese, and 5 in Greek, respectively.

Pause time represents the mean of the pause times that occurred between two correctly articulated stimuli. The maximum possible number of cleaned pause times for each participant was 49 for RAN Digits and for RAN Colors; smaller numbers indicate that one of the cleaning procedures was imposed. Across all the possible pause times for RAN Digits, 19 instances of cleaning took place in English, 24 in Chinese, and 14 in Greek, respectively. For RAN Colors, 40 instances of cleaning took place in English, 104 in Chinese, and 66 in Greek, respectively. Only the cleaned articulation and pause time measures were used in further analyses.

Results

Preliminary Data Analysis

Table 3-1 presents the descriptive statistics for the RAN total times and components and Table 3-2 presents the descriptive statistics for the reading measures. The three language groups were not significantly different from each other on age, $F(2, 117) = .02$. In addition, there were no significant gender differences on the RAN tasks across languages (all $ps > .15$).

Table 3-1

Descriptive Statistics of the RAN Total Times and Components Across Languages

	Chinese ($n = 40$)		English ($n = 40$)		Greek ($n = 40$)	
	M	SD	M	SD	M	SD
RAN-Colors						
Total Time[1]	41.07	7.48	41.63	11.05	39.33	7.85
Articulation Time[2]	441.68	51.15	456.51	78.40	524.01	58.21
Pause Time[2]	352.49	122.59	363.56	180.21	244.60	114.70
RAN-Digits						
Total Time[1]	21.78	4.55	26.68	7.73	24.47	4.99
Articulation Time[2]	316.08	47.95	391.09	71.01	392.36	58.65
Pause Time[2]	115.55	52.77	142.01	100.41	94.06	51.96

Note. [1] = Measured in seconds; [2] = Measured in milliseconds.

Table 3-2

Descriptive Statistics of the Reading Measures Across Languages

	Chinese (n = 40)		English (n = 40)		Greek (n = 40)	
	M	SD	M	SD	M	SD
Reading Accuracy	91.23 [a]	25.89	74.58 [c]	8.68	57.17 [e]	3.05
Reading Fluency	88.47 [b]	15.80	71.23 [d]	8.74	60.45 [f]	15.22

Note. [a] Character Recognition (max = 200); [b] One-Minute Reading (max = 180); [c] Word Identification (max = 106); [d] = Test of Word Reading Efficiency (max = 104); [e] = Word Identification (max = 60); [f] = Test of Word Reading Efficiency (max = 104).

An examination of the distributional properties of the RAN components in each language revealed some problems. All the RAN measures, with the exception of Color Naming total time and pause time in Chinese, were moderately skewed. In order to normalize the distributions, log transformations were performed (Tabachnick & Fidell, 2001). In addition, as was expected on the basis of previous studies (e.g., Ellis et al., 2004; Harris & Giannouli, 1999; Papadopoulos, 2001; Seymour et al., 2003), the performance of the Greek-speaking children on Word Identification was close to ceiling with 11 children (27.5%) reading all 60 words correctly. Thus, the results from analyses using Word Identification in Greek should be viewed with some caution.

In order to examine if there were significant differences in the performance of the three languages on RAN total times, one way MANOVA was performed with RAN Colors and RAN Digits total times as dependent variables and language as a fixed factor. The results showed that there was a main effect of language, Wilk's λ = .762, F (4, 232) = 8.46, $p < .001$. Follow-up univariate analyses showed that the languages differed significantly on RAN Digits, F (2, 117) = 8.08, $p < .001$, $\eta^2 = .121$, but not on RAN Colors, $F(2, 117) = .62, p > .05, \eta^2 = .011$. Post hoc analyses showed that the Chinese children were faster than the English or the Greek children in naming digits. No differences were found between the last two groups. Because these differences are theoretically uninteresting, they are not discussed further.

Correlations Between RAN and Reading

Table 3-3 presents the correlations and coefficients of determination between the RAN total times and the reading measures in the three languages. An initial examination of the correlation coefficients revealed that across languages there were some similar patterns of relationships, but also some noticeable differences.

Table 3-3

Correlations and (Coefficients of Determination) Between RAN and Reading Accuracy and Fluency in Chinese, English, and Greek

	Reading Accuracy			Reading Fluency		
	Chinese	English	Greek	Chinese	English	Greek
RAN-Colors	-.36*	-.17	-.38*	-.49**	-.64**	-.44**
	(.13)	(.03)	(.14)	(.24)	(.41)	(.19)
RAN-Digits	-.59**	-.28	-.55**	-.77**	-.68**	-.59**
	(.35)	(.08)	(.30)	(.59)	(.46)	(.35)

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

First, across languages, the correlations between RAN Digits and reading measures were higher than the correlations between RAN Colors and reading measures. Second, across languages, the correlations between RAN and reading fluency were higher than the correlations between RAN and reading accuracy. Although RAN was significantly correlated to reading accuracy in Chinese and Greek it was not significantly correlated to reading accuracy in English. Notably, the coefficients of determination between RAN and reading accuracy in Chinese and in Greek were four times larger than in English.

In order to examine if the correlations between the RAN total times and the reading measures differed significantly across languages, a z test was performed using Fischer's r to z transformations (Glass & Hopkins, 1984). First, we compared the correlations between the RAN total times and the reading accuracy measure across languages and then the correlations between the RAN total times and the reading fluency measure across languages. We adjusted the level of significance at .01 to control for Type I error. Despite some sizeable differences, none of the comparisons reached significance (all $ps > .09$). Second, within each language, we examined if the correlations obtained between the RAN total times and the reading accuracy measure differed significantly from the correlations obtained between the RAN total times and the reading fluency measure using Hotelling's t test (Glass & Hopkins, 1984). The results showed that the difference between the correlations was significant only in English ($t(37) = 4.21, p < .01$ for RAN Colors and $t(37) = 3.64, p < .01$, for RAN Digits). Finally, within each language, we compared the correlations obtained between RAN Colors and reading to the correlations obtained between RAN Digits and reading. The analyses showed that only in Chinese were the correlations between RAN Digits and One-Minute reading significantly greater than the correlations between RAN Colors and One-Minute reading ($t(37) = 4.99, p < .01$). To summarize, no significant differences were observed across languages that vary in orthographic consistency in RAN – reading correlations. In English, RAN was more strongly related to reading fluency than to reading accuracy, and in Chinese, RAN Digits was more strongly related to reading fluency compared to RAN Colors.

Correlations Between RAN Components and Reading Ability

Table 3-4 presents the correlations between articulation time, pause time, and reading measures in Chinese, English, and Greek, respectively. Table 3-4 indicates that different components appear to contribute to the relatively similar correlations that were observed earlier between RAN total times and reading outcomes in the three languages. More specifically, in Chinese, RAN Colors articulation time was not significantly correlated with reading measures. In English, RAN Colors articulation time was significantly correlated with reading fluency. In Greek, it was significantly correlated with both reading accuracy and reading fluency. With respect to RAN Digits, both articulation time and pause time were significantly correlated to reading accuracy and fluency in Chinese and in Greek, and with reading fluency in English.

Table 3-4

Correlations Between RAN Components and Reading Accuracy and Fluency in Chinese, English, and Greek

	Reading Accuracy			Reading Fluency		
	Chinese	English	Greek	Chinese	English	Greek
RAN Colors						
Articulation Time	.06	-.11	-.34*	-.12	-.52**	-.42**
Pause Time	-.40*	-.08	-.37*	-.57**	-.45**	-.40*
RAN Digits						
Articulation Time	-.46**	-.24	-.53**	-.63**	-.69**	-.57**
Pause Time	-.57**	-.20	-.45**	-.71**	-.59**	-.51**

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

Commonality Analyses with RAN Digits Components and Reading Outcomes

As articulation times and pause times generally were significantly correlated (*r*s varied from .08 to .69; the only nonsignificant correlation was between Chinese Color Naming pause time and articulation time), we performed commonality analyses to examine the unique and shared contribution of the RAN components to the reading measures across languages. Commonality analysis is a method of variance partitioning designed to identify proportions of variance in the dependent variable that may be attributed uniquely to each of the independent variables, and proportions of variance that are attributed to various combinations of independent variables (Pedhazur, 1982). The reading accuracy and fluency measures in each language were used as dependent variables and were first residualized from the effects of age and nonverbal intelligence. Because the analysis involved two independent variables (articulation time and pause time), there were $2^2 - 1 = 3$ commonality components, two of which were unique and one was a second-order commonality component. Because generally higher correlations were observed for RAN Digits compared to RAN Colors, the commonality analysis was performed only with the RAN Digits components. Table 3-5 presents these results. Note that the sum values in the last row of Table 3-5 are equal to the addition of the unique and common variances accounted for by the three commonality components.

Table 3-5 indicates that there were some similarities as well as some striking differences in the importance of different components across the three languages.

First, the component shared by articulation time and pause time accounted for a sizeable proportion of the explained reading variance in all languages. In terms of reading fluency, the shared component accounted for roughly 55.5% (100 *(.2676/.4822)) of the explained variance in Chinese, 62.5% in English, and 42.1% in Greek. In terms of reading accuracy, the component shared by articulation time and pause time accounted for 53.8% of the explained variance in Chinese, 30.7% of the explained variance in English, and 55.3% of the explained variance in Greek. These numbers indicate that what articulation and pause times share is an important part of RAN's predictive validity. Second, articulation time was clearly more important in Greek than in English or Chinese. Articulation time accounted for 57.7% of the explained variance in Greek reading fluency, compared to 31.5% in English, and 16.5% in Chinese. In addition, articulation time accounted for 39.6% of the explained variance in Greek reading accuracy, compared to 1.3% in English, and 11.5% in Chinese. In general, the unique contribution of articulation time appears to increase as the orthographic consistency of the language increases. Finally, pause time was clearly more important in Chinese than in English or Greek, when reading fluency was the dependent variable. More specifically, pause time accounted for 28% of the explained variance in Chinese reading fluency, compared to 6% in English, and 0.2% in Greek. Pause time was again more important for reading accuracy in Chinese (34.7%) than in Greek (5.1%). However, pause time accounted for 68% of the explained variance in English reading accuracy, a finding that should be viewed against the nonsignificant contribution (a total of 4.5% of variance explained) of RAN to reading accuracy in English.

Table 3-5

Unique and Common Contributions of RAN Digits Articulation Time and Pause Time on Reading Accuracy and Fluency Across Languages

	Reading Accuracy			Reading Fluency		
	Chinese	English	Greek	Chinese	English	Greek
Unique Contributions						
1. Articulation Time	.0320	.0006	.1118	.0795	.1149	.1778
2. Pause Time	.0963	.0306	.0143	.1351	.0219	.0006
Common Contributions						
Common to 1 & 2	.1495	.0138	.1560	.2676	.2281	.1297
Sum	.2778	.0450	.2821	.4822	.3649	.3081

Discussion

The first objective of this study was to examine the relationship between RAN and reading across languages that vary in orthographic consistency. The results showed that there were sizeable differences in the RAN-reading relationship across languages. Importantly, the coefficients of determination between RAN and reading fluency in Greek were at least four times as large as the coefficients of determination between RAN and reading accuracy in English. This finding provides an explanation as to why some researchers have argued that RAN is more strongly related to reading in consistent orthographies, such as German, Italian, or Greek, compared to English (e.g., Di Filippo et al., 2005; Landerl & Wimmer, 2000; Mayringer et al., 1998; Nikolopoulos et al., 2006; Wimmer et al., 1999). It is most likely based on the fact that correlations between RAN and reading speed in orthographically consistent languages are compared against correlations between RAN and reading accuracy in orthographically inconsistent languages. Our results indicated that when correlations between similar RAN tasks and similar reading measures were compared across languages, no significant differences were observed. We should note, however, that the correlations between RAN and reading accuracy measures were significant in Chinese and Greek, and the coefficients of determination about four times as large as the nonsignificant coefficients of determination between RAN and reading accuracy measures in English.

The absence of significant differences in the RAN-reading correlations across languages has implications regarding the different theoretical hypotheses regarding why RAN is related to reading. First, we speculated that if Torgesen and his colleagues' (e.g., Torgesen et al., 1997; Wagner & Torgesen, 1987) hypothesis was correct, RAN should be more important for reading in English than in any other orthography. However, we showed that there were no statistically significant differences in the correlations across languages and correlations between RAN and Word Identification in English failed to reach level of statistical significance. Second, the findings of this study provide cautious support for Bowers and Wolf's (1993) hypothesis that slow visual recognition of letters (or perhaps strokes or stroke patterns in the case of Chinese), as indexed by RAN performance, compromises the formation of inter-letter associations at both the sub-word and word levels, which in turn affects the quick recognition of words. If this hypothesis was correct, then (a) RAN should be significantly correlated to reading in all languages, (b) higher correlations should be observed between RAN Digits and reading than between RAN Colors and reading, and (c) RAN should become more important for tasks that rely more on orthographic processing. Our results indicate that RAN was significantly correlated with all other reading measures but reading accuracy in English, and that no significant differences were observed across languages in these correlations. We also observed higher correlations between RAN Digits and reading than between RAN Colors and reading, although the differences were significant only in Chinese. Finally, RAN – reading fluency correlations were generally higher than RAN – reading accuracy correlations, although this difference was significant only in English. Thus, most of the differences were in the direction predicted by Bowers and Wolf's hypothesis, albeit mostly not statistically reliable.

Finally, we hypothesized that if Manis and his colleagues' (1999) hypothesis was correct, then we should observe stronger correlations between RAN and reading in Chinese than in English, and, in turn, stronger correlations in English than in Greek on the basis of the fact that Chinese has the most arbitrary symbol-sound mappings, whereas Greek has the most regular symbol-sound mappings. No statistically significant differences were found between the respective total time correlations across languages. At the components level, however, the commonality analyses indicated that the unique contribution of pause time was generally greater the more inconsistent the orthography is, as would be predicted on the basis of Manis and his colleagues' hypothesis. Thus, to the extent that pause time is the critical component in the RAN – reading relationship, Manis and his colleagues' hypothesis is supported by our results.

The natural follow-up question then is what theoretical model may account for the RAN – reading relationship across languages, if the evidence presented in this study does not provide clear support to the existing hypotheses. We argue that across languages there is a foundational level of speed of processing effects that partially drives the RAN – reading relationship. The results of the commonality analyses revealed that the component shared by articulation time and pause time accounted for roughly half of unique variance in reading predicted by RAN. This finding is in line with Wolf and Bowers' (1999) argument that RAN may operate as a *lexical midpoint* in a cascading system of processing speed effects and with Bowey, McGuigan, and Ruschena's (2005) finding that, at all levels of reading development, RAN measures some speed of processing. There are two caveats to this interpretation. First, speed of processing is not a sufficient explanation for the RAN-reading relationship across languages as pause time and/or articulation time accounted for additional unique variance in reading well beyond the contribution of the component shared by articulation and pause time. Second, the interpretation of the shared component as representing speed of processing is somewhat problematic given that it accounted for an almost equal proportion of variance in reading accuracy and fluency in Chinese (53.8% vs. 55.5%) and for a bigger proportion of variance in reading accuracy than fluency in Greek (55.3% vs. 42.1%). If the shared component would reflect only speed of processing, we would expect it to be more important for the speeded tasks.

Beyond this foundational level, RAN may be related to reading for different reasons across languages. For example, in Greek, pause time did not explain any unique variance in reading but RAN was significantly related to both reading accuracy and reading fluency. This finding indicates that pause time may not be the key component in the RAN – reading relationship in Greek (or in any other transparent language) and, therefore, any explanations relating RAN to reading should not involve pause time or the sub-processes involved in the pause time. In English, RAN was significantly related only to reading fluency and, similarly to Greek, pause time had the smallest contribution to reading fluency compared to articulation time or to the component shared by articulation time and pause time. This finding is in line with McBride-Chang and Manis' (1996) argument that in groups of average or above-average students, variability in rapid naming is not related to variability in their reading accuracy scores. On the other hand, in Chinese, pause time made twice as large contribution to reading outcomes as articulation time, and it was important for both reading accuracy and reading fluency. This result is similar to what previous studies (e.g., Georgiou et al., 2006; Neuhaus et al., 2001) have reported for younger English-speaking participants, raising the possibility that what underlies RAN – reading relationship may vary both across development and across languages.

Some limitations of the present study should be noted. First, the sample size of the current study was relatively small. It is possible that the small sample size may have reduced the power to find significant differences in the correlations across languages (Cohen & Cohen, 1983), and future studies should attempt to replicate these findings with a larger sample size. Second, as pointed out earlier, there was little variability in Word Identification in Greek, which may have resulted in attenuated correlations between RAN and word identification. Nevertheless, previous studies in Greek using reading tasks that produced greater variability reported similar correlation coefficients between RAN and reading. For example, Georgiou et al. (2005) reported that the correlations between RAN and word decoding in grade 1 were .41 for RAN Colors and .46 for RAN Digits, respectively, which are very close to the ones reported in this study. Third, the differences between our findings and Manis et al.'s (1999) findings may be due to methodological differences. Whereas Manis and his colleagues (1999) examined the effect of grade 1 predictors on grade 2 reading outcomes in English and controlled for initial vocabulary knowledge, the present study was concerned with the concurrent relationship between RAN and reading across languages with a sample of grade 4 children and did not control for vocabulary knowledge. Fourth, the fact that the sample of the present study consisted of older readers may have resulted in an underestimation of the contribution of RAN to reading compared to what has been reported in previous studies with younger readers (e.g., Blachman, 1984; Bowers & Swanson, 1991; de Jong & van der Leij, 1999; Georgiou et al., 2006; Kirby et al., 2003; Lepola et al., 2005; McBride-Chang et al., 2003; McBride-Chang & Zhong, 2003; Schatschneider et al., 2004). Finally, future research on RAN across languages should consider including other variables, such as speed of processing, articulation rate, phonological awareness, and orthographic processing that may mediate the relationship between RAN and reading in different languages.

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IV. PHONOLOGICAL AND ORTHOGRAPHIC PROCESSING SKILLS AS PREDICTORS OF READING IN ENGLISH AND GREEK

Over the last two decades, a wealth of evidence has established the prominent role of phonological processing, defined as the use of the sound structure of oral language in processing written and oral information, in reading acquisition. Three different aspects of phonological processing – phonological awareness, phonological short-term memory, and rapid automatized naming (RAN) – have been shown to predict the rate of reading acquisition in several alphabetic languages varying in orthographic consistency (e.g., Bruck, Genesee, & Caravolas, 1997; de Jong & van der Leij, 1999, 2002; Holopainen, Ahonen, & Lyytinen, 2001; Manis, Doi, & Bhadha, 2000; Mayringer, Wimmer, & Landerl, 1998; Muter, Hulme, Snowling, & Stevenson, 2004; Parrila, Kirby, & McQuarrie, 2004; Wagner & Torgesen, 1987). There has also been a tendency among researchers to assume that the predictive models of early reading development generalize across languages (e.g., Frith, 1985; Marsh, Friedman, Welch, & Desberg, 1981) despite the lack of empirical cross-linguistic studies. In addition, relatively little is known about the role of orthographic processing, defined as the ability to use visual-orthographic information in processing words, in early reading development (Barker, Torgesen, & Wagner, 1992; Berninger, 1994; Burt, 2006; Cunningham, Perry, & Stanovich, 2001; Wagner & Barker, 1994). Thus, the purpose of this study was to examine how phonological and orthographic processing predict word decoding and reading fluency in children learning to read in English (opaque language) and children learning to read in Greek (transparent orthography).

We suggest that recent theoretical developments – more specifically, the *psycholinguistic grain size theory* (PGST) and the theories of how RAN is related to reading – lead to expectations that both phonological processing and orthographic processing skills contribute differently to reading development in languages varying in orthographic consistency. In the rest of the introduction, we will first review PGST and predictions derived from it. We will then summarize results from existing studies (a) on the effects of phonological processing skills on reading across languages and (b) on the effects of orthographic processing on reading across languages. Finally, we will present an overview of the present study.

The Psycholinguistic Grain Size Theory of Reading Development

Recently, Ziegler and Goswami (2005) introduced the *psycholinguistic grain size theory* (PGST), according to which "the dramatic differences in reading accuracy and reading speed found across orthographies reflect fundamental differences in the nature of the phonological recoding and reading strategies that are developing in response to the orthography" (p. 19). On one hand, children who are learning to read in orthographically consistent languages, such as Finnish, Greek, German, or Italian, rely heavily on grapheme-phoneme recoding strategies because the relationship between graphemes and phonemes is straightforward. On the other hand, children learning to read in orthographically inconsistent languages, such as English or Danish, cannot rely on smaller grain sizes because inconsistency is much higher for smaller grapheme units than for larger units. The reduced reliability of small grain sizes leads children to develop flexible unit size recoding strategies, such as grapheme-phoneme correspondence, analogy, and whole-word recognition. Based on this observation, Ziegler and Goswami (2005) went as far as to argue that "it might even be the case that some of the most sophisticated processing architecture (e.g., two separate routes to pronunciation in the skilled reading system) may in fact only develop in English" (p. 20).

By making a distinction between the strategies employed by the readers of different orthographic systems with the intention to explain the cross-linguistic differences in reading accuracy and fluency, PGST has implications with respect to the roles of phonological and orthographic processing skills on reading development. If reading in orthographically inconsistent languages relies upon effective use of multiple recoding strategies, then it follows that both phonological awareness skills and orthographic processing skills should be more important for reading development in orthographically inconsistent languages than in orthographically consistent languages. This is because decoding in orthographically inconsistent languages depends not only on the recognition of single graphemes and the retrieval of their corresponding (and possibly multiple different) sounds but also on the recognition of bigger grain-size units, such as rimes and their corresponding sound units. Whereas phonological awareness is the *sine qua non* for the former, orthographic knowledge is also needed for the latter. Similarly, if reading in consistent orthographies relies on a grapheme-phoneme recoding strategy, then phonological short-term memory should play a larger role in reading in these languages because the phonological information of each grapheme needs to be available for the blending to occur and the naming of the word to be successful.

Although specific predictions can be made regarding the role of phonological awareness, phonological short-term memory, and orthographic processing in learning to read in languages that vary in orthographic consistency, the PGST does not allow any predictions regarding the role of rapid automatized naming (RAN) speed on reading. However, some of the current theories of RAN seem to lead to different predictions regarding how orthographic consistency should affect RAN's contribution to reading development. If RAN measures the ability to access and retrieve phonological representations from long term memory, as suggested by Torgesen, Wagner, and their colleagues (e.g., Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Wagner & Torgesen, 1987; Wagner et al., 1997), then it should be more strongly related to reading in consistent orthographies because the phonological representation of each single grapheme should be retrieved quickly enough for the grapheme-phoneme recoding strategy to be effective. On the contrary, if RAN measures the ability to form orthographic representations, as suggested by Bowers and her colleagues (Bowers, Golden, Kennedy, & Young, 1994; Bowers, Sunseth, & Golden, 1999; Sunseth & Bowers, 2002), then RAN should be more important for reading in orthographically inconsistent languages because for the larger grain-size unit strategies to succeed the orthographic information of those units must be developed.

Similarly, PGST does not explain the mechanism by which reading fluency is accomplished. Wimmer (2006) criticized PGST for providing a rather time-limited perspective because in consistent orthographies children achieve high levels of accuracy after a few months of reading instruction and the main characteristic of further development is not reading accuracy but reading fluency. If we accept the axiom that children in consistent orthographies do not switch reading strategies depending on the type of reading task (accuracy or fluency), then fluency can be achieved only if grapheme-phoneme decoding strategy becomes itself faster. If this speculation is correct, then orthographic processing skills should not predict fluency development any more than accuracy development, whereas RAN should be a prominent predictor of reading fluency, an argument that is in line with existing empirical findings (e.g., Caravolas, 2006; de Jong & van der Leij, 1999). In contrast, in orthographically inconsistent orthographies fluency can be achieved only if multiple unit size strategies become more reliable and readily available. In turn, that would likely demand the joint contribution of both RAN and orthographic processing skills.

Because of the relatively short life of the PGST and the RAN theories, the predictions expressed above have not been directly tested. In the rest of this introduction, we will provide indirect evidence for the predictions by reviewing the literature on the relationship between orthographic consistency and phonological processing and on the relationship between orthographic consistency and orthographic processing.

Orthographic Consistency and Phonological Processing

Cross-sectional and longitudinal studies conducted in languages varying in orthographic consistency have produced conflicting findings as to the importance of each one of the phonological processing skills in reading acquisition. In English-speaking children, the contribution of phonological awareness to later reading ability appears to remain strong at least through the elementary school and survive the statistical control of prior reading achievement, whereas the contribution of RAN appears to be time-limited and dependent on the type of RAN tasks used (Letter and Digit Naming versus Color and Object Naming) and the reading competence of the children (e.g., Blachman, 1984; Bowers & Wolf, 1993; Cardoso-Martins & Pennington, 2004; Georgiou, Parrila, & Kirby, 2006; Meyer, Wood, Hart, & Felton, 1998; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002; Torgesen et al., 1997; Wolf & Bowers, 1999). Finally, conflicting findings have been reported regarding the contribution of phonological short-term memory. For example, Swanson and his colleagues (e.g., Swanson & Alexander, 1997; Swanson & Howell, 2001) reported significant contributions of phonological short-term memory on reading whereas others have shown that it is only weakly related to reading when considered along with phonological awareness and/or RAN (e.g., Parrila et al., 2004; Torgesen et al., 1997).

In contrast to studies in English, the majority of studies conducted in orthographically consistent languages, such as German, Finnish, and Dutch, have shown that phonological awareness: (a) may not be an important predictor of reading (e.g., Aarnoutse, van Leeuwe, & Verhoeven, 2005; Harris & Giannouli, 1999; Holopainen et al., 2001) or (b) may be important but only during the first one or two years of schooling (e.g., Aidinis & Nunes, 2001; de Jong & van der Leij, 2002; Di Filippo et al., 2006; Landerl & Wimmer, 2000; Lepola, Poskiparta, Laakkonen, & Niemi, 2005; Leppänen, Niemi, Aunola, & Nurmi, 2006; Loizou & Stuart, 2003; Papadopoulos, 2001; Wesseling & Reitsma, 2000). It is hypothesized that the effect of consistent spelling-sound correspondences is sufficiently powerful to secure children's phonological recoding skills after a few months of reading experience, regardless of their pre-reading levels of phonological awareness (Caravolas, 2006; Landerl, 2006; Orsolini, Fanari, Tosi, De Nigris, & Carrieri, 2006; Porpodas, 1999; Wimmer, Landerl, & Schneider, 1994). Accordingly, several studies have suggested that RAN may play a more prominent role than phonological awareness in predicting further reading development in consistent orthographies (e.g., de Jong & van der Leij, 1999, 2002; Mayringer et al., 1998; van den Bos, 1998; Wimmer, 1993; Wimmer, Mayringer, & Landerl, 2000). Finally, phonological short-term memory appears to play a rather non-significant role in learning to read in orthographically consistent languages (e.g., de Jong & van der Leij, 1999; Nikolopoulos, Goulandris, Hulme, & Snowling, 2006).

The few published studies that have directly compared children learning different alphabetic languages have also provided mixed findings. Patel, Snowling, and de Jong (2004) compared the predictors of reading ability in English and Dutch and found that "the concurrent predictors of reading in English and Dutch were *strikingly similar* [italics added]" (p. 793). Phoneme deletion (measured by accuracy and response time) was a significant predictor of individual differences in reading, whereas rapid naming of colors, animals, and objects was not. The authors concluded that phonological awareness is a predictor of individual differences in reading skill in both transparent and opaque orthographies. However, they also reported that the language by phoneme deletion interaction term accounted for significant amount of variance in word reading accuracy after the effects of language, age, vocabulary, phoneme deletion, and RAN were controlled; follow-up analyses revealed that phoneme deletion accuracy was a significant predictor of word reading accuracy only for the English children.

Mann and Wimmer (2002), in turn, examined the predictors of reading in English and German. At the end of kindergarten, grade 1, and grade 2, children were given two tests of phonological awareness (phoneme identity judgment and phoneme elision), RAN Colors, letter identification, and short tests of word and nonword reading accuracy and speed. Results from regression analyses showed that the only significant predictor of both reading accuracy and speed in English was phonological awareness. In German, there were no significant predictors of reading accuracy whereas RAN was the only significant predictor of reading speed. Although Mann and Wimmer's (2002) results may reflect genuine differences between languages in the extent to which reading acquisition relies on different phonological processes, there are notable methodological problems that may compromise this conclusion. First, lack of variability in word and nonword reading accuracy scores was evident in the German sample. Second, there was lack of variability in phoneme identity judgment, a task used to create a composite phonological awareness score, which was, in turn, used to predict reading accuracy and speed.

Recently, Caravolas, Vólin, and Hulme (2005) suggested that when phonological awareness is measured with sufficiently difficult tasks, a significant contribution of phonological awareness on reading ability in regular orthographies can be detected even with older children. Caravolas et al. (2005) examined the effect of phonological awareness on reading and spelling in a regular orthography (Czech) and in an opaque orthography (English) with a group of normally developing children in grades 2 to 5 (Czech sample) and grades 2 to 7 (English sample). Phonological awareness, measured by phoneme elision and spoonerisms tasks, was a significant predictor of reading ability in both Czech and English.

To summarize, the existing studies have provided contradictory findings with respect to the contribution of phonological processing skills on reading across alphabetic languages that vary in orthographic consistency. The selection of tasks is likely critical as it appears to moderate the relationship between phonological awareness, RAN, and reading. First, many phonological awareness tasks, such as rhyme awareness or phoneme judgment, are likely too easy for grade 1 students in orthographically consistent languages and produce little variability, which, in turn, may be responsible for nonsignificant effects. In contrast, a task such as phoneme elision is more difficult and is more likely to create variability even among older readers. Second, alphanumeric RAN tasks (digit and letter naming) have been found in many single-language studies to be stronger predictors of reading than non-alphanumeric RAN tasks (color and object naming; e.g., Cardoso-Martins & Pennington, 2004; Felton & Brown, 1990). Yet, none of the existing cross-linguistic studies used alphanumeric RAN tasks, possibly undermining the RAN – reading relationship. Finally, it is possible that the differences found in the predictive value of the phonological processing skills may be partly due to the measures used to assess reading ability. Research in English-speaking populations has primarily focused on the prediction of reading accuracy, whereas research conducted in orthographically consistent languages has primarily focused on the prediction of individual differences in reading speed. Wolf and Bowers (1999) argued that phonological awareness is more strongly related to word reading accuracy and that RAN is more strongly related to reading fluency (see also, Bowers, 1995; Katzir et al., 2006; Manis et al., 2000; Savage & Frederickson, 2005). Thus, to the extent that phonological awareness and RAN are differentially related to specific types of reading outcomes, then the use of reading speed measures in consistent orthographies might have accentuated the role of RAN and the use of reading accuracy measures in inconsistent orthographies might have accentuated the role of phonological awareness.

Orthographic Consistency and Orthographic Processing

Although the importance of phonological processing in predicting reading ability has been generally accepted, the role of orthographic processing is not yet fully understood. Difficulties arise because of discrepancies in the way orthographic processing has been conceptualized and the way it has been operationalized (Burt, 2006; Hagiliassis, Pratt, & Johnston, 2006). Impressively, Wagner and Barker (1994) presented as many as 11 definitions of orthographic processing used in research. For example, Stanovich and West (1989) defined orthographic processing as “the ability to form, store, and access orthographic representation(s)” (p. 404), and Perfetti (1984) defined orthographic processing as “the knowledge a reader has about permissible letter patterns” (p. 47).

Several studies have demonstrated the importance of orthographic processing for reading acquisition in English (e.g., Badian, 1993, 2001; Cunningham et al., 2001; Cutting & Denckla, 2001; Holland, McIntosh, & Huffman, 2004; Torgesen et al., 1997). For example, Torgesen et al. (1997) showed that orthographic processing accounted for a significant amount of unique variance in grade 4 and 5 word-reading accuracy and reading comprehension even after the influence of general verbal ability and phonological awareness were controlled.

Studies conducted in other languages are rare, confounded by bilingualism, and have produced conflicting results. For example, Arab-Moghaddam and Sénéchal (2001) examined the effects of phonological and orthographic processing skills on reading in English and Persian, an orthographically consistent language. Persian-speaking children in grades 2 and 3, who had lived in English-speaking Canada for an average of 4 years, were tested on word reading in English and Persian. Arab-Moghaddam and Sénéchal (2001) found that the predictors of reading performance were similar across languages: phonological and orthographic processing skills each predicted unique variance in word reading in English and Persian once the effects of grade level, vocabulary, and reading experience were controlled. Importantly, in both languages, the amount of unique variance accounted for by orthographic processing was twice the amount accounted for by phonological processing.

Geva, Wade-Woolley, and Shany (1993), in turn, studied children learning to read both English and vowelised Hebrew, which has almost perfect grapheme-to-phoneme correspondences. They reported that although both phonological and orthographic processing predicted reading acquisition in English, only phonological skills predicted reading acquisition in Hebrew. These contrasting findings suggest that while orthographic processing has been shown to contribute significantly to reading acquisition in English, its role needs to be further examined in more consistent orthographies.

Overview of the Current Study

Several researchers have argued that in order to have a comprehensive understanding of the mechanisms involved in reading, models of reading development should be tested across languages varying in orthographic consistency. Thus, the purpose of the current study was to compare concurrently and longitudinally the relative importance of phonological processing (phonological awareness, phonological memory, and RAN) and orthographic processing in predicting word reading accuracy and fluency in children learning to read an orthographically consistent language (Greek) and in children learning to read an orthographically inconsistent language (English).

Within the family of alphabetic scripts, Greek provides an interesting contrast to English because of its high degree of consistency for reading. Although in Greek there are no statistical estimations of the degree of consistency, as there is, for example, in English (e.g., Ziegler, Stone, & Jacobs, 1997) and French (e.g., Ziegler, Jacobs, & Stone, 1996), the almost perfect one-to-one correspondence between its graphemes and phonemes (see Porpodas, 2004, for a description of a few exceptions) and the predominance of open (CV) consonant-vowel syllables render Greek orthography consistent. Because the pronunciation of most Greek words is highly predictable the need for memorizing the pronunciation of a given word as a whole (as in */have/-/behave/* in English), or remembering the appropriate context dependent rule of pronunciation (e.g., *bit* – *bite*: final *e*) is significantly reduced.

Method

Participants

Letters of information describing the study were sent to parents of 161 grade 1 English-speaking Canadian and 92 grade 1 Greek-speaking Cypriot children. One-hundred-thirty-two English-speaking children (70 girls and 62 boys, mean age = 79.48 months, *SD* = 3.98) and 75 Greek-speaking children (42 girls and 33 boys, mean age 82.20 months, *SD* = 3.33), whose parents consented to participate in the study, were followed from grade 1 until grade 2. They were all native speakers of English and Greek, respectively. The Canadian children were assessed in April/May of grade 1 and January/February of grade 2 whereas the Cypriot children were assessed in April/May of grade 1 and grade 2, respectively. By grade 2 the sample consisted of 110 English-speaking children (59 girls and 51 boys, mean age = 79.52 months, *SD* = 4.01) and 70 Greek-speaking children (40 girls and 30 boys, mean age 83.06 months, *SD* = 3.35). Twenty-two English-speaking children (16.6% of the sample) and five Greek-speaking children (6.6% of the sample) withdrew from the study. In order to examine if the performance of the children who withdrew from the study differed significantly from the rest of the children, we performed *t* tests on their grade 1 performance scores. None of the *t* tests reached significance for either English-speaking (all *p*s > .12) or Greek-speaking children (all *p*s < .08). Because no significant differences were observed the analyses were conducted with the children who were assessed at both measurement points. The children in both countries were coming mostly from middle-to-upper-middle SES families. None of the children participating in this study were identified as having learning, emotional, or sensory disabilities.

Reading Instruction

Formal instruction in reading in Cyprus, where the data for the Greek-speaking children were collected, begins at the start of grade 1, when children are on average 6 years of age. Early reading instruction involves emphasis on grapheme-phoneme correspondences or other letter combination patterns (i.e., digraphs), while whole language approach is still in use with the intention of building some sight vocabulary. Grammatical and syntactic rules are introduced towards the end of grade 1 and are taught systematically from grade 2 onward. The method of reading instruction in Alberta, where the data for the English-speaking children were collected, places emphasis on both grapheme-phoneme correspondences and on whole-word recognition strategies. This method of reading instruction is known as *Balanced Literacy Program* and it has been thoroughly described in many previous studies (e.g., Sénéchal & LeFevre, 2002; Sénéchal, LeFevre, Thomas, & Daley, 1998). Thus, the two samples experienced comparable instruction in early reading.

Materials

Due to the cross-linguistic nature of the study, we decided to use those phonological awareness, phonological memory, and RAN measures that have been shown in previous studies to be robust predictors of early reading in both English and Greek, and that had similar or comparable versions for both languages. Similarly, we selected the orthographic, non-word reading, and reading fluency tasks in English on the basis that comparable tasks could be developed in Greek.

Phonological Awareness

In English, Phoneme Elision, adopted from the CTOPP (Wagner, Torgesen, & Rashotte, 1999), was used as a measure of phonological awareness. Items were recorded digitally onto a laptop computer and presented through separate speakers. There were three practice items and 24 test items: four test items required the participant to say the word without saying one of the syllables, and the remaining 20 items required the participant to say a word without saying a designated sound in the word. The position of the phoneme to be removed varied across those 20 items; in eight cases it involved the initial phoneme (e.g., *farm* without the /f/ is *arm*); in six cases, the medial phoneme (e.g., *winter* without the /t/ is *winner*), and in six cases, the final phoneme (e.g., *sheep* without the /p/ is *she*). Testing was discontinued after three consecutive errors. The participant's score was the number of correct items. Split-half reliability coefficient in our English-speaking sample was .87.

The Greek version of Phoneme Elision had the same number of items as the English task. However, given that the items after the deletion of a phoneme must produce a real word and that in contrast to the majority of the English words, the typical Greek words are two or more syllables, complete matching of the words in the two languages was impossible. Instead, we devised a list of items that required the children to delete the same sound (initial, medial, final) from the word as it was required from the English-speaking children. Specifically, four test items required the participant to say the word without saying one of the syllables (e.g., *λεμόνι* /lemoni/ (lemon) without the /le/ is *μόνη* /moni/ (alone)), eight test items required the participant to delete the initial phoneme (e.g., *πόλη* /poli/ (town) without the /p/ is *όλοι* /oli/ (all)); six test items required the participant to delete the medial phoneme (e.g., *δίνω* /đino/ (give) without the /n/ is δύο /đio/ (two)), and six test items required the participant to delete the final phoneme (e.g., *ζώα* /zoa/ (animals) without the /a/ is *ζω* /zo/ (live)). Testing was discontinued after three consecutive errors. Split-half reliability coefficient of phoneme elision in our Greek–speaking sample was .89.

Naming Speed

Color Naming. 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. Wolf and Denckla (2005) reported test-retest reliability of Color Naming to be .90. Color Naming in Greek was administered the same way as in English. The corresponding names of colors in Greek are μπλε (*mble*) for blue, μαύρο (*mavro*) for black, πράσινο (*prasino*) for green, κόκκινο (*kokkino*) for red, and κίτρινο (*kitrino*) for yellow. The mean phoneme length for the Greek color names was 5.6, whereas for the English it was 3.6. This difference was significant, $t(8) = 2.54$, $p < .05$.

Digit Naming. 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. Digit Naming in Greek was administered in the same way as in English. The corresponding names of digits in Greek are τέσσερα (*tessera*) for four, επτά (*epta*) for seven, οκτώ (*okto*) for eight, πέντε (*pende*) for five, δύο (*dio*) for two, and τρία (*tria*) for three. The mean phoneme length for the Greek digit names was 4.8, whereas for the English it was 3.6. This difference was not significant, $t(10) = 1.43$, ns.

Phonological Short-Term Memory

Forward Digit Span from WISC-III (Wechsler, 1992) was used to assess phonological short-term memory in both language groups. The strings of digits were presented orally with a time interval about 0.5 second between each digit. The child had to repeat the digits in each string in correct order. The strings started with only two digits, and one digit was added for each new digit string. The task was terminated when the child failed both trials of a given length. The performance score was the number of digit strings that the child could accurately provide. Split-half reliability coefficient for this task in our English-speaking sample was .69, whereas the corresponding reliability coefficient in our Greek-speaking sample was only .51.

Orthographic Processing

The Orthographic Choice task was adapted from the work of Olson and colleagues (e.g., Olson, Forsberg, Wise, & Rack, 1994; Olson, Wise, Conners, Rack, & Fulker, 1989). The students viewed pairs of letter strings that sounded alike (e.g., *rain - rane*) and were asked to circle the one that was spelled correctly. Thirty pairs of phonologically similar letter strings were presented to the children on a sheet of paper. Individual's score was the number of correctly circled real words. Cronbach's alpha reliability coefficient for Orthographic Choice in our English-speaking sample was .80. The Orthographic Choice test in Greek had the same number of items as the English one. However, given that irregularity in Greek orthography can be found only in the spelling of the phonemes /o/, /i/, and /ε/, the selected real words and their pseudohomophones differed only in the way that the aforementioned phonemes were represented (e.g., /σχολε̲ί̲ο/ (school) versus /σχολί̲ο/). Cronbach's alpha reliability coefficient for this task in our Greek-speaking sample was .87.

Nonword Reading

Form H Word Attack from Woodcock Reading Mastery Tests-Revised (WRMT-R) (Woodcock, 1998) was used to assess decoding in grades 1 and 2. Participants were asked to read 45 nonwords presented on a laptop screen as if they were real English words. The number of characters in the English Word Attack task was 215. Testing was discontinued after six consecutive errors. The participant's score was the number of items correct. Split-half reliability coefficient in our sample was .94 for grade 1 and .93 for grade 2, respectively.

Similar to its original version in English, the Greek Word Attack task consisted of 45 pronounceable non-words that were derived from real words after changing two or three letters (either by substituting them or using them backwards). It was originally piloted in a study by Papadopoulos and Georgiou (2000) and was later used in other studies, showing satisfactory psychometric properties in its Greek version with both typically developing populations (e.g., Papadopoulos, 2001) and children exhibiting reading difficulties (e.g., Papadopoulos, Chalarambous, Kanari, & Loizou, 2004). The number of characters in Greek Word Attack task was 218. Testing was discontinued after six consecutive errors. Participant's score was the number of items correct. Split-half reliability coefficient in our sample was .94 in grade 1 and .87 in grade 2, respectively.

Reading Fluency

Gray Oral Reading Test (GORT) (Wiederholt & Bryant, 2001) was used to assess subjects' text-reading fluency. The participants were asked to read as fast and as accurately as possible two short stories whose content was familiar to both North American and Cypriot children. The reading comprehension questions that follow each story were not administered because it was not the intention of this study to examine reading comprehension. An individual's score was the time taken to read the two short stories. Wiederholt and Bryant (2001) reported test-retest reliability for GORT to be .93. The Greek version of this task was a translation/back translation of the English GORT. Thus, although attention was paid to ensure that the words in the translated texts were of the same difficulty level as in English, the length of the task in the two languages was dissimilar. More specifically, the English GORT contained 61 words for a total of 232 characters, whereas the Greek GORT contained 53 words for a total of 281 characters.

Test of Word Reading Efficiency (TOWRE) (Torgesen, Wagner, & Rashotte, 1999) was used to assess subjects' word-reading fluency. 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. The Greek version of this task had the same format as the English one. It consisted of 104 words beginning with one syllable words and ending with three syllable words. However, the Greek version of the task had longer words compared to the English task. More specifically, although the Greek TOWRE contained 644 characters, the English TOWRE contained 607 characters.

Procedure

In grade 1, the children were administered measures of phonological awareness, rapid naming speed, phonological memory, orthographic processing, word decoding, and reading fluency. In grade 2, only the dependent measures of word decoding and reading fluency were administered. All participants were tested individually in their respective schools during school hours by trained experimenters. Testing in grade 1 was divided into two sessions lasting roughly 30 to 40 minutes. The first session consisted of Color Naming, Elision, Digit Naming, and Word Attack.

During the second session Digit Span, Orthographic Choice, TOWRE, and GORT were administered. Half of the participants in each language group received first the first session whereas the other half received first the second session. The order of the tasks within each session and across groups was fixed.

Statistical Analysis

In order to examine the relative strength of different predictors on reading accuracy and fluency both concurrently and longitudinally, we used Structural Equation Modeling (SEM). SEM is a multivariate method for determining the magnitude and influence of one or several presumed causes on one or several presumed effects. Maximum likelihood estimation procedures were used to analyze the variance/covariance matrix of the observed variables using AMOS 7.0 (Arbuckle, 2006). To evaluate model fit, chi-square values and a set of fit indexes were used: (a) the Comparative Fit Index (CFI); (b) the Goodness of Fit Index (GFI); and (c) the Root Mean Square Error of Approximation (RMSEA). Non-significant chi-square, CFI and GFI indices above .95 suggest model acceptance (Hu & Bentler, 1999). RMSEA values below or at .05 indicate a close fit but values as high as .07 are regarded as acceptable (Browne & Cudeck, 1993).

Separate models were constructed with Word Attack, TOWRE, and GORT as the outcome variables. The first step was to estimate the fit of a baseline model, depicted in Figure 1, with all possible correlations between the predictor variables (Elision, Digit Span, RAN-Digits, and Orthographic Choice) and all possible paths from the predictor variables to the outcome variable present in grades 1 and 2 (Word

Attack, TOWRE, and GORT) separately for English and Greek. Age was included as a control variable but it was not allowed to correlate with other predictor variables in the model. Given that the models are close to saturated (i.e., a model coefficient is allocated to almost all of the covariances), we expected that they would provide almost perfect fit to the data (e.g., Hayduk, 1986). To increase the degrees of freedom and to examine whether the most parsimonious well-fitting models are similar in the two languages, non-significant correlations and regression paths were dropped one at a time until all remaining paths in the models were significant. Age was retained in all models as a control variable, even if it was not significantly predicting the reading outcomes.

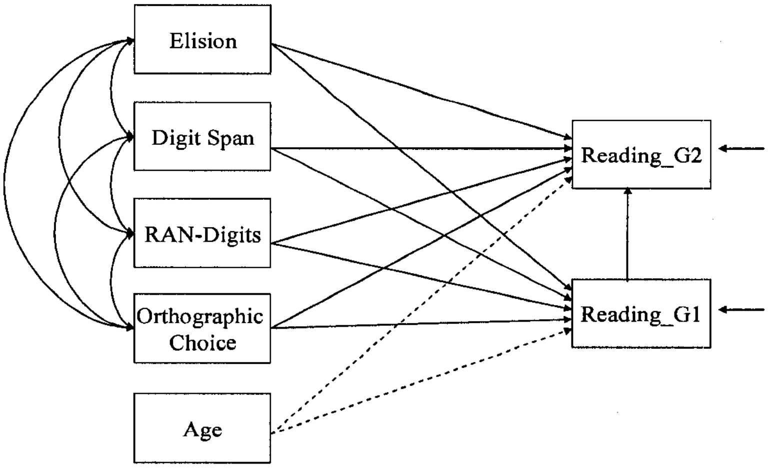


Fig. 4-1. Model of relations between the predictor variables and the reading outcome in grade 2

Next, we examined in more detail the cross-linguistic differences by performing multi-group analyses. To increase the degrees of freedom in the tested models, only those correlations between the predictor variables and paths from the predictor variables to the outcome measures that were significant in one or both of the languages were retained. We then tested first the fit of a multi-group model in which no cross-language constraints were imposed. This was followed by testing the invariance of the regression paths in the two language groups by imposing equality constraints on the direct effects of the predictor variables on Word Attack, TOWRE, and GORT. More specifically, the process of constraining the regression paths was done in a stepwise fashion in which we first constrained the direct effects of Elision on the reading outcomes. In testing for the invariance of the regression paths, we compared the χ^2 value of the constrained model with that of the initial multi-group model in which no cross-language constraints were imposed. If the difference in χ^2 values, given the difference in the degrees of freedom between the two models (*df* constrained – *df* unconstrained), was significant, then this indicated that the specific predictor was contributing in a different way to the outcome variable in the two languages. Next, we examined, one at a time, the invariance of the regression paths of Digit Span, RAN-Digits, and Orthographic Choice on the reading outcomes following the same procedure. Testing for invariance was performed in the same way as described above for Elision.

Results

Preliminary Data Analysis

Descriptive statistics for the entire sample of English and Greek children are shown in Table 4-1. One English- and five Greek-speaking children failed to name all the colors and were not administered the RAN-Colors task. Similarly, two English- and two Greek-speaking children could not complete GORT in grade 1. In order to examine if there were significant differences between the two groups on age, *t* tests were performed. The results revealed that the Greek-speaking children were significantly older than the English-speaking children both in grade 1, $t(178) = 6.13, p < .001$, and in grade 2, $t(178) = 7.02, p < .001$.

Table 4-1

Descriptive Statistics of All the Measures in the Study

	English			Greek		
	N	M	SD	N	M	SD
Elision	110	11.79	5.77	70	14.51	5.45
RAN-Colors	109	1.29	.44	65	1.33	.34
RAN-Digits	110	.61	.22	70	.55	.14
Digit Span	110	6.30	1.55	70	6.04	1.18
OC	110	23.10	4.48	70	22.50	6.01
WAT-G1	110	16.13	9.33	70	38.66	6.50
WAT-G2	110	20.80	8.98	70	41.41	2.97
TOWRE-G1	110	35.48	15.37	70	31.19	11.39
TOWRE-G2	110	47.24	16.08	70	43.49	11.89
GORT-G1	108	77.06	65.90	68	82.64	38.16
GORT-G2	110	46.87	37.20	70	44.07	21.55

Note. OC = Orthographic Choice; WAT = Word Attack; TOWRE = Test of Word Reading Efficiency; GORT = Gray Oral Reading Test; G1 = Grade 1; G2 = Grade 2.

A closer look at the distributional properties of the variables revealed some problems. The rapid naming speed tasks were positively skewed and log transformations were applied in order to reach normality. The distribution of Orthographic Choice was negatively skewed. Reflection plus square root transformation was performed to reach normality. Despite the effectiveness of the transformations, some of the measures were still affected by the presence of outliers. More specifically, performances of three English- and four Greek-speaking children were outliers on RAN-Digits and performances of three English- and two Greek-speaking children were outliers on RAN-Colors. The outliers in both tasks were located at the high end of the distribution indicating slow performance. In order to reduce the possible effect of outliers, their responses were replaced by a value equal to the next highest non-outlier-score plus one unit of measurement (Tabachnick & Fidell, 2001). In this way the rank of the outlier's score within the distribution was preserved without disturbing the distribution either by deleting the score or by retaining it in its original form. The transformed scores were used in all further analyses.

Table 4-2 displays the correlations between the measures used in the study separately for each language group (Greek above the diagonal and English below the diagonal). Generally, we observed a similar pattern of correlations in the two languages regarding the relationship of the independent measures with reading. Rapid naming was more strongly related to reading fluency than to word decoding, and phonological awareness was more strongly related to word decoding than to reading fluency. Orthographic Choice was strongly correlated with both word decoding and fluency measures in both languages. With respect to phonological memory, we observed that Digit Span was more strongly related to different reading measures in English than in Greek. The dependent measures of word decoding and fluency showed high stability from grade 1 to grade 2. Grade 1 Word Attack in Greek correlated .63 with Word Attack in grade 2.

Table 4-2

Correlations Between the Different Measures in the Study

		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1.	Age		.07	-.02	-.08	-.06	.08	.06	.03	.16	.17	-.18	-.18
2.	Elision	.00		-.34**	-.35**	.27*	.31**	.53**	.35**	.36**	.32**	-.33**	-.36**
3.	RAN-Colors	-.23*	-.39**		.51**	-.13	-.06	-.41**	-.34**	-.35**	-.34**	.40**	.35**
4.	RAN-Digits	-.20*	-.45**	.73**		-.14	-.44**	-.46**	-.41**	-.74**	-.64**	.71**	.59**
5.	Digit Span	.00	.52**	-.17	-.24*		.39**	.41**	.25*	.26*	.30*	-.18	-.36**
6.	OC	-.06	.57**	-.32**	-.43**	.44**		.38**	.32**	.66**	.69**	-.67**	-.67**
7.	WAT-G1	-.04	.67**	-.20*	-.39**	.47**	.68**		.63**	.58**	.50**	-.53**	-.50**
8.	WAT-G2	-.01	.70**	-.37**	-.49**	.44**	.67**	.89**		.48**	.51**	-.46**	-.47**
9.	TOWRE-G1	.02	.64**	-.40**	-.56**	.49**	.82**	.77**	.80**		.87**	-.92**	-.83**
10.	TOWRE-G2	.02	.57**	-.46**	-.64**	.40**	.72**	.70**	.79**	.86**		-.85**	-.89**
11.	GORT-G1	.03	-.57**	.42**	.60**	-.44**	-.79**	-.70**	-.75**	-.91**	-.87**		.83**
12.	GORT-G2	.01	-.59**	.42**	.66**	-.43**	-.69**	-.67**	-.75**	-.84**	-.91**	.89**	

Note. Correlations above the diagonal are from the Greek-speaking sample whereas correlations below the diagonal are from the English-speaking sample.
OC = Orthographic Choice; WAT = Word Attack; TOWRE = Test of Word Reading Efficiency; GORT = Gray Oral Reading Test; G1 = Grade 1; G2 = Grade 2.
* $p < .05$. ** $p < .01$.

The corresponding correlation in English was .89. Grade 1 TOWRE and GORT in Greek correlated .87 and .83 with TOWRE and GORT in grade 2. The corresponding correlations in English were .86 and .89, respectively.

Predictors of Word Decoding

In order to examine the predictors of word decoding, the baseline model (Figure 1) was fitted to the data with grade 1 and grade 2 Word Attack scores as the dependent variables. RAN-Digits was used as a measure of rapid naming speed because, in both languages, it produced generally larger correlations with the dependent variables than RAN-Colors. As was expected on the basis of the small number of degrees of freedom, the model fitted the data very well (χ^2 (4, N = 110) = .62, p = .892, CFI = 1.00, GFI = .99, RMSEA = .00, for English, and χ^2 (4, N = 70) = 1.44, p = .838, CFI = 1.00, GFI = .99, RMSEA = .00, for Greek, respectively).

Next, we deleted one at a time the non-significant paths to produce the most parsimonious model in which Word Attack was the dependent variable in each language. Figure 2 shows the final models. The models provided a good fit to the data (χ^2 (7, N = 110) = 3.48, p = .837, CFI = 1.00, GFI = .99, RMSEA = .00, for English, and χ^2 (10, N = 70) = 5.45, p = .859, CFI = 1.00, GFI = .97, RMSEA = .00, for Greek, respectively), and accounted for a moderate proportion of the variance in grade 1 (English: R^2 = .58; Greek: R^2 = .41) and a high proportion of the variance in grade 2 for English (R^2 = .83), but not for Greek (R^2 = .38). There were two significant predictors of grade 1 Word Attack in English – Elision (β = .418) and Orthographic Choice (β = .439) – and three significant predictors of grade 1 Word Attack in Greek – Elision (β = .350), Digit Span (β = .274), and RAN-Digits (β = -.316). Not surprisingly, there was a strong autoregressive path from Word Attack in grade 1 to Word Attack in grade 2 in both languages. However, even after controlling for the autoregressive effect, Elision ($\beta = .142$) and RAN-Digits ($\beta = -.141$) measured in grade 1 were significant predictors of Word Attack in grade 2 in English. In Greek, Word Attack in grade 1 was the only significant predictor of Word Attack in grade 2. It should be noted that given the strong autoregressive effect in both languages, the evaluation of other longitudinal predictors of grade 2 Word Attack is highly conservative.

After establishing the most parsimonious model for each language separately, we used multi-group analyses to examine if there were any differences across the two languages in the significant predictors of Word Attack. The unconstrained multi-group model included all paths that were significant in either or both of the models shown in Figure 2 and fitted the data very well (χ^2 (10, $N = 170$) = 3.87, $p = .953$, CFI = 1.00, GFI = .99, RMSEA = .00).

Table 4-3 presents the changes in χ^2 values when different predictors of interest were constrained to be equal across the languages. The fit of the multi-group model deteriorated significantly when the direct effects of Elision ($\Delta\chi^2 = 8.79$, $p < .01$) or Orthographic Choice ($\Delta\chi^2 = 18.33$, $p < .001$) on grade 1 Word Attack were constrained to be equal across the two languages. In contrast, when the direct effects of Digit Span or RAN-Digits were constrained to be equal across languages, there were no significant changes in model fit. For Word Attack in grade 2, only constraining the direct effects of Elision ($\Delta\chi^2 = 4.92$, $p < .05$) and Word Attack in grade 1 ($\Delta\chi^2 = 6.09$, $p < .05$) resulted in a significantly poorer fitting model.

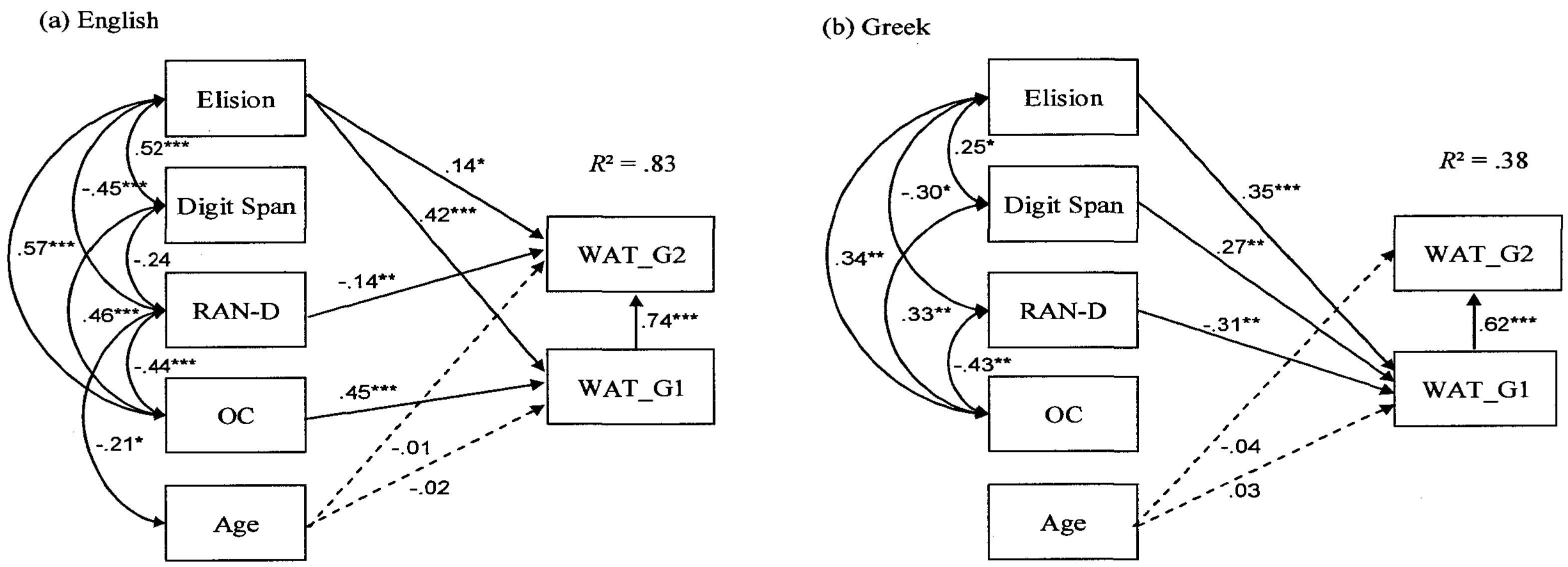


Fig. 4-2. The baseline path model of predictors of Word Attack in grade 2 in English (a) and Greek (b).

Table 4-3

Changes in χ^2 After Constraining Paths to be Equal Across Language Groups

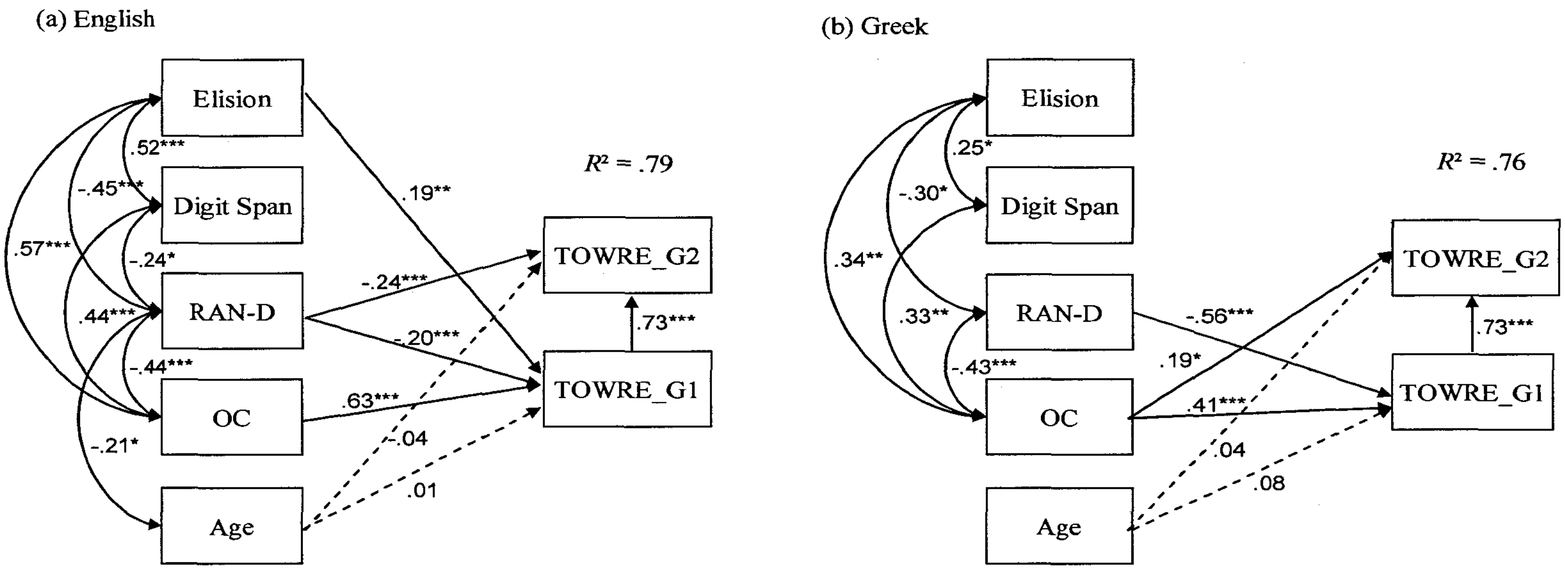
	Grade 1			Grade 2		
	WAT	TOWRE	GORT	WAT	TOWRE	GORT
$EL_E = EL_G$	8.79**	4.98*	--	4.92*	--	--
$DS_E = DS_G$	.12	--	--	--	--	--
$\text{RAN-D}_E = \text{RAN-D}_G$	1.33	8.15**	.55	2.36	6.86**	4.29*
$OC_E = OC_G$	18.33**	10.93**	11.75**	--	.29	3.38
$\text{WAT\_G1}_E = \text{WAT\_G1}_G$	--	--	--	6.09*	--	--
$\text{TOWRE\_G1}_E = \text{TOWRE\_G1}_G$	--	--	--	--	.31	--
$\text{GORT\_G1}_E = \text{GORT\_G1}_G$	--	--	--	--	--	.49
All Direct Effects Equal	48.97***	23.36***	12.34*	24.72***	8.51*	10.21*
All Indirect Effects Equal	--	--	--	31.15***	23.36**	12.59**

Note. WAT = Word Attack, TOWRE = Test of Word Reading Efficiency; GORT = Gray Oral Reading Test; EL = Elision; DS = Digit Span; RAN = Rapid Automatized Naming; OC = Orthographic Choice.
$_E$ = English; $_G$ = Greek.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Thus, these results indicate that Elision is a stronger predictor, both concurrently and longitudinally, of Word Attack in English than in Greek. Orthographic Choice, in turn, is a strong concurrent predictor of grade 1 Word Attack only in English. Finally, the autoregressive effect of grade 1 Word Attack on grade 2 Word Attack was stronger in English than in Greek.

Predictors of Word-Reading Fluency

The second set of analyses examined the predictors of TOWRE in grade 1 and grade 2. The baseline models fitted the data very well (χ^2 (4, N = 110) = .63, p = .890, CFI = 1.00, GFI = 1.00, RMSEA = .00, for English, and χ^2 (4, N = 70) = 1.48, p = .829, CFI = 1.00, GFI = .99, RMSEA = .00, for Greek, respectively). The most parsimonious model in each language is shown in Figure 3. The models provided a good fit to the data (χ^2 (7, N = 110) = 3.45, p = .840, CFI = 1.00, GFI = .99, RMSEA = .00, for English, and χ^2 (10, N = 70) = 3.93, p = .950, CFI = 1.00, GFI = .98, RMSEA = .00, for Greek, respectively) and accounted for a high proportion of the variance in grade 1 TOWRE (English: R^2 = .75; Greek: R^2 = .68) and grade 2 TOWRE (English: R^2 = .79; Greek: R^2 = .76). There were three significant predictors of grade 1 TOWRE in English – Elision (β = .188), RAN-Digits (β = -.204), and Orthographic Choice (β = .629) – and two unique predictors of grade 1 TOWRE in Greek – RAN-Digits (β = -.559), and Orthographic Choice (β = .408). Longitudinally, there was a strong autoregressive path from grade 1 TOWRE to grade 2 TOWRE for both English and Greek. Despite the strong autoregressive effect, RAN-Digits in English (β = -.245) and Orthographic Choice in Greek (β = .194) accounted for additional variance in grade 2 TOWRE.


(a) English

(b) Greek

Fig. 4-3. The baseline path model of predictors of TOWRE in grade 2 in English (a) and Greek (b).

Next, we examined the cross-linguistic differences in the predictors of TOWRE. The unconstrained multi-group model (χ^2 (12, *N* = 170) = 5.23, *p* = .950, CFI = 1.00, GFI = .99, RMSEA = .00) included all paths that were significant in either or both of the models shown in Figure 3. When the direct effects of Elision ($\Delta\chi^2$ = 4.98, $p < .05$), RAN-Digits ($\Delta\chi^2$ = 8.15, $p < .01$), or Orthographic Choice ($\Delta\chi^2$ = 10.93, $p < .01$) on grade 1 TOWRE were constrained to be equal across the two languages the model fit deteriorated significantly. When the direct effect of RAN-Digits ($\Delta\chi^2$ = 6.86, $p < .05$) on grade 2 TOWRE was constrained to be equal, the model fit also deteriorated significantly whereas the same was not true when the effect of Orthographic Choice or grade 1 TOWRE was constrained. Thus, the findings of these analyses indicate that concurrently RAN-Digits exerts a significantly stronger effect in Greek than in English, and that Elision and Orthographic Choice were stronger predictors of grade 1 TOWRE in English than in Greek.

Predictors of Text-Reading Fluency

The final set of analyses examined the predictors of GORT in grade 1 and grade 2. The baseline models fitted the data very well (χ^2 (4, *N* = 110) = .63, *p* = .890, CFI = 1.00, GFI = 1.00, RMSEA = .00, for English, and χ^2 (4, *N* = 70) = 1.48, *p* = .829, CFI = 1.00, GFI = .99, RMSEA = .00, for Greek, respectively). Figure 4 presents the most parsimonious model for each language. The models provided a good fit to the data (χ^2 (7, *N* = 110) = 4.45, *p* = .726, CFI = 1.00, GFI = .99, RMSEA = .00, for English, and χ^2 (10, *N* = 70) = 6.75, *p* = .748, CFI = 1.00, GFI = .98, RMSEA = .00, for Greek, respectively), and accounted for a high proportion of the variance in grade 1 (English: R^2 = .75; Greek: R^2 = .69) and in grade 2 (English: R^2 = .82; Greek: R^2 = .71).

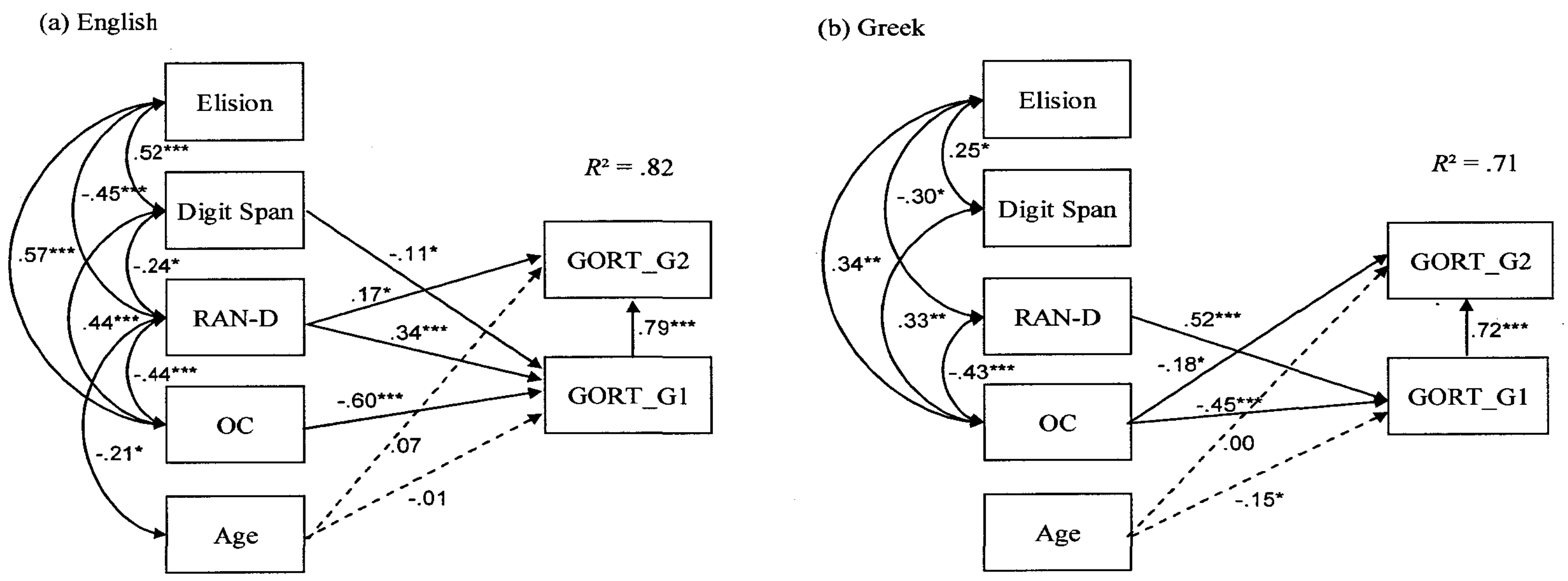


Fig. 4-4. The baseline path model of predictors of GORT in grade 2 in English (a) and Greek (b).

For both English and Greek, RAN-Digits ($\beta = .355$, for English and $\beta = .520$, for Greek, respectively) and Orthographic Choice ($\beta = -.648$, for English and $\beta = -.445$, for Greek, respectively) were the unique predictors of GORT in grade 1. Longitudinally, there was a strong autoregressive path from GORT in grade 1 to GORT in grade 2. After this autoregressive effect was controlled, RAN-Digits in English ($\beta = .173$) and Orthographic Choice in Greek ($\beta = -.177$) predicted additional unique variance in grade 2 GORT.

Finally, we examined if there were any differences in the significant predictors of GORT across the two languages. The unconstrained multi-group model (χ^2 (12, N = 170) = 8.91, $p = .711$, CFI = 1.00, GFI = .99, RMSEA = .00) included all paths that were significant in either or both of the models shown in Figure 4. A significant change in model fit was observed when the effect of Orthographic Choice ($\Delta\chi^2 = 11.75$, $p < .01$) on grade 1 GORT was constrained to be equal across the two languages. Similarly, constraining the path between RAN-Digits and grade 2 GORT produced a significant change in the model fit ($\Delta\chi^2 = 4.29$, $p < .05$). Thus, similar to what we observed for TOWRE, Orthographic Choice was a better predictor of grade 1 GORT in English than in Greek. In addition, RAN-Digits was a better predictor of grade 2 GORT in English than in Greek.

To summarize, the results of the structural equation modeling demonstrate that there are significant differences in both the number of significant predictors and the strength of the predictors of reading across languages. First, Elision appears to predict Word Attack better than it predicts TOWRE or GORT, and its contribution is greater in English than in Greek. Second, Digit Span was in most models a non-significant predictor of reading outcomes (with the exception of grade 1 Word Attack in Greek and grade 1 GORT in English) and this pattern was the same across languages. Third, RAN-Digits was a stronger predictor of the reading fluency measures than of Word Attack. Notably, its effect in TOWRE in grade 1 was stronger in Greek than in English. However, only in English did RAN-Digits have a direct effect on grade 2 TOWRE and GORT. Fourth, Orthographic Choice was a stronger predictor of grade 1 reading outcomes in English than in Greek. However, only in Greek did Orthographic Choice have a direct effect on grade 2 TOWRE beyond the contribution of the autoregressor. Finally, much more similarities in the predictors across languages were observed in the reading fluency models than in the word decoding models.

Total Effects on Word Attack, TOWRE, and GORT in Grade 2

On several occasions, the above analyses indicated that the timing of the most significant effects may vary across the languages creating an appearance of significant differences that may be short-lived. For example, in the TOWRE and GORT models for Greek-speaking children RAN-Digits strongly predicted grade 1 reading performance but not grade 2 performance after the autoregressive effect was controlled. In contrast, the similar models for the English-speaking children indicated that RAN-Digits predicted moderately both grade 1 and grade 2 reading outcomes. The opposite pattern, however, was observed for Orthographic Choice. These results leave open the possibility that in spite of initial significant differences between the languages, the total effect (the sum of direct (unmediated) and indirect (mediated) effects) of RAN-Digits to grade 2 reading fluency may be very similar.

To obtain estimates of total effects, the SEM analysis model displayed in Figure 1 was fitted to the data three times for each language, first with grade 2 word decoding accuracy (Word Attack) as the dependent variable, and then with word reading fluency (TOWRE), and text reading fluency (GORT) scores as the dependent variables, respectively.

Table 4-4 shows the standardized estimates of the total effects of Elision, RAN-Digits, Digit Span, and Orthographic Choice on grade 2 Word Attack, TOWRE, and GORT in English and Greek. These estimates indicate that Elision had the highest impact on Word Attack in English. In contrast, RAN-Digits had the highest impact on Word Attack in Greek. In addition, Orthographic Choice made a contribution to Word Attack in English but not in Greek.

Table 4-4

Total Effects of Elision, RAN-Digits, Digit Span, and Orthographic Choice on Grade 2 Word Attack, TOWRE, and GORT

	English[a]			Greek[b]		
	WAT	TOWRE	GORT	WAT	TOWRE	GORT
Elision	.414	.085	-.103	.173	-.002	-.055
RAN-Digits	-.143	-.395	.426	-.298	-.404	.343
Digit Span	.024	.044	-.096	.129	.070	-.130
OC	.367	.484	-.405	.076	.467	-.439

Note. WAT = Word Attack, TOWRE = Test of Word Reading Efficiency; GORT = Gray Oral Reading Test; OC = Orthographic Choice.
[a] *N* = 110; [b] *N* = 70.

The reading fluency measures were clearly affected most by RAN-Digits and Orthographic Choice, and the contributions of these two predictors were comparable in English and Greek. Digit Span made a relatively small contribution to the dependent variables in both languages. Taken together with the SEM results presented above, we can conclude that there are differences in the predictors of reading in the two languages. These differences are more obvious for word decoding than for reading fluency measures, and they are more prominent in the contributions of Elision and Orthographic Choice than in the contributions of Digits Span and RAN.

Discussion

The primary objective of this study was to examine the concurrent and longitudinal predictors of word decoding and reading fluency in children learning to read an orthographically consistent language (Greek) and in children learning to read an orthographically inconsistent language (English). We found that there were not only similarities but also differences in the predictors and the magnitude of their influence across languages and across type of reading outcome.

Phonological awareness, measured with Elision, was found to contribute significantly to the prediction of English Word Attack in grades 1 and 2 and in grade 1 TOWRE. Elision was also a significant predictor of grade 1 Word Attack in Greek. However, as indicated by the results of the multi-group analyses, phonological awareness was more important in predicting Word Attack and TOWRE in English than in Greek. These results provide support for arguments that reading development in consistent orthographies imposes less demands on phonological awareness than reading development in inconsistent orthographies (e.g., Goswami, 1999; Mayringer et al., 1998; Landerl, 2006; Mann & Wimmer, 2002; Wesseling & Reitsma, 2000; Wimmer et al., 1994).

RAN-Digits predicted significantly grade 1 Word Attack only in Greek, but the difference with the English model was not significant. When reading fluency measures were used as dependent variables, RAN-Digits made a significant contribution in both languages. Notably, RAN-Digits effect on grade 1 TOWRE was larger in Greek than in English, but only in English did RAN-Digits have a direct effect in grade 2 TOWRE and GORT over and beyond the contribution of the autoregressors. These findings are in line with the findings of previous studies showing that RAN is a reliable predictor of reading fluency (e.g., Bowers, 1995; Georgiou et al., 2006; Katzir et al., 2006; Savage & Frederickson, 2005; Schatschneider et al., 2002), that it is likely exerting its influence early on in reading development (e.g., de Jong & van der Leij, 2002; Compton, 2003; Wagner et al., 1997), and that it might be a stronger predictor of reading accuracy in orthographically consistent languages than in orthographically inconsistent languages (e.g., Mann & Wimmer, 2002; Wimmer et al., 2000).

Our findings shed also some light on Patel and her colleagues' (2004) results that RAN, measured with colors, animals, and objects, was not a significant predictor of reading across languages. Similarly, when we repeated the SEM analyses with RAN-Colors in the place of RAN-Digits, we found that RAN-Colors was significantly predicting word decoding and reading fluency in Greek, but not in English, and constraining the regression weights to be equal across languages resulted in a non-significant change in the χ^2 value. The fundamental question of why RAN-Digits is a stronger predictor of reading ability than RAN-Colors remains to be resolved.

Recently, Bowey, McGuigan, and Ruschena (2005) showed that the robust association between alphanumeric RAN tasks (digit and letter naming) and reading within their fourth-grade sample was largely mediated by phonological processing and that relative to non-alphanumeric RAN tasks (color and object naming), alphanumeric RAN better assesses an underlying phonological processing ability that is common to word reading ability. Correlations in Table 4-2 indicate that for English-speaking children, RAN-Digits did indeed show higher correlations with Elision than RAN-Colors. However, the same pattern of relationships was not evident in the Greek-speaking sample. What RAN tasks measure and why they are related to reading are clearly questions that warrant further investigation.

The third component of phonological processing, phonological memory, contributed significantly only when predicting grade 1 word decoding in Greek. This result may reflect the fact that the last few items in Word Attack in Greek were relatively long, and therefore, retaining phonological information in short-term memory would have been helpful for successful blending and naming to take place. Nevertheless, the results of multi-group analysis indicated that the difference between the regression weights in the two languages were not statistically significant. Thus, our results are in line with those reported recently by Caravolas and her colleagues (2005). In their study, general IQ and Digit Span were the only non-significant predictors of reading speed and spelling in English and Czech. Likewise, there are a number of studies conducted in various languages showing that phonological memory is only weakly correlated with reading ability (e.g., de Jong & van der Leij, 1999; Dufva, Niemi, & Voeten, 2001; Muter & Snowling, 1998; Parrila et al., 2004; Scarborough,

1998) and that compromised phonological memory does not constrain the acquisition of reading skills (e.g., Gathercole, Tiffany, Briscoe, Thorn, & The ALSPAC team, 2005; Porpodas, 1999).

Orthographic processing was a robust predictor of word decoding in English and reading fluency in both languages. This finding is particularly important in light of arguments regarding the preferred strategy in word decoding across languages that vary in orthographic consistency (Ziegler & Goswami, 2005, 2006). Several researchers have argued that children who are learning to read an orthographically consistent language, such as Greek or German, rely heavily on grapheme-phoneme decoding strategies (e.g., Aro & Wimmer, 2003; Ellis et al., 2004; Goswami, 2002; Harris & Giannouli, 1999; Havelka & Rastle, 2005; Landerl, 2006). In these languages, phonological recoding can reliably operate at the smallest grain size because the mapping of graphemes onto phonemes is relatively unambiguous. In contrast, children who are learning to read an orthographically inconsistent language, such as English, are forced to use a variety of decoding strategies (e.g., Decker, Simpson, Yates, & Locker, 2003; Goswami, 2002; Goswami, Porpodas, & Wheelwright, 1997; Landerl, 2000; Seymour, 2005; Wimmer & Goswami, 1994; Ziegler et al., 2001). Our findings support these arguments in terms of decoding accuracy. In English, the best predictors of word decoding were phonological awareness and orthographic processing. In Greek, the best predictor of word decoding was RAN, and orthographic processing did not contribute significantly. The significant effect of orthographic processing on Word Attack in English may also reflect the fact that many of the Word Attack items in English have common letter patterns that can be decoded as orthographic units rather than letter-by-letter.

To the extent that the orthographic processing measure used in this study captured the use of larger orthographic units, the results of this study support the argument that readers in English rely on both small and large grain size units to decode compared to their Greek counterparts (e.g., Goswami, 1999; Goswami et al., 1997; Ziegler & Goswami, 2005). Importantly, although orthographic processing did not predict word decoding in Greek, it did predict significantly reading fluency in both grades 1 and 2 and even when the autoregressor's effect was controlled. This finding suggests that Greek-speaking children made use of their orthographic knowledge only when there was a need for a speeded response.

Our findings provide an extension to Ziegler and Goswami's (2005) psychological grain size theory (PGST) by providing an account of how grain size theory may be used to explain the rapid attainment of reading fluency in consistent orthographies. Recently, de Jong (2006) and Wimmer (2006) criticized PGST for its explicit focus on the development of reading accuracy. Specifically, Wimmer (2006) argued that "learning to read (*as viewed in PGST*) is more or less equated with acquisition of recoding accuracy" (p. 447) and went on to propose that one possibility for PGST to accommodate reading fluency attainments would be to postulate a developmental trend from relying on small to relying on large grain sizes.

However, it may also be the case that, with development, speed of processing small grain size units becomes automatic and this *per se* leads to better performance in fluency tasks. If children learning to read a consistent orthography receive positive feedback from effective use of phonological recoding in word identification, then they may as well rely on the same grain size for efficient reading fluency. This, in turn, would result in word length effects. Indeed, Ziegler et al. (2001) demonstrated that German adult readers exhibited strong length effects for words and nonwords compared to their English-speaking Australian counterparts. Prompted by this finding Ziegler and his colleagues concluded that "orthographic consistency determines not only the relative contribution of orthographic versus phonological codes within a given orthography, but also the preferred grain size of units that are likely to be functional during reading" (p. 379). However, evidence from eye-movement studies and word naming in Italian (a consistent orthography) challenges this conclusion (Barca, Burani, Di Filippo, & Zoccolotti, 2006; Burani, Marcolini, & Stella, 2002; Orsolini et al., 2006; Zoccolotti, De Luca, Di Pace, Gasperini, Judica, & Spinelli, 2005). For example, Spinelli, De Luca, Di Filippo, Mancini, Martelli, and Zoccolotti (2005) reported that Italian fourth grade children did not show a length effect for reading words from three to five letters. In adult readers the effect remained absent up to eight letters. The absence of a length effect in high frequency words may imply that during the development of reading a serial sub-lexical word reading strategy is supplemented by a more parallel lexical strategy. Evidence also from Dutch studies (e.g., Coenen, van Bon, & Schreuder, 1997; Geudens & Sandra, 1999) suggests that children, after few months of reading instruction, may use an orthographic strategy in reading words aloud.

A third possibility is that children in consistent orthographies demonstrate flexibility in using different grain size units depending on task demands. On the one hand, in timed conditions when a response must be generated quickly, large grain size units are likely to be employed. On the other hand, in untimed conditions when maximum accuracy is desirable, phonological recoding is likely to be employed. Our findings provide evidence in support of this explanation. In word decoding Greek-speaking children relied on small grain size units as indicated by the significant effect of phonological awareness. In contrast, in reading fluency tasks Greek-speaking children relied on large grain size units as indicated by the significant effect of orthographic processing. Thus, it is conceivable that Greek-speaking children adjust the grain size units to match the task demands. When no speed is required there is a reliance on phonological recoding and when a speeded response is needed, bigger grain size units are employed. Based on these observations, we can argue that even in consistent orthographies, two routes of pronunciation assembly are necessary to describe the reading process, but the activation of each route relies upon the demands of the reading task.

Limitations

Despite the importance of our findings, there are some limitations that should be acknowledged. First, our findings can be generalized only to the languages under investigation and for the ages of the participants we had in our sample. Greek has been used by many researchers as an example of a transparent orthography (e.g., Goswami et al., 1997; Landerl, 2000; Seymour, Aro, & Erksine, 2003) but there are still objections to this conceptualization (e.g., Miles, 2000). To the extent that the purpose of this study was to identify differences in processes involved in reading in a consistent orthography and in an inconsistent orthography, then using Greek might not have been an optimal solution compared to languages such as Finnish or Turkish, which are considered close to 100% consistent.

Second, the reading accuracy and fluency tasks were not strictly matched in the two languages. Greek and English belong to different families of languages and have different orthographic and phonological characteristics. For example, there is a large body of short single syllable words in English, whereas there is only a small number of such words in Greek. Given the number of single-syllable words used in existing reading tests in English (see e.g., Woodcock Reading Mastery Tests-Revised; Woodcock, 1998), it is not possible to construct word reading tasks in Greek that would be strictly parallel in terms of length and word frequency to the English ones. On the other hand, using more multi-syllabic words in English likely will not create an equal task because of significant differences in the syllable structures between Greek and English.

Third, we should acknowledge the whole-word nature of the orthographic processing task used in our study. Ideally, grain sizes bigger than graphemes, and yet smaller than words, should also be tested. Perhaps a task like *Word Likeness* in which individuals are asked to select the letter string that looks like a real word in English from a pair of pronounceable nonwords (e.g., *filk* - *filv*) should be added to the existing set of tasks. In that case we would have more convincing evidence that orthographic knowledge (lexical and sub-lexical) predicts reading differently in languages varying in orthographic consistency.

Fourth, similar to many previous studies (e.g., Holland et al., 2004; Leppänen et al., 2006; Parrila et al., 2004; Schatschneider et al., 2002), we did not include any measures of general cognitive ability in our study. Although frequently used, controlling for general cognitive ability can also be ill advised unless the relationship between the chosen general ability measure and other included predictors is well understood. As pointed out by Parrila et al. (2004), an additional problem arises when general cognitive ability is operationalized as a vocabulary measure, as it is likely that vocabulary is differentially related to various phonological processing abilities (e.g., Avons, Wragg, Cupples, & Lovegrove, 1998; Baddeley, Gathercole, & Papagno, 1998; Metsala, 1999). Furthermore, other cross-linguistic studies have indicated that IQ does not contribute significantly to reading speed (e.g., Caravolas et al., 2005). Finally, we made sure that the children who participated in this study were able to understand and execute the instructions given to them and that none of them was known to have any developmental disabilities.

Finally, we used observed variables instead of latent variables in the SEM analyses. When relationships among latent variables are examined, the relationships are free of measurement error because the error can be estimated and removed, leaving only common variance. On the other hand, SEM analyses using observed variables assume that the measures have perfect reliability coefficients, which clearly is not the case.

Conclusions

The findings of our study add to a small but growing body of research that directly compares children learning to read in two different languages varying in orthographic consistency, and suggest that both phonological and orthographic processing skills are important in early reading acquisition. However, at least at the early stages of reading development, the effects of these predictor variables are moderated by the characteristics of the language, a conclusion that is based on the differential effects of phonological awareness and orthographic processing on word decoding and reading fluency measures. Although some of the differences might be short-lived (see Table 4-4), our findings challenge Patel and colleagues' (2004) suggestion that "to the extent that alphabetic languages map orthography to phonology, the predictors of reading performance are likely to be universal" (p.794). In contrast, we argue that the orthography children are learning to read is an important factor that needs to be taken into account when models of reading development are being generalized across languages. By considering the differences between language systems, cross-linguistic studies can be a powerful tool in our attempt to understand both universal and language-specific processes involved in reading acquisition.

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V. GENERAL DISCUSSION

A plethora of studies have examined the role of phonological as well as "extra-phonological" factors on reading acquisition. The studies converge on the conclusion that phonological awareness is necessary for an effortless development of early reading skills, but not sufficient (Catts & Kamhi, 1999; Scarborough, 1998a; Share & Stanovich, 1995; Stanovich, 1992). RAN, the ability to rapidly name visually presented familiar symbols, has evolved as a promising additional precursor of reading ability, accounting for a significant amount of variance over and above what is explained by phonological awareness (Wolf & Bowers, 1999).

Despite the improved understanding of RAN and its relation to reading, Kirby, Parrila, and McQuarrie (2003) pointed out that studies vary greatly as to when phonological awareness and RAN are measured, what and how many 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. The purpose of this dissertation was to address some of these unresolved issues by examining the role of RAN (alphanumeric and non-alphanumeric) within and across languages, concurrently and longitudinally, and in the presence of other known correlates of reading acquisition.

Understanding the nature of RAN and why it is related to reading has both theoretical and practical implications. In terms of theory, we need to gain a better understanding of what processes develop within RAN, what processes different RAN tasks share and to what extent, and which of these processes account for RAN's relationship with reading measures. From the practical point of view, more elaborate RAN-specific information can assist in improving the existing intervention programs (e.g., de Jong & Vrielink, 2004; Thaler, Ebner, Wimmer, & Landerl, 2004; Wolf, Miller, & Donnelly, 2000).

Several different proposals have been put forward to account for the relationship between RAN and reading. For example, it has been suggested that slowness in identifying letters makes it difficult for children to relate letters to their sounds fast enough to establish a 'sight vocabulary' – a store of representations of words learned through repeated reading that are instantly recognized on sight (e.g., Bowers & Wolf, 1993). Alternatively, there have been suggestions that RAN deficits merely provide additional evidence that children with reading difficulties have problems with any tasks that involve phonology (e.g., Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997). Others have suggested that RAN deficits reflect a more general difficulty in speed of processing – that is, in the speed with which any kind of mental operation can be performed (e.g., Kail & Hall, 1994).

Despite the different explanations, and regardless of convincing evidence that slow RAN performance is a persistent characteristic shared by many poor readers even in adulthood (e.g., Birch & Chase, 2004; Parrila, Georgiou, & Corkett, 2007; Vukovic, Wilson, & Nash, 2004), there is still no unequivocal evidence about which of the several mental operations involved in RAN are problematic and cause slow performance.

RAN Components and Reading

One of the approaches employed in order to delineate why RAN is related to reading is to tease apart RAN total time into its constituent components of articulation time and pause time. Researchers have tended to agree that pause time is the key component that is responsible for the RAN-reading relationship (e.g., Cobbold, Passenger, & Terrell, 2003; Georgiou, Parrila, & Kirby, 2006; Neuhaus, Foorman, Francis, & Carlson, 2001) and that the role of articulation time is less central. However, with the exception of a single study (Clarke, Hulme, & Snowling, 2005), the existing studies fall short in examining pause time in relation to other cognitive processing skills, such as phonological awareness and orthographic processing. Thus, the purpose of the study presented in Chapter II was to examine (a) how RAN components – articulation time and pause time – predict reading accuracy and reading fluency in grades 2 and 3, and (b) how RAN components are related to measures of phonological awareness, orthographic knowledge, and speed of processing.

Regarding the first question, the results showed that RAN pause time, but not articulation time, was more strongly related to reading fluency measures than to reading accuracy measures and that although the relationship with reading accuracy measures tended to decrease from grade 2 to grade 3, the correlations with reading fluency remained stable. The components were rather weakly, and in most instances non-significantly, related to pseudoword reading. Notably, the concurrent correlations between the RAN components and word reading accuracy measures were low (perhaps unusually low) and non-significant. A possible explanation may be the participants' performance on the reading accuracy measures, which was beyond grade level. More specifically, the mean group performance on Word Identification in grades 2 and 3 was equal to a grade equivalent (GE) of 2.7 and 4.4, respectively. Likewise, the mean group performance on Word Attack in grades 2 and 3 was equal to a GE of 3.8 and 5.1, respectively. According to some researchers, RAN is not a good predictor of reading in groups of average or above-average readers (e.g., McBride-Chang & Manis, 1996; Savage, Frederickson, Goodwin, Patni, Smith, & Tuersley, 2005). The participants in this study were generally good readers, a fact that may have contributed to lower than usual correlations between RAN and reading accuracy measures.

With respect to the second question, the results showed that articulation time was not significantly related to any cognitive processing skills measure at any time of measurement. On the other hand, the relationship between pause time, phonological awareness, and orthographic knowledge was subject to the effects of grade level. Specifically, the concurrent correlations between RAN pause time and orthographic knowledge tended to increase across time whereas the concurrent correlations between RAN components and phonological awareness tended to decrease across time. Unfortunately, a speed of processing measure was available only in grade 3 and, therefore, no arguments regarding the effects of grade level can be made. Nevertheless, the concurrent correlation between pause time and speed of processing was not significant. This finding suggests that speed of processing cannot be the underlying cause of the RAN-reading relationship.

RAN and Reading Across Languages

The relationship between RAN and reading has been established in many alphabetic (e.g., *Dutch*: de Jong & van der Leij, 1999; *English*: Compton, 2003; Parrila, Kirby, & McQuarrie, 2004; Savage & Frederickson, 2005; *Finnish*: Lepola, Poskiparta, Laakkonen, & Niemi, 2005; *German*: Wimmer & Mayringer, 2001; *Greek*: Nikolopoulos, Goulandris, Hulme, & Snowling, 2006; and *Italian*: Di Filippo et al., 2005) and non-alphabetic (e.g., *Chinese*: Ho & Lai, 1999; McBride-Chang & Kail, 2002; *Japanese*: Kobayashi, Haynes, Macaruso, Hook, & Kato, 2005; and *Korean*: Cho & McBride-Chang, 2005) languages. Despite several single-language studies that have examined the relationship between RAN and reading, to date, there are no cross-linguistic studies that have examined if the strength of this relationship is the same across languages and types of reading outcomes, and, most importantly, whether RAN is related to reading for the same reason(s) across languages. Thus, Study II (see Chapter III) sought to examine the RAN-reading relationship in three languages, namely Chinese, English, and Greek that vary widely in orthographic consistency.

As pointed out in the Introduction, examining the contribution of RAN across languages that vary in orthographic consistency is another way to test the existing theoretical accounts of RAN-reading relationship. For example, Manis, Seidenberg, and Doi (1999) argued that the critical property of RAN is that the visual stimuli in the task have to be mapped rapidly to their names, and that these mappings are arbitrary.

If Manis and his colleagues' hypothesis is correct, then we should observe stronger correlations between RAN and reading in Chinese than in English, and, in turn, stronger correlations in English than in Greek on the basis of the fact that Chinese has the most arbitrary symbol-sound mappings, whereas Greek has the most consistent symbol-sound mappings. Interestingly, we failed to detect any significant differences across languages, despite the fact that some differences were relatively large (i.e., the difference in the correlations between RAN and reading accuracy in Chinese and RAN and reading accuracy in English).

When the contribution of the RAN components was examined across languages, an interesting pattern of relationships was observed. On one hand, the contribution of articulation time generally increased with increasing orthographic consistency. On the other hand, the contribution of pause time generally increased with increasing orthographic inconsistency. Surprisingly, pause time in Greek accounted for only a small proportion of variance in reading accuracy and for no variance in reading fluency. In Greek, RAN was related to reading because of the unique contribution of articulation time and of the component shared between articulation time and pause time, which likely reflects speed of processing involved in rapid execution of both components.

Taken together, the findings of this study suggest that a universal explanation of why RAN is related to reading may be far from becoming a reality. Beyond a foundational level of speed of processing effects, RAN may be related to reading for different reasons across languages. Wolf and Bowers (1999) argued that RAN represents a demanding array of attentional, perceptual, conceptual, memory, lexical, and articulatory processes that places heavy emphasis on precise timing requirements within each subprocess and across all subprocesses. If pause time is likely not critical for reading in Greek, then Wolf and Bowers' (1999) theoretical naming model may not generalize to this language or to languages with similar orthographic characteristics. Future studies should try to replicate these findings with a larger sample size and with different age groups.

Phonological and Orthographic Processing Skills as Predictors of Reading in English and Greek

It has been argued that cross-linguistic studies are indispensable for the identification of universal processes in oral and written language, both in the development and in their breakdown (Bates, Devescovi, & Wulfeck, 2001). Additionally, Goswami (2003) has recommended that theories of normal and problematic reading development should draw upon the findings of longitudinal studies. Thus, the third study in this dissertation examined the concurrent and longitudinal contribution of RAN, phonological awareness, short-term memory, and orthographic knowledge on word decoding and reading fluency in grades 1 and 2 in two alphabetic languages, English and Greek, that vary in orthographic consistency.

Previous studies that have directly compared children learning different alphabetic languages have provided contradictory results on the contribution of phonological and orthographic processing skills to reading across alphabetic languages that vary in orthographic consistency (e.g., Bruck, Genesee, & Caravolas, 1997; Caravolas, Vólin, & Hulme, 2005; Mann & Wimmer, 2002; Patel, Snowling, & de Jong, 2004). The discrepancies can be attributed to two interrelated factors. First, the selection of tasks is likely critical as it appears to moderate the relationship between phonological awareness, RAN, and reading. Many phonological awareness tasks, such as rhyme awareness and phoneme judgment, are likely too easy already for grade 1 students in orthographically consistent languages and produce little variability, which, in turn, may be responsible for nonsignificant effects. In contrast, a task such as phoneme elision is more difficult and is more likely to create variability even among older readers. Furthermore, alphanumeric RAN tasks (digit and letter naming) have been found in many single-language studies to be stronger predictors of reading than non-alphanumeric RAN tasks (color and object naming). Yet, none of the existing cross-linguistic studies have used alphanumeric RAN tasks, possibly undermining the RAN-reading relationship. Second, it is possible that the differences found in the predictive value of the phonological and orthographic processing skills may be partly due to the measures used to assess reading ability. Research in English-speaking populations has primarily focused on the prediction of reading accuracy, whereas research conducted in orthographically consistent languages has primarily focused on the prediction of individual differences in reading speed. To the extent that phonological awareness, RAN, and orthographic knowledge are differentially related to specific types of reading outcomes, then the use of reading speed measures in consistent orthographies might have accentuated the role of RAN and/or orthographic knowledge and the use of reading accuracy measures in inconsistent orthographies might have accentuated the role of phonological awareness.

Results of Study III suggest that there are no only similarities but also noteworthy differences in the predictors of early reading acquisition across languages that vary in orthographic consistency. RAN Digits, but not RAN Colors, predicted significantly grade 1 Word Attack only in Greek, but the difference with the English model was not significant. When reading fluency measures were used as dependent variables, RAN Digits made a significant contribution in both languages. Notably, the effects of RAN Digits on grade 1 word reading fluency was larger in Greek than in English. On the other hand, phonological awareness was related more to word decoding than to reading fluency in both languages, and was more important in predicting word decoding and word reading fluency in English than in Greek. The third component of phonological processing, phonological short-term memory, was only weakly related to reading across languages and did not survive the statistical control of other cognitive processing skills, with the exception of a small unique contribution to word decoding in grade 1 in Greek and text reading fluency in grade 1 in English. Finally, orthographic processing was a robust predictor of word decoding in English and of reading fluency in both languages. These findings suggest that both phonological and orthographic processing skills are important for reading. However, their predictive strength varies as a function of orthography.

Revisiting the RAN-Reading Theoretical Accounts

In light of the most prominent theoretical explanations of why RAN is related to reading, the results of the three empirical studies presented in this dissertation do not provide unequivocal support for any of them. First, in line with the findings of previous studies (e.g., Cronin & Carver, 1998; Kirby et al., 2003; Lepola et al., 2005; Manis, Doi, & Bhadha, 2000; Parrila et al., 2004; Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007; Savage & Frederickson, 2005), RAN and phonological awareness contributed independent predictive variance in reading (see Studies I and III). Interestingly, the results of Study I showed that the concurrent correlations between RAN and phonological awareness were significant in grade 1, but dropped to non-significant levels in grades 2 and 3. Certainly, this finding casts doubts on the redundancy of these two cognitive processing skills and whether they should be subsumed under the overarching category of phonological processing. Second, RAN appears to predict reading independent of orthographic processing. Study I showed that RAN pause time, measured in grades 1 and 2, explained unique amount of variance in reading even after controlling for orthographic processing. Only in grade 3, and when RAN's effects on reading decreased, controlling for orthographic processing resulted in a non-significant contribution of RAN. In addition, it was hypothesized that if RAN is related to reading through the effects of orthographic processing, as Bowers and Wolf (1993) have suggested, and if orthographic processing is a significant predictor of reading across languages, then RAN should be significantly related to reading across languages. However, as Study II showed, neither RAN Digits nor RAN Colors were significantly related to reading accuracy in English. Third, it was expected on the basis of Manis and his colleagues' (1999) hypothesis that RAN would be more strongly related to reading in Chinese that in English, and, in turn more strongly related to reading in English than in Greek, because Chinese has the most arbitrary symbol-sound mappings and Greek has the most consistent symbol-sound mappings. Interestingly, no statistically significant differences were found between the RAN total time-reading correlations across languages. Although this finding runs counter to what would have been expected if

Manis et al.'s hypothesis was correct, the results of the commonality analysis showed that the contribution of the RAN components was in line with their prediction. The unique contribution of pause time was generally greater the more inconsistent the orthography was.

Finally, the findings of Study I suggest that speed of processing is unlikely the explanation of why RAN is related to reading because both RAN components accounted for unique variance in reading in grade 3, even after controlling for speed of processing. This is in line with the findings of previous studies that controlled for the effects of speed of processing on reading (e.g., Bowey, McGuigan, & Ruschena, 2005; Cutting & Denckla, 2001). Additionally, if speed of processing was the only reason why RAN is related to reading then similar patterns of relationships should be observed for alphanumeric (digits and letters) and non-alphanumeric (objects and colors) RAN tasks. However, Studies I and III indicated that alphanumeric RAN was a stronger predictor of reading than non-alphanumeric RAN. Even in Study II, the correlations between RAN Digits and reading were systematically higher than the correlations between RAN Colors and reading, although only in Chinese the differences were statistically significant.

It may be that a certain level of speed of processing is a lower-level requirement for the development of the specific associations necessary for RAN and for reading. Nonetheless, beyond this baseline level of effects in rapid naming, alphanumeric RAN reflects both the speed of access to phonological information in long-term memory and the ease of building up high-quality orthographic representations that facilitate fluent reading. The degree of association with phonological and/or orthographic processing changes across time, such that RAN is more strongly related to phonological processing in earlier years than later and to orthographic processing in later grades than earlier. Because of this specific association to phonological and orthographic processing, alphanumeric RAN (digits and letters) tasks are stronger predictors of word reading and reading fluency than non-alphanumeric RAN (objects and colors) tasks, which in addition to speed of processing they reflect the time to access semantic information (e.g., Humphreys, Riddoch, & Quinlan, 1988; Johnson, Paivio, & Clark, 1996; Närhi et al., 2005; Wolf & Goodglass, 1986). This extra step of meaning establishment, not present in alphanumeric RAN tasks, could also explain why RAN Objects has been found in some studies to be a unique predictor of reading comprehension (e.g., Badian, 1993; Johnston & Kirby, 2006; Sprugevica & Høien, 2004; Wolf, Bally, & Morris, 1986). Because semantic information is not necessary for accurate word reading, controlling for the baseline requirements of speed of processing results in a non-significant contribution of non-alphanumeric RAN (e.g., Bowey et al., 2005; Cats, Gillipsie, Leonard, Kail, & Miller, 2002).

The RAN-reading relationship is also subject to the requirements imposed by the different orthographic systems. Because the transition from an alphabetic to an orthographic phase of reading development takes place much earlier in orthographically consistent languages than in orthographically inconsistent languages, the shifting from the phonological to the orthographic processing likely takes place much earlier in orthographically consistent languages, perhaps by the end of grade 1, a time that readers in orthographically consistent languages begin to use orthographic information to read (e.g., Barca, Burani, Di Filippo, & Zoccolotti, 2006; Coenen, van Bon, & Schreuder, 1997; Orsolini, Fanari, Tosi, De Nigris, & Carrieri, 2006).

The effect of consistent grapheme-phoneme correspondences in transparent orthographies is sufficiently powerful to secure the distinctness of the phonological representations after a few months of reading instruction (Goswami, Ziegler, & Richardson, 2005). As a result, their quality, after reaching a critical threshold level, adds little to the RAN-reading relationship. On the other hand, the inconsistent grapheme-phoneme correspondences in orthographically inconsistent languages contribute to poorly-defined phonological representations that remain a persistent barrier for reading disabled children (e.g., *Danish*: Elbro, 1998; Elbro & Jensen, 2005; *English*: Perfetti & Hart, 2002; Richardson, Thomson, Scott, & Goswami, 2004; Swan & Goswami, 1997). In turn, this may explain why RAN has been found to be a stronger predictor of reading in groups of poor readers than in groups of average readers (e.g., Meyer, Wood, Hart, & Felton, 1998; Scarborough, 1998b) and why it distinguishes poor readers from average readers, but not average readers from good readers (Savage et al., 2005). Because speed of access to phonological representations remains critical among poor readers, RAN continues to be a strong predictor of reading ability in this group.

Limitations of the Studies

The findings of the present studies should be viewed under the light of some limitations. First, the reading accuracy and fluency tasks in studies II and III were not strictly matched across languages. Chinese, English, and Greek belong to different families of languages and, as a result, it was not possible to construct word reading tasks in one language that would be strictly parallel in terms of word length, syllable structure, and frequency to another language. Second, the orthographic processing task used in Studies I and III assessed whole-word orthographic knowledge. Ideally, grain sizes bigger than graphemes, and yet smaller than words, should also be tested. Perhaps a task like *Word Likeness* (Siegel, Share, & Geva, 1995) in which individuals are asked to select the letter string that looks like a real word in English from a pair of pronounceable nonwords (e.g., *filk - filv*) should be added to the existing set of tasks to obtain a better idea of what type of orthographic knowledge (lexical or sub-lexical) RAN is related to. Third, speed of processing was used only in one study and only in one grade. Thus, it was not feasible to examine Bowey and her colleagues' (2005) argument that RAN, across the developmental span, measures some speed of processing. Fourth, the sample of the current studies consisted of typically developing children. Thus, the findings of these studies cannot be generalized to impaired reading populations. Fifth, the influence of factors, such as SES, print exposure, parents' educational level, and instructional practices on RAN and reading were not statistically controlled. This may be particularly relevant, and difficult, in the case of the two cross-linguistic studies.

The last limitation is related to reliability and validity of the RAN tasks. Due to time restrictions, the children participating in the three studies were not retested on the RAN tasks to obtain estimates of test-retest reliability. Although frequently done, the practice of relying on reliability coefficients reported in previous studies is not optimal because testing conditions and participants' characteristics may vary from study to study. Similarly, the current dissertation does not provide any direct evidence of construct validity. The few studies on this issue have generated partly conflicting findings. For example, working with an unselected sample of 8-11-year-old Finnish-speaking children, Närhi et al. (2005) showed that the best fitting model for each age group was one with two interrelated latent factors representing the alphanumeric and non-alphanumeric RAN. In contrast, van den Bos, Zijlstra, and Spelberg (2002) demonstrated that interrelations of the RAN tasks were different for 10-year-old children (and younger) compared to 12-year-old children (and older). More specifically, the RAN tasks were loading on two factors (one alphanumeric RAN factor and one non-alphanumeric RAN factor) in the latter group of participants, but these factors were not identifiable at the younger age levels.

Although it was not the purpose of this dissertation to assess the construct validity of RAN, the different developmental pattern of relationships between alphanumeric and non-alphanumeric RAN tasks with reading outcomes in Study I suggests that not all RAN tasks are measuring the same construct, at least beyond grade 2. Whether or not all RAN tasks measure the same underlying construct may depend also on the language. Study II indicated that both RAN Colors and RAN Digits predicted reading equally well in Greek, but not in Chinese, in which RAN Digits was a better predictor of reading than RAN Colors.

Conclusion

The findings of the studies presented in this dissertation jointly suggest that the relationship between RAN and reading is more complex than any of the prominent RAN-reading theoretical accounts would suggest. The RAN-reading relationship may be better viewed as a function of development and of the characteristics of the orthographic systems. At an early phase of reading development, RAN reflects both the speed of access to and retrieval of phonological representations and the ease of building up orthographic representations. At a later phase of reading development, RAN reflects only the latter, which is more important for reading fluency than for reading accuracy. However, the shifting from the phonological to the orthographic processing takes place much earlier in orthographically consistent languages because the phonological representations are less ambiguous due the high degree of grapheme-phoneme correspondences. After all, it should be faster to access 27 phonemes used in Greek (e.g., Holton, Mackridge, & Philippaki-Warburton, 2004) than 44 phonemes used in English (e.g., Coltheart & Rastle, 1994) or approximately 4,600 characters used in Chinese (e.g., Cheung, McBride-Chang, & Chow, 2006). Finally, at a foundational level, RAN reflects speed of processing that is present irrespective of the orthographic characteristics.

Future studies should strive to integrate information derived from different sources, such as behavioral measures, fMRI, ERP, or eye movement in order to gain a better understanding of the cognitive activities involved in the processing of information during the performance of the RAN tasks (e.g., Breznitz & Meyler, 2003; McCrory, Mechelli, Frith, & Price, 2005; Misra, Katzir, Wolf, & Poldrack, 2004). Certainly, the cross-linguistic approach used in this study to examine the validity of the different RAN-reading theoretical accounts is promising. However, before definite conclusions can be drawn, replication of the findings with larger sample sizes and with latent factors is warranted.

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