Examining the Nature of the Rapid Automatized Naming (RAN)-Orthographic Processing Relationship in University Students

by

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Abstract

According to Bowers and Wolf (1993), rapid automatized naming (RAN) is related to reading because of its contribution to orthographic processing. However, the nature of the RAN-orthographic processing relationship remains unclear. Thus, the purpose of this study was two-fold: (a) to examine the relationship of RAN with different measures of orthographic processing (lexical and sub-lexical; accuracy and response time) and (b) to examine what processing skills may account for the relationship between RAN and orthographic processing. One hundred university students (70 females; mean age = 21.42 years, *SD* = 2.59) were tested on measures of RAN, orthographic processing, discrete naming, phonological recoding, and speed of processing. The results indicated that RAN correlates only with lexical orthographic processing response time and that phonological recoding speed explains the RAN-orthographic processing relationship. These findings suggest that RAN contributes to how quickly letter sequences are mapped in order to form the orthographic representations which are important for whole word recognition.

Preface

This thesis is part of a larger project led by Dr. George Georgiou in the Department of Educational Psychology at the University of Alberta. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "RAN and reading in university students", Study ID: Pro00011194, December 22nd, 2009. I collected part of the data used in this thesis and also scored them according to standard procedures.

Dedication

To my mother, who is always where I am.

Acknowledgments

I would like to thank my supervisor, Dr. George Georgiou for his instruction, guidance and for providing me the experience of learning many new things.

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CHAPTER 1: INTRODUCTION

Rapid Automatized Naming (RAN) defined as the ability to name as fast as possible highly familiar visual stimuli, such as letters, digits, colors and objects has been repeatedly found to predict reading ability across different languages (e.g., Bowey, McGuigan, & Ruschena, 2005; Compton, 2003; de Jong, 2011; Georgiou, Parrila, & Papadopoulos, 2008; Landerl & Wimmer, 2008; Lervåg & Hulme, 2009; Manis, Doi, & Bhadha, 2000), ages (e.g., Compton, 2003; Felton, Naylor, & Wood, 1990; Korhonen, 1995), and ability levels (e.g., normal readers: Compton, 2003; Lervåg & Hulme, 2009; and individuals with dyslexia: Felton et al., 1990; Korhonen, 1995).

An upsurge of interest in the use of RAN occurred after the pioneering studies of Denckla and Rudel (1974, 1976) in which dyslexic children were not significantly different from normal readers in color naming accuracy, but were significantly less proficient in color naming speed. Since the early 70s, a plethora of studies has established that fast performance on RAN tasks is related to better oral reading ability and conversely that slow RAN performance is associated with the presence of reading difficulties (see Kirby, Georgiou, Martinussen, & Parrila, 2010, for a review). One of the reasons RAN has become so popular is its effectiveness in predicting reading over and above the contribution of other known predictors of reading, such as verbal and nonverbal IQ (Badian, 1993), letter knowledge (Georgiou, Torppa, Manolitsis, Parrila, & Lyytinen, 2012), phonological short-term memory (Parrila, Kirby, & McQuarrie, 2004), and phonological awareness (e.g., Bowers & Swanson, 1991; Kirby, Parrila, & Pfeiffer, 2003). A second reason is RAN's association to the double-deficit hypothesis of dyslexia, according to which individuals with both RAN and phonological awareness deficits experience the most severe reading difficulties (Kirby et al., 2003; Wolf & Bowers, 1999).

The stimuli used in RAN tasks have generally been of two types, either alphanumeric (letters and digits) or non-alphanumeric (colors and objects). Alphanumeric stimuli often lead to higher correlations with reading than do non-alphanumeric stimuli (e.g., Bowey et al., 2005; Compton, 2003; Georgiou et al., 2008; Wolf, Bally, & Morris, 1986). However, non-alphanumeric stimuli are preferred for use with young children or those who may have not learned letters and digits well enough to be considered "highly familiar" (e.g., Lervåg & Hulme, 2009; Parrila et al., 2004).

Even though the contribution of RAN as a predictor of reading is undisputable, it remains unclear what mechanism underlies the RAN-reading relationship (Kirby et al., 2010). According to one of the prominent theoretical explanations, RAN is related to reading because of its contribution to orthographic processing (Bowers & Wolf, 1993). Bowers, Golden, Kennedy, and Young (1994) suggested that if a beginning reader is slow (indexed by his/her performance in RAN) when identifying the letters in words, then these letters will not be activated quickly enough to form letter sequences. As a result, the readers will not be sensitive enough to frequently occurring letter patterns that they see in print. The speed of naming visual stimuli (like letters or digits) is important for "learning and retrieving orthographic patterns" (Bowers et al., 1994, p. 173).

To date, only a handful of studies have tested the assumptions of the orthographic processing theoretical account and have provided mixed findings (e.g., Bowers, Sunseth, & Golden, 1999; Conrad & Levy, 2007; Manis et al., 2000; Powell, Stainthorp, & Stuart, 2014). For example, Manis and colleagues (2000) found that RAN (letters and digits) was accounting for a significant 6.6% to 17.2% of the variance in orthographic processing after controlling for phonological awareness. In contrast, Pae, Sevcik, and Morris (2010) found that RAN (letters and objects) was accounting for a non-significant 1% of the variance in orthographic processing after controlling for phonological awareness.

Therefore, the purpose of the present study was to examine the nature of the RAN-orthographic processing relationship and what processing skills may account for this relationship. More specifically, in my thesis I will examine the kind of orthographic processing tasks (lexical and sub-lexical; accuracy and response time) RAN tasks (alphanumeric and non-alphanumeric) may relate to and contrast three different mechanisms (phonological recoding, speed of processing, and speed of lexical access) that may account for the RAN-orthographic processing relationship. The current study is important because it aims to elucidate the nature of one of the most dominant theoretical accounts of the RAN-reading relationship. If we increase our understanding of how RAN relates to orthographic processing, then we have better chances to understand the RAN-reading relationship.

CHAPTER 2: LITERATURE REVIEW

Rapid Automatized Naming (RAN) and Reading

Rapid Automatized Naming (RAN) is the ability to name as fast as possible highly familiar visual stimuli, such as letters, digits, colors and objects (Wolf & Bowers, 1999). The stimuli used in the RAN tasks are distinguished into two categories: alphanumeric (letters or digits) and non-alphanumeric (colors or objects). Whereas the alphanumeric RAN tasks correlate more strongly with reading in school-age children, the non-alphanumeric RAN tasks are used with preschool children because they are not yet familiar with letters and digits (e.g., Kirby et al., 2010). Although several forms of RAN tasks exist, the traditional RAN tasks consist of five symbols repeated ten times each and arranged in semi-random order in five rows of ten (Wolf & Denckla, 2005).

RAN has been found to be a strong predictor of reading ability across languages (e.g., Compton, 2003; de Jong & van der Leij, 1999; Georgiou, Papadopoulos, & Kaizer, in press; Landerl & Wimmer, 2008; Liao, Georgiou, & Parrila, 2008; Manis et al., 2000; Parrila et al., 2004; Savage & Frederickson, 2005). Notably, RAN continues to predict reading over and above the contribution of other correlates of reading such as verbal and nonverbal IQ (e.g., Cornwall, 1992), articulation rate (e.g., Parrila et al., 2004), speed of processing (e.g., Georgiou et al., 2009), phonological awareness (e.g., Kirby et al., 2003), phonological short-term memory (e.g., Parrila et al., 2004), and orthographic processing (e.g., Moll, Fussenegger, Willburger, & Landerl, 2009).

Even though, there are several studies that have examined the relationship between RAN and reading in children (see Kirby et al., 2010, for a review), only a few studies have examined the RAN-reading relationship in adults (e.g., Arnell, Joanisse, Klein, Busseri, & Tannock, 2009; van den Bos, Zijlstra, & Spelberg, 2002; van Dyke, Johns, & Kukona, 2014). Van den Bos et al. (2002), for example, found that RAN was a significant predictor of word fluency accounting for 54% of the variance. Studies that tested the double-deficit hypothesis in adulthood have also shown that adults in the double-deficit group performed significantly worse than controls on different reading measures (e.g., Cirino, Israelian, Morris, & Morris, 2005; Miller et al., 2006).

The Orthographic Processing Theoretical Account

Despite the acknowledged importance of RAN in predicting reading, it remains unclear what the mechanism underlying the RAN-reading relationship is. As a result different theoretical accounts have been proposed (see Georgiou & Parrila, 2013, for a review). In this thesis, I will examine in more detail the orthographic processing theoretical account. According to Bowers and Wolf (1993), RAN is related to reading because of its contribution to orthographic processing. They proposed that slow letter or digit naming speed can signify the disruption of the automatic processes that generate the orthographic patterns, which lead to quick recognition of words.

Review of Previous Studies

The studies that have examined the orthographic processing theoretical account can be classified into two groups depending on the methodology used.

Some correlational studies have examined the unique contribution of RAN to orthographic processing (e.g., Loveall, Channell, Phillips, & Conners, 2013; Manis et al., 2000; Mesman & Kibby, 2011; Pae et al., 2010). Manis et al. (2000), for example, tested 85 Grade 1 children on RAN (letters and digits), orthographic choice (e.g., *tite-tight-tait*), and word likeness (e.g., *beff-ffeb*), and found that after partialling out the effects of phonemic awareness RAN letters continued to account for 11% to 17.2% of the variance and RAN digits for 6.6% to 11.3% of the variance in orthographic processing. In contrast, Pae and colleagues (2010) found that RAN accounted for a non-significant 1% of variance in orthographic processing after controlling for the effects of phonological awareness.

A few other studies conducted mainly by Bowers and colleagues have also tested the orthographic processing theoretical account and have similarly provided mixed findings (see Bowers et al., 1999; Conrad & Levy, 2007; Powell et al., 2014; Sunseth & Bowers, 2002). For example, Bowers et al. (1999) conducted two studies. In study 1, they classified 31 grade 2 and 32 grade 3 children into four groups: one group with no deficits in phonological awareness and RAN, two groups with single deficits in either RAN or phonological awareness, and one group with double deficits. The children were tested in a number of reading, RAN, and phonological awareness tests, as well as in Quick Spelling Test (QST). In QST, the children had to orally report the letters in four-letters words (e.g., *that*), pseudowords (e.g., *kile*) or nonwords (e.g., *mvhw*) that they were presented on a computer screen for a brief amount of time (250 msec). Bowers and colleagues (1999) hypothesized that children with a naming speed deficit would be less accurate in reporting the different types of letter strings and would benefit less than children in the other deficit groups from the orthographic structure found in words and pseudowords. In contrast to their hypothesis, they found that children with a single naming speed deficit reported fewer letters only in the nonwords condition and could benefit from the orthographic structure found in words and pseudowords.

In study 2, Bowers et al. (1999) separated their sample of 122 grade 3 children into two groups: one with a naming speed deficit (NSD) and one with a phonological deficit (PD). Both groups were tested in an orthographic choice task, a word likeness task, and in QST. Their results showed that the NSD children performed less accurately and more slowly on the orthographic choice and the word likeness tests than the PD children. However, in QST, the only difference between the two groups was found in the nonwords condition (e.g., *mvhw*). The NSD group performed worse in the nonwords whereas both single deficit groups performed equivalently in the word and pseudoword conditions.

Similar to Bowers et al. (1999), Sunseth and Bowers (2002) separated their sample of grade 3 children into four groups: one with no deficits, one with a phonological deficit (PD), one with a naming speed deficit (NSD), and one with double deficits (DD). All children were tested on a number of orthographic processing measures (orthographic choice accuracy and speed, word-likeness accuracy and speed, QST, and embedded and non-embedded word task accuracy). In the latter, children were shown embedded words (e.g., *pdkqeachcz*) on the computer screen one at a time and were then asked to read aloud the real word hidden into the string (e.g., *each*). Sunseth and Bowers (2002) hypothesized that children with a naming speed deficit would be accurate but slower readers and would have greater difficulty in the orthographic processing tasks. In line with their hypothesis, children with slow naming speed were slower and less accurate on the various orthographic tasks than children with no deficits. However, the same pattern applied to children with a phonological deficit. Only the DD group performed worse on the QST and on the embedded task.

Conrad and Levy (2007) also reported mixed findings. The aim of their study was twofold: first, they sought to examine the relationship between RAN performance, letter processing, and the formation of letter string memory representations. Second, they aimed to explore the relationship between RAN and orthographic knowledge. Their sample consisted of 72 grade 2 children who were split into three groups: a group that was slow on RAN versus one that was fast on RAN and a group of average readers. The participants were then tested in an orthographic choice task (e.g., *rain – rane*), in probe tasks, a memory span task, and phonological awareness tasks.

Two different probe tasks were used, one with words and another with illegal nonwords. The participants viewed a word (e.g., *feel*) or nonword (e.g., *lndc*) which was followed by a probe (e.g., *l*). The probes could be single letters (e.g., *l*), two letter clusters (e.g., *od*), or whole words/nonwords (e.g., *even*/*ncdk*). Additionally, the initial word/nonword could be presented in four different duration times (1, 1.5, 2, and 2.5 seconds). The participants had to press a computer key if the probe was present or not in the word or nonword they had previously seen. Conrad and Levy (2007) hypothesized that the slow RAN group would need longer time to study the letter string, would not benefit from the orthographic structure found in the words and nonwords of the probe task, and would have greater difficulty with larger sizes of the probes (e.g., *h* vs. *ba* vs. *tall*).

Results showed that children with a naming speed deficit (NSD) performed less accurately compared to children without NSD on the orthographic choice task. However, Conrad and Levy (2007) also found that the slow RAN group did not encounter any problems with longer probe sizes, did not need longer study times, and was able to use the orthographic structure in the probe task. This finding was in contrast to their hypothesis. They concluded that orthographic skills should not be seen "as a mediator of the relation between naming speed performance and reading ability" (p. 221).

Finally, Powell et al. (2014) examined two groups of 10 and 11 year old children, one that was slow on RAN and a control group, both matched on phonological awareness. The participants were tested in a word reading test which included regular words (e.g., *went*), irregular (e.g., *want*) and pseudowords (e.g., *thent*), an orthographic choice task (accuracy and latency), a word likeness task (accuracy and latency), and in an orthographic learning task. The orthographic learning task consisted of two phases: the exposure and the recall phase. In the exposure phase, the participants had first to name the letter string that they were shown on the computer screen and then they had to decide if it was a word or a pseudoword. In the recall phase, the participants had to remember the pseudowords they had seen in the exposure phase and then they had to select the target stimulus (e.g., *ferd*) among four options (e.g., *ferd*, *furd*, *ferp*, *furp*). Powell et al. (2014) hypothesized that the low RAN group would have a difficulty with irregular words. This would suggest a deficiency in orthographic processing. The results showed that the low RAN group was slower and less accurate in all letter strings of the word reading test. The same applied to the orthographic choice task and the word likeness task. However, in the orthographic learning task, the low RAN group was more accurate than controls. Powell et al. (2014) concluded that the low RAN group showed a deficit in orthographic knowledge both in whole words and in parts of the words. However, the low RAN group surprisingly demonstrated a strength in orthographic learning, a task that according to the researchers, tests the ability to form new orthographic representations at the word level.

A possible explanation for the conflicting findings may be the kind of orthographic processing measures used in different studies (QST, probe tasks, orthographic learning task). However, the contradictory findings may also reflect researchers' limited understanding of what orthographic processing is or what measures should be used to test it. Some researchers have argued that orthographic processing consists of lexical and sub-lexical units (Deacon, Commissaire, Chen, & Pasquarella, 2013; Hultquist, 1997). Hultquist (1997) explicitly stated that orthographic processing includes "knowledge of both whole word and subword units" (p. 90). On the one hand, sub-lexical orthographic processing refers to the knowledge individuals have of the regularities in sub-lexical letter-patterns and is measured with tasks in which participants have to choose the most plausible spelling for a nonword (e.g., *baff* - *bbaf*). On the other hand, lexical orthographic processing refers to the word representations that reflect the orthographic patterns existing in a language's writing system, and is measured by tasks in which participants have to choose the correct spelling of a real word (e.g., *turtle-tertle*).

The RAN-Orthographic Processing Relationship in Other Correlational Studies

Some researchers have reported correlations between RAN and orthographic processing measures that could also unravel the relationship between the two constructs. Unfortunately, they are also mixed, much like what we have observed in the studies that directly tested the RAN-orthographic processing relationship. On the one hand, some studies have found strong correlations between RAN and orthographic processing (e.g., Compton, Olson, DeFries, & Pennington, 2002; Cunningham, Perry, Stanovich, & Share, 2002; Manis, Seidenberg, & Doi, 1999; Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 2009; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997). For example, Roman et al. (2009) reported that the correlation between RAN and orthographic choice was -.57.

On the other hand, some studies have reported weak and non-significant correlations between RAN and orthographic processing (e.g., Cutting & Denckla, 2001; Georgiou, Parrila, & Kirby, 2009; Hagiliassis, Pratt, & Johnston, 2006; Kruk, Mayer, & Funk, 2013; Moll et al., 2009). For example, in Hagiliassis et al.’s (2006) study, the correlations between RAN and orthographic processing ranged from .18 to .38.

What is Accounting for the RAN-Orthographic Processing Relationship?

Even though the relationship between RAN and orthographic processing has been tested, researchers have not provided an explanation concerning the mechanism that accounts for their relationship. In this thesis, I will examine three possible explanations: (a) the phonological recoding hypothesis, (b) the speed of processing hypothesis, and (c) the speed of lexical access hypothesis.

The Phonological Recoding Hypothesis

According to Jorm and Share (1983), phonological recoding, defined as print to sound translation, functions as a self-teaching mechanism, which enables the reader to form orthographic representations of words. This process is important for reading acquisition and provides the basis for general- and word-specific orthographic knowledge (Share, 1995).

Phonological recoding could explain the relationship between RAN and orthographic processing. When encountered with a word, the reader converts the graphemes into phonemes in order to build an orthographic representation. If a reader is quick in retrieving the sounds of the letters in a word (indexed by his/her performance in RAN), then the letters would be activated quickly enough to allow the formation of the word’s orthographic representation.

If the hypothesis is correct, then RAN should correlate with measures of phonological recoding. The existing findings are mixed. For example, some studies have shown that RAN is significantly related to phonological recoding (e.g., Hagiliassis et al., 2006; Manis et al., 2000; Mesman & Kibby, 2011), but some others have reported non-significant correlations (e.g., Cunningham et al., 2002; Georgiou et al., 2008; Roman et al., 2009).

The Speed of Processing Hypothesis

Kail and Hall (1994) have argued that the relationship between RAN and reading is attributed to general processing speed. There is a global mechanism responsible for age-related changes in speed of processing, which is evident in children and adolescents who perform cognitive tasks. Their speed of processing increases due to their age. This suggests that the naming of letters, digits, colors and objects could become faster due to age-related factors and not due to automaticity. Similar to the RAN-reading relationship, speed of processing may explain the relationship between RAN and orthographic processing. Readers may perform better in an orthographic processing task not because of better performance in RAN, but because of a general processing speed factor that enables them to perform better in RAN and orthographic processing as they grow older.

Some studies have found that speed of processing measures (e.g., Symbol Search, Cross Out) correlate strongly with both RAN and orthographic processing (e.g., Cutting & Denckla, 2001; Georgiou et al., 2009; Hagiliassis et al., 2006), but some others have failed to do so (e.g., Georgiou, Parrila, Kirby, & Stephenson, 2008). Importantly, Cutting and Denckla (2001) found that when speed of processing was controlled for, the significant correlation between RAN and orthographic processing ($r = -.28$) became non-significant ($r = -.14$).

The Speed of Lexical Access Hypothesis

An alternative hypothesis may relate to speed of lexical access as operationalized by discrete naming tasks. Georgiou et al. (2009) have argued that RAN is a strong predictor of reading fluency because the words in the reading fluency measures are recognized as fast as single digits and letters. An individual who is quick in discrete naming may access quickly the lexical representations of words stored in his/her mental lexicon and retrieve them. The relationship between discrete naming and serial RAN has been established (e.g., Bowers & Swanson, 1991; de Jong, 2011). However, to my knowledge, no studies have examined the relationship between discrete naming and orthographic processing.

The Present Study

The purpose of the present study was two-fold: (a) to examine the relationship of RAN with different measures of orthographic processing (lexical and sub-lexical; accuracy and response time) and (b) to examine what processing skills may account for the relationship between RAN and orthographic processing. It was hypothesized that:

(1) RAN will be related to orthographic processing at the lexical level and only with response time.

(2) Speed of processing will account for the RAN-orthographic processing relationship.

CHAPTER 3: METHOD

Participants

One hundred first year students in the Faculty of Education (males=30, females=70, mean age= 21.42 years; SD = 2.59 years) were recruited from the participant pool program in the Department of Educational Psychology at the University of Alberta. All participants reported English as their native language and did not experience any reading or sensory difficulties. For their participation the students received credit towards their course.

Materials

Rapid Automatized Naming (RAN).

Serial naming. Serial RAN was assessed with two measures: Digits and Objects. Participants were asked to name, as quickly as possible five digits (*2, 4, 6, 7, 9*) or objects (*book, chair, hand, dog, star*) repeated ten times each and arranged semi-randomly in five rows of 10. Both tasks were administered on a laptop computer. Prior to each task, there was a practice trial in order to ensure familiarity. A participant's score was the total time to name all stimuli and was recorded by pressing a button when the participant finished naming the stimuli. Because there were very few naming errors (the mean was less than 1), they were not considered further.

Discrete naming. The same stimuli used in the serial RAN tasks were used in discrete naming. The stimuli were repeated randomly three times on the computer screen and the participants had to name them individually on the microphone as fast as possible. Response times for discrete digits and discrete objects were recorded.

Orthographic Processing.

Orthographic choice. The orthographic choice task was divided in two parts. Orthographic Choice 1 included 25 pairs of easy words (e.g., take - taik), and aimed to assess response time. Orthographic Choice 2 included 25 more complex pairs of words (e.g., guarantee – gaurantee) that aimed to measure accuracy. The participants viewed pairs of words on a computer screen and were asked to choose the correctly spelled word as fast and as accurately as possible, by pressing either the right or the left Control button of a keyboard. Response times and accuracy for each pair of words were recorded. The Cronbach's alpha reliability coefficient for Orthographic Choice 2 in our sample was .78.

Word likeness. The word likeness task was divided in two parts. Part 1 included 20 pairs of nonwords with easier items (e.g., dake – daik) that aimed to measure response time. Part 2 included 23 more complex items (e.g., tays –tayz) that aimed to measure accuracy. Participants viewed pairs of nonwords on a computer screen and were instructed that one of the nonwords could have been real because it follows the rules of English orthography. The participants were asked to identify which item looked like a real word by pressing the right or left Control button as fast and as accurately as they could. Response times and accuracy were recorded for each pair of nonwords. The Cronbach's alpha reliability coefficient for Word Likeness 2 in our sample was .80.

Phonological Recoding.

Phonological choice (Parrila et al., 2007). Pseudowords were presented two at a time juxtaposed on the computer screen. Only one pseudoword in each pair sounded like a real word when read aloud (e.g., klass-cliss, fite-fipe). Participants were asked to respond to each item as fast as possible by pressing the button corresponding to their choice of which word in each pair sounded like a real word. The task contained 20 pairs of pseudowords presented in random order. Reaction time and accuracy on each item were recorded. The Cronbach's alpha reliability coefficient for Phonological Choice accuracy in our sample was .72.

Speed of Processing.

Visual matching (Woodcock & Johnson, 1989). In this task, participants were asked to circle identical numbers dispersed in 60 rows. Each of the 60 rows in the task consisted of six digits, two of which were identical (e.g., 8 9 5 2 9 7), and participants were asked to circle the identical digits in each row. Participants completed a practice trial prior to timed testing. The performance measure was the number of rows completed correctly within a 3-min time limit. The Cronbach's alpha reliability coefficient in our sample was .85.

Response Time Calculation

A number of steps were followed for the calculation of the mean response times. First, the response times associated with incorrect answers were deleted. Second, in discrete objects and discrete digits, response times lower than 200 milliseconds (msec) or higher than 2000 msec were deleted. In Word Likeness 1 and Orthographic Choice 1 and Phonological Choice response times lower than 200 msec or higher than 10000 msec were deleted. Next, the first mean was calculated. Third, response times higher or lower than 2SDs from the mean were deleted. Finally, a new mean was calculated which was the response time used in the analyses.

Procedure

The participants were tested individually, in one session lasting approximately an hour, in a quiet room in the university by the author and a trained graduate student. Participants read an information letter about the study and signed a consent form prior to testing.

CHAPTER 4: RESULTS

Descriptive Statistics

Table 1 presents the descriptive statistics for all the measures used in the study. In line with our expectation, the accuracy in Orthographic choice 1, word likeness 1, and phonological choice was at ceiling and for this reason only the response times from these measures were used. In turn, because there were a couple of errors in Orthographic choice 2 and word likeness 2, we used only the accuracy scores of these measures in further analyses.

Table 1

Descriptive Statistics on all Measures

	M	*SD*	*Min*	*Max*
RAN Digits	19160.83	3468.97	12363.00	29945.00
RAN Objects	31155.59	4399.19	22097.00	41642.00
Discrete Digits	527.61	81.23	404.21	960.13
Discrete Objects	630.58	74.90	476.79	888.64
Orthographic Choice 1 AC	24.09	1.27	15	25
Orthographic Choice 1 RT	762.74	128.51	485.09	1133.00
Orthographic Choice 2 AC	17.73	3.14	10	25
Orthographic Choice 2 RT	1658.02	553.24	856.22	3309.83
Word Likeness 1 AC	17.15	1.44	12	19
Word Likeness 1 RT	1076.54	433.15	440.83	2988.00
Word Likeness 2 AC	16.93	3.61	9	23
Word Likeness 2 RT	1374.39	532.63	690.17	3072.00
Phonological Choice AC	17.96	1.93	12	20
Phonological Choice RT	1657.37	474.38	830.59	3279.00
Visual Matching	55.61	4.23	40	60

Note. AC=accuracy; RT=reaction time (msec); RAN=Rapid Automatized Naming.

Correlations between RAN and Orthographic Processing

Table 2 presents the correlations of serial RAN, discrete RAN, phonological choice, and visual matching with lexical (accuracy and response time) and sub-lexical (accuracy and response time) orthographic processing. On the one hand, none of the measures correlated significantly with either lexical or sub-lexical orthographic processing accuracy. Discrete naming and phonological choice correlated significantly with sub-lexical orthographic processing response time, the highest correlation being with phonological choice (r =.48). On the other hand, all measures correlated significantly with lexical orthographic processing response time, the highest correlations being with discrete objects (r =.49), discrete digits (r =.49), and phonological choice (r =.49). After correcting for multiple correlations (.05 level of significance divided by 24), the correlation between RAN Objects and Lexical Orthographic Processing response time was no longer significant.

Table 2

Correlations between Orthographic Processing and Other Measures

	Lexical Orthographic Processing		Sub-lexical Orthographic Processing	
	RT1	AC2	RT1	AC2
RAN Digits	.33**	-.11	.12	-.15
RAN Objects	.25*	.01	.13	-.03
Discrete Digits	.49**	.03	.37**	-.04
Discrete Objects	.49**	.02	.39**	-.04
Ph. Choice RT	.49**	-.01	.48**	.03
Visual Matching	-.41**	-.04	-.16	.03

Note. RAN=Rapid Automatized Naming; RT=Response Time; AC=Accuracy.
N = 100. * $p < .05$; ** $p < .01$.

Regression Analyses

In order to investigate the mechanism that may account for the relationship between serial RAN and lexical orthographic processing response time, four sets of hierarchical regression analyses were performed. First, we entered serial RAN (digits or objects) at step 1 of the regression analysis to examine how much of the variance in orthographic processing response time was accounted for by each serial RAN task. RAN digits and objects accounted for 10.5% and 6.4% of the variance in lexical orthographic processing response time, respectively. Next, we entered phonological choice at step 1 of the regression equation and serial RAN (digits or objects) at step 2. We repeated this analysis with visual matching and discrete naming in the place of phonological choice. After controlling for phonological choice, RAN digits no longer accounted for a significant amount of variance in lexical orthographic processing response time. In contrast, after controlling for visual matching or discrete digits, RAN digits continued to be a unique predictor of orthographic processing response time, even though the amount of variance decreased to 4.5% and 4.2%, respectively. In terms of RAN objects, controlling for either phonological choice or visual matching and discrete objects, reduced the unique contribution of RAN objects to non-significant levels.

Table 3

Results of Hierarchical Regression Analyses with Phonological Choice, Visual Matching, Rapid Naming and Discrete Naming as Predictors of Lexical Orthographic Processing

		Lexical Orthographic Processing Response Time		
Step	Variable	β	ΔR^2	p
1.	RAN Digits	.325	.105	.001
1.	RAN Objects	.254	.064	.011
1.	Phonological Choice	.493	.243	.000
2.	RAN Digits	.174	.027	.063
2.	RAN Objects	.139	.018	.126
1.	Visual Matching	-.407	.165	.000
2.	RAN Digits	.223	.045	.020
2.	RAN Objects	.137	.017	.162
1.	Discrete Digits	.486	.237	.000
2.	RAN Digits	.213	.042	.019
1.	Discrete Objects	.491	.241	.000
2.	RAN Objects	.095	.008	.315

Note. RAN = Rapid Automatized Naming.

CHAPTER 5: DISCUSSION

The first goal of this thesis was to examine the nature of the RAN-orthographic processing relationship. This is important given that the orthographic processing account is one of the prominent theoretical accounts used to explain the RAN-reading relationship. In line with our hypothesis RAN correlated significantly only with lexical orthographic processing and only with response time. The size of the correlations was similar to that reported by Georgiou and colleagues (2009) in a study with Grade 3 children followed until Grade 5. The fact that RAN correlated only with lexical orthographic processing deviates from Wolf, Bowers, and Biddle's (2000) proposal according to which slow RAN performance may inhibit the formation of appropriate mappings between phonemes and graphemes at the lexical and sub-lexical level.

Nevertheless, the correlations between RAN and lexical orthographic processing response time were rather weak (.33 for digit naming and .25 for object naming). The fact that the correlations between discrete naming and lexical orthographic processing response time were stronger (.49 for both digit naming and object naming) suggests that the serial demands of RAN do not add anything to the RAN-orthographic processing relationship. Our findings are in contrast to those of previous studies who found that RAN correlates also with sub-lexical orthographic processing (Loveall et al., 2013; Manis et al., 2000; Powell et al., 2014). A possible explanation may be that in these studies the participants were children whereas in our study the participants were adults. We would expect adults to have solid orthographic representations for high frequency words and do not need to build them from scratch. This may also explain why we did not find significant correlations between RAN and lexical orthographic processing accuracy. It appears that, in adulthood, what matters is the speed with which individuals can retrieve existing orthographic representations and not the capacity of their mental lexicon.

When viewed in conjunction with the findings of several studies reporting correlations between RAN and orthographic processing, a developmental pattern emerges. More specifically, in early grades when children are still in the process of building orthographic representations, RAN has been found to correlate with both lexical and sub-lexical orthographic processing (e.g., Georgiou et al., 2008; Loveall et al., 2013; Manis et al., 2000; Manis et al., 1999). For example, in a study with Grade 2 children, Manis et al. (2000) found that RAN correlated .30-.44 with lexical orthographic processing and .35-.51 with sub-lexical orthographic processing. During this developmental period, RAN has also been found to correlate significantly with orthographic learning (Bowey & Miller, 2007). In upper elementary, we notice a gradual decrease in the RAN-sub-lexical orthographic processing. Already by Grade 4 some researchers have reported non-significant correlations with sub-lexical orthographic processing tasks (e.g., Georgiou et al., 2009; Hagiliassis et al., 2006). At the same time, the correlations with lexical orthographic processing remain significant and are rather stable (e.g., Georgiou et al., 2009; Torgesen et al., 1997). During this developmental period, RAN does not correlate significantly with orthographic learning (Powell et al., 2014). In adolescence, although only a few studies have reported correlations between RAN and orthographic processing, they converge on the finding that RAN correlates significantly only with lexical orthographic processing (e.g., Bekebrede, van der Leij, & Share, 2009; Roman et al., 2009). Finally, in our study with young adults we found that RAN correlated significantly only with lexical orthographic processing and only with response times. Thus, it appears that there is a gradual shift from significant correlations with both lexical and sub-lexical orthographic processing accuracy to lexical orthographic processing accuracy and from lexical orthographic processing accuracy to lexical orthographic processing response time.

The second purpose of this study was to examine what processing skill may account for the RAN-orthographic processing relationship, by contrasting three different mechanisms, namely phonological recoding, speed of processing, and speed of lexical access. Based on previous studies (e.g., Cutting & Denckla, 2001; Georgiou et al., 2009; Hagiliassis et al., 2006), we hypothesized that speed of processing would account for the RAN-orthographic processing relationship. Even though our results showed a significant relationship between speed of processing and RAN/lexical orthographic processing, speed of processing did not eliminate RAN Digits' contribution to lexical orthographic processing response time. In contrast, our findings showed that only when we controlled for phonological recoding response time, RAN Digits' contribution to lexical orthographic processing response time dropped to non-significant levels.

There are a few limitations of the present study. First, because our sample consisted of university students, we cannot generalize our findings to children.

Certainly, future studies should replicate our findings with younger children. Second, we did not assess visual processing even though visual skills may impact both RAN and orthographic processing. Third, our phonological choice task was used as an indicator of phonological recoding. However, it shared the same format as our orthographic processing measures, which, in turn, may have amplified its relationship with orthographic processing. Future studies should replicate our findings using different measures of phonological recoding. Finally, we did not assess print exposure although studies have shown that a significant amount of variance in orthographic processing can be attributed to print exposure (e.g., Cunningham, Perry, & Stanovich, 2001; Cunningham & Stanovich, 1990, 1993).

To conclude, the findings of this study showed that RAN correlates with lexical orthographic processing speed and that the mechanism underlying the RAN-orthographic processing relationship is phonological recoding response time. Given that there are different theoretical accounts of the RAN-reading relationship (see Georgiou & Parrila, 2013, for a review), the RAN-orthographic processing theoretical account had not been examined in depth. The results of this study help us increase our understanding of how RAN is related to orthographic processing.

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