THE EFFECTS OF PHONOLOGICAL REPRESENTATION ON RAN SPEED ACROSS TWO STAGES OF READING DEVELOPMENT

By

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To my grandmother

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Rapid automatized naming (RAN) is a remarkably robust and stable predictor of reading disability and highly correlated with reading speed; however, there remains an ongoing debate regarding the precise underpinnings of this relationship. A long standing hypothesis is that RAN taps the integrity of a phonological access mechanism which is critical to reading, but this theory has been difficult to prove. As such, alternative non-phonological theories have been forwarded, also with inconclusive results. To attempt to investigate the strengths of the conflicting hypothesis, in this study the performance of novice (Kindergarten) and experienced (3rd Grade) normal readers were compared on RAN tasks in which (1) phonological density and (2) type of naming stimuli (objects versus digits) were controlled.

Because Rime Neighborhood Density (RND) exerts a facilitation effect on other non-repeated naming tasks, it was predicted that RAN performance for words of high RND would be faster than words of low RND. Also, because beginning reading is mediated by phonology, a larger effect of RND was predicted for novice readers. These predictions were only partially borne out: manipulation of the phonological variable RND

exerted a facilitation effect on RAN response times for objects, but not digits, in older, but not younger, children. Additionally, a large difference in RAN speed across groups was fully accounted for by efficiency in sight word reading, even after controlling for non-phonological and developmental variables, including age and processing speed.

These results suggest that phonology's relationship to RAN performance is stimulus dependent and highly related to the development of automatic word reading skill. Taken together, results from this study support the hypothesis that RAN is largely independent of phonology. Implications for a common neural substrate that supports both RAN and reading are discussed.

CHAPTER 1
INTRODUCTION AND REVIEW OF THE LITERATURE

Background

A large portion of the reading difficulties experienced by individuals with dyslexia can be sufficiently accounted for by the *phonological deficit hypothesis*, even in studies that specifically set out to challenge it (Vellutino, 1979; Ramus, Rosen, Dakin, Day, Castellote, White & Frith, 2003). Indeed, a robust literature base examining dyslexia points to a deficiency in the speech-sound processing system on tasks that directly support the phonological demands of reading, such as phonological awareness, phonological memory, decoding, word identification, and spelling (see Vellutino, Fletcher, Snowling & Scanlon, 2004 and Shaywitz & Shaywitz, 2005 for reviews). In addition, a phonological deficiency has been implicated in the disruption of non-reading cognitive and linguistic processes that are often associated with dyslexia, including executive function (Smith-Spark, Fisk, Fawcett & Nicolson, 2003), working memory (Ramus & Szenkovitz, 2008), and syntactic processing (Wiseheart, Altmann, Park & Lombardino, 2009). While the phonological story of dyslexia has been empirically honed over the past three decades (see Ramus & Szenkovits, 2008 for review) an interesting sub-plot has been developing for at least as long, which implicates a second deficit in dyslexia: naming speed.

Geshwind and Fusillo (1966) first reported the naming speed deficit in an adult patient with alexia who was extremely slow, albeit accurate, at naming colors on a classic congruent version of the Stroop task. Geshwind and Fusillo surmised that this patient's lack of automaticity resulted from an acquired lesion in the connection between visual and verbal processing mechanisms which affected both naming speed and reading. Based on the premise that a “pastel version” of the neurological disruption in alexia might also be found in developmental reading disorders (i.e., dyslexia), Denckla and Rudel (1976) investigated children’s performance on the color naming paradigm and found, consistent with Geshwind and Fusillo’s patient, that naming speed-- and not accuracy--clearly differentiated poor vs. skilled readers. Since then, a large number of studies have investigated naming speed deficits in dyslexia using colors, as well as objects, letters, and digits as stimulus items (Denckla, 1999). These tasks, collectively referred to as Rapid Automatized Naming (RAN) tasks have become a mainstay in both reading research and clinical diagnostic practice and results from these studies are rather astounding: Wolf et al. (2002) report that “naming speed differences distinguish dyslexic readers from peers across all languages tested to date (p. 49).”

RAN Performance Across the Lifespan

In RAN, individuals are simply asked to name, as quickly and accurately as possible, a randomly repeating array of 5-6 highly familiar stimulus items presented on a page. Non-alphanumeric stimuli (sets of objects or colors) are generally used for pre-readers, with alphanumeric (letters and digits) used for older students.

Among individuals with reading impairment, RAN deficits can be detected very early on—as young as 3 years of age (Puolakanaho, et al., 2007)-- and are maintained into adulthood (Berninger, et al. 2006; Miller, et al., 2006). Even after extensive reading remediation, RAN deficits, when present, are found to persist in adolescents and adults (Felton & Brown, 1990; Wolf, 1990). Compared to typically developing peers, slower RAN times are also reported for highly accomplished university students with childhood histories of reading impairment (Cirino, et al., 2005; Ramus Rosen, Daikin, Day, Castelo & White, 2003).

There is also evidence that individuals with normal reading ability but who have family histories of developmental dyslexia have slower RAN times than controls. This genetic link has been reported for very young children, prior to reading instruction during the preschool years (Scarborough, 1990), in children with typical reading achievement during the school-age years (Gayan & Olson, 2001) as well as in asymptomatic (i.e. normal reading) parents of children with dyslexia (Berninger et al., 2006; Miller et al., 2006). While there is some evidence that individuals with very low IQs perform poorly on RAN (Wolf,et al., 2002), research generally finds that RAN is unassociated with overall intelligence at or above the normal range (Bowers, Steffy & Tate, 1988; Denckla & Rudel, 1976; Berninger et al., 2006; Ramus et al., 2003). Taken together, these studies provide strong empirical evidence that RAN performance has little to do with developmental maturation or environmental factors. As such, many researchers concur that RAN is driven by a biologically-based mechanism (Miller et al., 2006; Berninger et al., 2006; Nation, 2005; Scarborough, 1990; Wolf, 2007).

Perhaps the most interesting findings regarding naming speed deficits in dyslexia come from comparing the developmental relationships between phonological awareness (PA) and RAN across languages. In terms of reading subskills, children learning to read consistent orthographies are found to make quicker gains in reading accuracy than beginning readers of English, generally reaching 90% accuracy levels of decoding in 1st grade (Caravolas, 2005). Deficits in both accuracy and speed are found in English; while in highly consistent orthographies (such as German and Dutch) reading accuracy errors are rare, even among the most impaired readers (Caravolas, 2005; Moll, Fussenegger, Willburger, & Landerl, 2009). Rather, dyslexia in consistent orthographies is characterized by slow and laborious but accurate reading.

For children learning to read English, both PA and RAN are related to reading accuracy (Mann & Wimmer, 2002; Wagner, et al., 1997) and reading speed (Mann & Wimmer, 2002; Bowey, McGuigan & Ruschena, 2005) during the first several years of literacy instruction. Beyond third grade, however, this relationship diverges such that PA becomes more predictive of reading accuracy and RAN becomes more predictive of reading speed (Bowey et al., 2005; Hogan, Catts & Little, 2005). In more consistent orthographies, however, the influence of PA on word reading accuracy appears to be limited to the very early stages of reading acquisition (Verhagen, Aarnoutse, & van Leeuwe, 2008) and after first grade, RAN arises as the single best predictor of reading (Brizzolara et al., 2006; de Jong & van der Leij, 2002; Mann & Wimmer, 2002; Moll, et al., 2009). These findings suggest that RAN deficits contribute to reading speed even in languages where orthography decreases the phonological demands on reading. Additionally, RAN deficits are also found to predict reading, even in languages, such as Chinese, which use non-alphabetic orthography (Ho, Chan, Tsang, & Lee, 2002). Many researchers have interpreted these data as support for the hypothesis that RAN deficits in dyslexia are largely independent of phonology (Breznitz, 2006; Wolf, et al., 2002).

Practical and Theoretical Importance of Understanding RAN

Along with phonological awareness, RAN contributes more variance to reading than any other task. In more transparent alphabetic systems, RAN, alone, arises as the strongest predictor of reading skill. Because RAN is universally implicated in reading impairment, understanding the precise mechanisms involved in this task will help refine current models of reading and further our theoretical understanding of dyslexia and other, more general disorders of reading.

On a more practical level, RAN is consistently reported to be highly correlated with performance on tasks of reading speed; therefore, it is hypothesized that the same source of disruption that underlies deficits in RAN also underlies deficits in reading speed. Reading speed is integral to reading fluency, which can have profound effects on comprehension of connected text. In fact, deficits in reading fluency have been identified as the primary source of difficulty for those who struggle with reading beyond the initial years of literacy instruction, contributing more variance to reading comprehension than any other factor, including phonemic decoding, vocabulary knowledge, or verbal reasoning (Torgesen & Hudson, 2006). Unfortunately, current methods for treating reading fluency deficits are extremely time intensive and have a poor success rate for eliminating reading comprehension deficits. Thus, there is a clear and critical need to develop more efficacious and effective treatment strategies for remediating fluency deficits. Understanding the mechanisms that disrupt RAN performance will hopefully forward the work towards this endeavor.

The purpose of this study was to explore the direct effects of phonology on RAN using a novel experimental design and to test whether or not children change the way they perform RAN across the early years of reading development. This chapter reviews the pertinent studies that have informed this research. Following a brief overview of various phonological and non-phonological accounts of RAN's relationship to reading, I discuss some important methodological shortcomings of previous studies and present a rationale for using the experimental design employed in this study. Next, I review potential contributions of stimulus variables and developmental reading skill on RAN performance across two stages of early reading skill. Finally, the chapter concludes with an outline of the experimental research questions.

What does Rapid Automatized Naming (RAN) measure? Theoretical accounts of RAN

Phonological Hypothesis

Based on the widely held view that dyslexia is causally related to weak or underspecified phonological representation (Vellutino, et al., 2004; Shaywitz & Shaywitz, 2005), one theory is that RAN is one of many ways to tap phonological representation. As such, RAN is subsumed within a triad of phonological processing tasks which include phonological awareness, phonological memory and phonological retrieval (Manis, Siedenberg & Doi, 1999; Wagner, Torgesen, Laughon, Simmon & Raschotte, 1993). Specifically, Wagner et al. (1993) posit that RAN measures retrieval time of phonological codes from long term memory. This phonological explanation posits that RAN and PA tap the *same source* of failure in dyslexia and individual variability on PA and RAN are explained as reflecting different types of phonological processing difficulty.

Converging evidence suggests that PA and RAN have differential effects on reading throughout the school years. For children learning to read English, Hogan, et al. (2005) report that by 2^{nd} grade, PA loses its predictive value and offers no additional information in predicting word reading ability in 4^{th} grade, with alpha-numeric RAN emerging as the most powerful predictor of reading impairment in subsequent years. In languages with more regular orthographies, studies have shown that naming speed is more important than PA for predicting word reading skill (de Jong & Van der Leij, 2002).

In a recent large-scale study which examined both children with dyslexia and their biological parents, automaticity of serial letter naming, but not PA, was shown to be a stable deficit across generations (Berninger, et al. 2006). For serial picture naming speed, however, independent variance to reading is increasingly shared with phonological processing over the school-age years (Catts, Gillispie, Leonard, Kail & Miller, 2002; Parilla, Kirby & McQuarrie, 2004). Thus, Bowey, et al., (2005) have suggested that beginning reading is supported by both phonological processing and orthographic knowledge but that in older readers, RAN is mediated primarily by phonological processing.

Speed of Processing (SOP) Hypotheses

Many investigators have posited that perhaps general processing speed accounts for RAN's unique contribution to reading (Wolf et al., 2002; Kail & Hall, 1994). Support for this hypothesis comes from event related potential (ERP) studies which find that, compared to normal readers, peak latencies when performing both RAN and word reading are significantly slower for dyslexic individuals, beginning within the first 100 ms of the tasks (Breznitz, 2006). However, behavioral studies converge on the finding that general processing speed fails to fully account for RAN performance in typically developing children (Georgiou, Kirby & Parilla, 2008), in dyslexic children (Powell, Stainthorp, Stuart, Garwood & Quinlan, 2007) or in dyslexic adults (Ramus et al., 2003; Ramus & Szenkovits, 2008).

A domain-specific version of the SOP account of RAN is implicated in the visual-verbal asynchrony hypothesis. This hypothesis explains slower RAN times in dyslexia as a disruption in a fundamental timing mechanism that coordinates access to orthographic codes (Bowers & Wolf, 1993; Wolf, 2007). This theory depicts an asynchrony of neurological processes that inhibits one's ability to coordinate the visual orthographic code with the auditory/verbal phonological code. Consistent with this theory is the finding that RAN is highly associated with exception word reading-- and not decoding-- even when phonological variables (PA) are controlled (Clarke, Hulme & Snowling, 2005). This visual-verbal timing mechanism has been studied extensively in ERP studies by Breznitz and colleagues (see Breznitz, 2006 for review) and has been expanded to include an explanation for the persistent reading fluency deficits commonly found in dyslexia. This view is also in line with Geshwind and Fusillo's (1966) original characterization of the naming speed deficit.

Orthographic Coding Hypothesis

Because readers of different orthographies perform differently on PA and RAN measures, research has recently been focused on examining the orthography-RAN relationship, which is theoretically related to the visual-verbal asynchrony hypothesis. Numerous studies conducted in English find RAN to be significantly related to orthographic knowledge (Bowey et al., 2005; Breznitz, 2006; Wolf, et al., 2002; Manis, et al., 1999). Extending this line of reasoning, Moll, et al.(2009) predicted that in a highly consistent orthography, such as German, RAN should be more related to word reading than to non-word reading (decoding) because word reading is orthographically driven, whereas decoding non-words is much less dependent on knowledge of orthographic patterns. Investigating this possibility in a study that included over one thousand German children, RAN was found to contribute equal variance, above and beyond PA, to both word and non-word reading speed. The authors concluded that these findings "strongly suggest that a mechanism different from orthographic processing is involved" in RAN (p. 20, Moll, et al., 2009).

In addition, Moll et al. (2009) also found orthographic spelling errors to be highly correlated with PA, which was unexpected because most spelling errors in German are orthographic rather than phonological. One explanation for this finding is that complex measures of PA (e.g., phoneme deletion in non-words) were used, which may have been more sensitive to phonological deficits of German children than typically employed PA tasks that use real words. Interestingly, several recent studies employing complex PA tasks have also found PA deficits in readers of consistent orthographies, including Dutch (Patel, Snowling & de Jong, 2004; Verhagen, et al., 2008) and Czech (Caravolas, 2005). Results from these studies indicate that when more difficult tasks of explicit phonological awareness are used, PA predicts both reading speed (Caravolas, 2005; Patel et al., 2004) and reading accuracy (Patel et al., 2004; Verhagen, et al., 2008). Thus, it appears that irrespective of the orthography one learns to read, dyslexia is characterized by deficiencies in both PA and RAN across cultures. Taken together these findings appear to relate "reading problems in all languages to a universal impairment in phonological processing (p. 355, Caravolas, 2005)."

Multi-Component Processes Hypothesis

In line with a broader conceptualization of the visual-verbal timing mechanism, many researchers concur that RAN is highly predictive of reading because naming objects or symbols across a page requires the same set of component processes -- including visual uptake, lexical retrieval, and articulation—as reading. As such, RAN is described as a "proxy" of reading. Among these common component processes, it is worthy to note that, in and of themselves, both visual and articulatory processing skills have largely been refuted as being sufficient to cause reading impairment (see Vellutino et. al., 2004 and Shaywitz & Shaywitz, 2005 for review).

Double Deficit Hypothesis

Arguably the most widely studied phonologically independent explanation of RAN comes from studies conducted within the framework of the *double deficit hypothesis (DDH;* Wolf et al., 2002). The DDH argues that RAN and PA reflect a *different source* of failure for individuals with reading impairment, the general consensus being that PA deficits reflect one source of processing difficulty in reading while RAN deficits reflect a different source of processing deficit, each manifested as a different type of reading difficulty. Thus, it is predicted that individuals with a *double deficit* in both types of processing will be more impaired and more difficult to remediate than those who have a single deficit.

The DDH has been supported on the basis of two widely substantiated findings. The first of these is that PA and RAN contribute unique and independent variance to different sub-skills of reading. Numerous studies indicate that PA deficits are highly correlated with reading accuracy while RAN deficits are strongly related with reading speed (Compton, DeFries & Olson, 2001; Georgiou, et al., 2008; Manis, et al., 1999; Schatschneider, Carlson, Francis, Foorman & Fletcher, 2002; Wolf et al., 2002). The second widely reported finding that supports the DDH is that impaired readers can be (somewhat) reliably divided into subgroups based on relative performance on these two tasks. In DDH studies conducted in English, a clear majority of impaired readers can be reliably classified as either single deficit (in either PA or RAN) or double deficit (in both PA and RAN) subtypes (Compton et al., 2001; King, Giesse & Lombardino, 2007). Using a 1SD cut-off to subgroup readers, several investigations reveal remarkably similar findings regarding the percentage of impaired readers that fall within each sub-group. Regarding the supposition that RAN is biologically based, it is worthy to note that varying cut-off points changes the percentage of subjects classified into PA-only and DD groups significantly, while the percentage of those classified into RAN-only groups remains virtually unaffected (see Compton et al., 2001; King et al., 2007).

Despite the general acceptance of the DDH, many issues regarding the general idea of "sub-typing" remain inconclusive and are not without criticism. For example, researchers have cited a wide range of methodological problems that may contribute to spurious interpretations regarding possible sub-types of dyslexia. For example, Cirino, et al. (2005) have suggested that classifying subjects as reading impaired using only untimed measures creates a stronger bias for PA deficits to emerge relative to RAN deficits.

In addition, while correlations between RAN and PA have been reported to be low (Cornwall, 1992) and even non-existent (Felton & Brown, 1990), more recent studies reveal a moderate correlation, indicating some amount of shared variance (Powell, et al., 2007). Because of this, several researchers have raised concerns that using continuous correlated variables decreases statistical power and leaves open the possibility for statistical artifacts to emerge, including an increased chance of Type 1 errors (Compton, et al., 2001; Georgiou, et al., 2008; King, et al., 2007; Schatschneider, et al., 2002). Finally, the methodological issue that seems to taint all dyslexia research is that different investigations use different criteria to classify impaired readers. Wolf et al., (2002) has noted, for example, that pooling "garden variety" poor readers with dyslexic readers may markedly decrease the predictive validity of RAN. In dubious criticism of the DDH, Scarborough (2002) writes:

> . . . empirical support for the hypothesized sub-types is fairly limited. Moreover, proposed qualitative differences have tended to be confounded

> with severity of impairment. Although the notion of sub-typing is appealing, research spanning several decades has been rather unsuccessful in revealing consistent sub-groupings of disabled readers, and I am not sure that the latest sub-typing hypotheses will stand the test of time (p.104).

Introduction to the Problem

Is RAN Phonological?

One of the most contentious and currently unresolved debates in dyslexia research concerns the extent to which the usual suspect, phonology, is implicated in RAN. In the present review, it appears that for virtually every non-phonological explanation for RAN proposed--including recent accounts of an orthographic locus--a countervailing argument for a phonological locus emerges. Indeed, recent evidence from these studies converges to question "whether RAN has anything to do with orthographic processing (p. 20, Moll, et al., 2009)." Thus, given the lack of consensus regarding a non-phonological deficit in RAN and the preponderance of evidence for a phonological core deficit in dyslexia, exploration of the phonology-RAN relationship clearly warrants further attention. Despite over 30 years of inquiry, however, a phonological explanation for RAN deficits in dyslexia has been difficult to prove.

Problems with Previous Research

Central to the debate regarding the phonological underpinnings of RAN, it is important to note that previous research has routinely measured phonology on tasks of phonological awareness. There are many ways to measure phonological awareness. Examples include elision (ex: say the word "cat" without the "k" sound), sound matching (which word starts with the same sound as "cat": kid or dog?) and spoonerisms. Tasks such as these assess an individual's explicit awareness that the continuous speech stream of spoken language can be segmented into individual speech sounds, or phonemes. PA is especially important in learning to read alphabetic languages because it helps children map the sounds of a word onto individual letters (or letter combinations) of the writing system.

It is generally assumed that PA is a valid measure of phonological representation (Naples, Chang, Katz & Grigorenko, 2009; Swan & Goswami, 1997). This assumption stems from countless studies that find PA to be highly predictive of reading outcomes. Many researchers have argued, however that, in addition to phonological representation, phonological awareness tasks tap many non-phonological components, as well, such as such as memory and attention to support manipulation or judgment about phoneme boundaries (Denckla, 1999; Nation, 2005; Ramus, 2001).

In addition, orthographic knowledge plays a particularly important mediating role on phonological awareness performance and it is generally agreed that orthographic knowledge and phonological awareness develop in a reciprocal fashion (Hulme, Snowling, Caralvolas, & Carroll, 2005; Ventura, Kolinsky, Fernandes, Querido, & Morais, 2006; Ziegler & Goswami, 2005; Ramus, 2001). Castles & Coltheart (2004) argue that, "once children acquire reading and spelling skills, they change the way in which they perform phonological awareness tasks, using their orthographic skills, either in addition to or instead of their phonological skills, to arrive a solution (p. 102)." Thus, in cases where children have attained a certain level of orthographic knowledge, phonological awareness may not be a particularly stringent measure of underlying phonological representation. Addressing this issue, Share (2008) contends that measuring phonological awareness is something quite different from measuring phonological representation:

> …the available evidence indicates that phonemic awareness is best categorized as a reading subskill, not as a universal and emergent linguistic capability (Share, 1995). An alphabetic script is, first and foremost (although not solely), a phonemic code or "blueprint"—a graphic dissection of the segmental structure of spoken words. Phonemic awareness and letter knowledge have been labeled *corequisites* to alphabetic literacy (Share, 1995) or *codeterminants* (Bowey, 2005). Ehri and Soffer's (1999) term *graphophonemic* awareness aptly captures the inseparability of the two. Attempts to disentangle phonemic awareness and orthographic knowledge in the quest for ever "cleaner" studies of phonemic awareness unconfounded by letter knowledge are consequently misconceived (p. 597).

This characterization of phonological awareness holds important implications for reading research and challenges the validity of the theory that naming and reading speed deficits are independent of phonology because phonological awareness and orthography are inextricably tied to one another.

While previous lines of RAN research have investigated the phonology-RAN relationship almost exclusively by correlating PA performance with RAN performance, this study veers from this commonly employed methodology by examining the effects of phonology on RAN using an experimental design. The rationale for using this alternative approach is discussed in the following section.

Rationale for the Present Study

Framing RAN as a Lexical Retrieval Task

As mentioned previously, dyslexic subjects are able to name items in RAN accurately, but slowly. Since RAN requires a verbal response, many researchers have explored the possibility that slow RAN performance might be related to a reduced speed of articulation (de Jong & van der Leij, 2002; Georgiou, et al, 2008; Wolf & Obregón, 1992; Neuhous, Foorman, Francis & Carlson, 2001; Ackerman & Dykman, 1993). Converging results from these studies indicate that articulation time fails to differentiate dyslexic readers from normal readers (Wolf & Obregón, 1992), from underprivileged ("garden variety") poor readers (Ackerman & Dykman, 1993) and from readers with attention disorder (Ackerman & Dykman, 1993). Overwhelmingly, these studies find that individual variability in RAN performance is not related to articulation speed but to pause time.

Pause time has previously been explained as variability in general processing speed. Lervåg & Hulme (2009) argue, however that this explanation seems highly implausible because processing speed should also exert a general effect on articulation speed. Additional evidence against a speed of processing account was recently reported in a longitudinal study which found pause time to be highly correlated with both RAN and reading performance, even after controlling for processing speed (Georgiou, Parilla & Kirby, 2009). An alternative explanation explored in the present study is that pause time simply reflects the time it takes to retrieve a verbal name for a visual stimulus. If this explanation is correct, it was predicted in the present study that RAN performance would be subject to variability in the way the stimulus items are represented in the mental lexicon. Specifically, as poor phonological representation is implicated in dyslexia, and RAN is highly predictive of dyslexia, it was hypothesized in the present study that RAN performance, even among typical readers, would be particularly vulnerable to manipulations in phonological representation.

Evidence for a Phonological Locus in Non-RAN Lexical Retrieval Tasks in Dyslexia

It is well-documented that individuals with dyslexia experience persistent difficulties with spoken word retrieval that appear to be phonological in nature (Nation, Marshall & Snowling, 2001). Numerous studies exploring naming deficits in dyslexia have been reported (see Nation, 2005 for review). These studies find that while individuals with dyslexia consistently perform more poorly than typically developing peers on non-generative lexical retrieval tasks, such as confrontation naming of objects (Faust, Dimitrovsky & Shache, 2003; Dockerell, Messer, George & Wilson, 1998; Swan & Goswami, 1997), deficits in generative lexical retrieval tasks are also reported in dyslexia, including increased occurrences of tip-of- the-tongue (TOT) states (Faust, et al. , 2003), and increased word finding difficulties in conversational discourse (Dockerell, et al., 1998; German & Newman, 2007). Moreover, the general finding in all of these lexical retrieval studies is that the locus of difficulty for dyslexic individuals—for both generative and non-generative tasks— arises from the phonological level. For example, Nation, et al. (2001) found both poor comprehenders and dyslexic groups performed slower than controls on confrontation naming, but that the nature of this disruption differed for the two groups. Poor comprehenders had difficulty at the semantic level as evidenced by their slow and inaccurate naming, especially of low frequency words. In contrast, the dyslexic group had little difficulty with low frequency words but had difficulty retrieving words with longer names and made a disproportionate number of phonological errors. This was interpreted as evidence that the dyslexic children's naming errors were specific to phonological rather than semantic demands. Thus, when the lexical retrieval component of naming pictures in RAN is considered, it is plausible that the locus of difficulty for dyslexic individuals might also be specific to the phonological level.

Present Study

The overarching aim of the present study was to use an experimental design to test the hypothesis that phonology—specifically phonological representation—impacts

RAN performance. This hypothesis was informed by several lines of research. First, variability in RAN stems from pause time, which implicates variability in cognitive processing; however, the precise mechanism that accounts for pause time in RAN has been difficult to explain in terms of either phonological processing or general speed of processing (Georgiou, et al., 2009).

Secondly, because RAN is highly predictive of dyslexia and phonology appears to account for slow reaction times on non-repeated naming deficits in dyslexia (e.g. confrontation naming), it logically follows that pause time for naming items in a repeated matrix, such as RAN, reflects a similar phonological deficit. While this hypothesis has been implicated by several researchers (Ramus, 2001; Dockerell, et al., 1998; Nation, et al., 2001), I am unaware of any study that has experimentally tested this possibility.

Finally, given the consensus that dyslexia is primarily the result of weak or underspecified phonological representations (Shaywitz, Morris & Shaywitz, 2008; Fletcher, 2009), it can be argued that existing studies have failed to uncover a relationship between phonological representation and RAN because measures used for assessing phonology (i.e. types of phonological awareness tasks) are confounded by the coeval development of orthographic knowledge (Share, 2008). In this study, it was posited that by directly manipulating the strength of phonological representations of RAN stimulus items, subtle effects of phonology on RAN that have not been revealed in previous correlational studies using phonological awareness tasks might be revealed.

Strength of lexical representations has long been implicated in the development of proficient reading skill. Perfetti's (1992) *verbal efficiency theory*, for example, emphasizes that automaticity of word reading is intricately linked with the quality or strength of semantic, orthographic, and phonological representations. If RAN is indeed a proxy for reading, it stands to reason that RAN speed would also be highly sensitive to mental lexical representations.

Effects of Lexical Factors on Word Retrieval Speed

In order to retrieve a particular word in response to an external stimulus (such as a picture), activation of mental representations related to the word is accrued until a set *activation threshold* is met (Storkel & Morrisette, 2002). Response times (RTs) for either recognizing or naming a word, then, are presumed to measure the time it takes for activation to reach this threshold. Variability in the time it takes to retrieve the name of one picture versus another is a function of the initial *resting threshold* of those representations, prior to external activation (Storkel & Morrisette, 2002). Thus, word retrieval speed is faster for words with higher resting thresholds than for those with lower resting thresholds simply because less activation must be accumulated to reach the activation threshold.

Various lexical factors affecting resting thresholds can have profound facilitation or inhibitory effects on naming speed (Storkel & Morissette, 2002). In order to isolate the effects of RND on RAN speed, stimulus items used in these experiments were contrasted for high and low RND and matched for lexical frequency and semantic category. These variables are reviewed in the following section.

Neighborhood Density

Words that have many similar sounding words are said to reside in the same phonological neighborhood. Phonological neighborhoods contain words that differ by one phoneme: high density neighborhoods have many neighbors, whereas low density neighborhoods have few neighbors. Phonological neighborhoods can be constructed in terms of phonological similarity at either the onset or rime level. In controlling for quality of sub-lexical phonological representation, this study manipulated rime neighborhood density (RND). RND is defined as the number of phonological neighbors that share the rime of a target word. For example, “cat” shares the “at” with 24 other words in the English language and thus resides in a high dense neighborhood, while “orange” shares the “ange” with no other words in the English language and therefore resides in a very low dense neighborhood.

Previous studies have shown differential effects of neighborhood density across tasks. For example, inhibitory effects of density have been reported for gating and lexical decision tasks (Vitevitch, 2002). This effect has been attributed to increased competition between activation of the target word and activation of similar sounding words. In contrast, a substantial research base supports the prediction that, in so called “output phonology” tasks—those that require overt pronunciation-- words of high RND are more easily accessed from long-term memory and maintained in short-term memory longer than words of low RND (Andrews, 1992; Baus, Costa & Carreiras, 2008; Marian, Blumenfeld & Boukrina, 2008; Swan & Goswami, 1997; Ventura, et al., 2006.) Facilitation effects for high RND have been reported for tasks of spoken word retrieval, word reading and confrontation picture naming (Andrews, 1992; Baus, et al., 2008; Marian et al., 2008; Swan & Goswami, 1997; Ventura, 2006; Ziegler & Goswami, 2005). Ziegler & Goswami (2005) have explained this high RND advantage within the developmental frame work of *lexical restructuring*.

According to the *lexical restructuring theory (LRT*; Metsala and Walley, 1998), representations of holistic word units in the mental lexicon become increasingly more segmental at the phonological level in response to the increased pressure of a growing vocabulary (Metsala & Walley, 1998). Words from common rime neighborhoods are in high competition because of their phonological similarities, and therefore are "forced" to become restructured into smaller phonological units. For example, the holistic phonological representations of "cat" and "bat" are restructured as highly specified segmental phonological units of onset + rime (/k/ + /at/; /b/ + /at/). As a result of this fine grain restructuring, access to phonological information is more readily available for rime units from high density neighborhoods (i.e., words that share many rime neighbors) than for rime units from low dense neighborhoods (words that share few neighbors). So, words from high dense neighborhoods are presumed to have phonological representations that are easier to access than words from low dense neighborhoods. Andrews (1992) argues that, "comparisons of words that are similar to many other words to words that are similar to few provide a means of specifying the characteristics of the access mechanism (p.234)."

Lexical Frequency

In addition to the effects of phonological neighborhoods, naming speed is also affected by even slight variations in lexical frequency. The *lexical frequency effect* is demonstrated on various tasks of naming, such that words that occur in our lexicon with high frequency are accessed quicker on than words of low frequency on tasks of word reading and naming (Henry & Millar, 1993). Research finds an interactive relationship between lexical frequency and phonological variables (Storkel & Morrisette, 2002). For example, several investigations using both impaired and non-impaired readers find that the phonological effects on naming speed are more variable in low vs. high frequency words (Andrews, 1992; Marian et al., 2008; Nation, et al., 2006). This interaction is theoretically important to understanding the underlying components of RAN because every study in every language conducted thus far (Caravolas, 2005; Wolf, et al., 2002) has used highly frequent and familiar stimuli—colors, objects, digits, and letters—to assess rapid automatized naming. Because lexical frequency facilitates lexical retrieval speed, it remains unclear whether the locus of disruption in RAN stems from the lexical or sub-lexical level of representation (Ramus, 2001) and to what extent the phonological characteristics and the frequency of the stimuli used in these tasks impact performance. Therefore, in order to isolate the effects of sub-lexical variable RND in the present study, lexical frequency of the stimulus items used was carefully controlled.

Semantic Representation

The well-documented *concreteness effect* finds that concrete, picturable words (e.g. dog, house) are named faster than abstract words (e.g. life, red) (Goswami, 2008). This effect has been attributed to the fact that concrete words have more sensory referents and distinctive features than abstract words, and are thus, more robustly represented semantically. In keeping with standard object RAN tasks, pictures selected for this experiment represented objects that were also concrete, imageable, and highly familiar to children.

There is also evidence to suggest that different semantic categories are represented in different parts of the brain. For example, several studies involving adults with acquired neurological lesions have selective impairments for naming pictures representing living vs. non-living semantic categories (see Shelton & Caramazza, 2001 for review). In general, living things are found to be more difficult to recognize than non-living things. Humphreys and Forde (2001) suggest that this may be the result of the overlapping visual distinctive features of living things. However, Shelton and Caramazza (2001) maintain that “there may be non-overlapping areas of the brain that are important for processing different categories of items. The inferior areas of the temporal lobe appear to be especially important for processing living things and posterior area of the temporal lobe and fronto-parietal areas appear more important for processing non-living things (p. 441).”

Additionally, there is also believed to be a specialized region of the brain which is devoted specifically to the task of recognizing of faces (Farah, Wilson, Drain & Tanaka, 1998). Evidence for this comes from neurologically impaired patients with prosopagnosia who are able to easily recognize familiar objects but have selective impairments in recognizing familiar faces.

Acknowledging that there is some controversy surrounding the existence of anatomical specialization for semantic representation, and taking into account that findings from adult studies may not generalize to the developing brains of children, it is clear that semantic processing involves large, diffuse areas of the brain (Lervåg & Hulme, 2009). To avoid having privileged access to any one semantic category confound the effects of RND, the object RAN task used in the present study included case members from each of the previously discussed semantic categories such that equal numbers of natural kinds, artifacts, and facial features were used across the experimental conditions.

Developmental Changes in the Predictive Validity of Different RAN Stimulus Items

As mentioned previously, RAN’s relationship to reading varies across different stages of reading development. The general consensus is that young children’s performance on any RAN stimuli (colors, objects, letters, or digits) tends to be equally predictive of future reading ability (Bowey, et al., 2005). However, by the end of 1st grade, non-alphanumeric RAN loses predictive validity and alphanumeric RAN emerges as the most reliable predictor in subsequent years (Wolf, 2007). This interesting but largely unexplored finding has been substantiated in English (Vellutino, et al., 2004) as well as in languages with more consistent orthographies (Van der Bos, Zijlstra & Lutje Spelberg, 2002). More specifically, it has been documented that rapid naming of digits is more predictive of reading speed compared to rapid naming of other stimuli (Savage & Fredrickson, 2005; Clarke, et al., 2005). Several competing hypotheses, each reflecting countervailing theoretical explanations for RAN, have been forwarded to explain the high predicative validity of RAN-digits in older children.

Is Digit RAN Phonologically Driven?

One explanation for this finding is that digits are more difficult to name because they are arbitrary symbols which are weakly represented in terms of *phonological* detail (Manis, et al., 1999). This explanation is in line with the visual-verbal asynchrony hypothesis and emphasizes a phonologic -orthographic relationship between RAN and reading. Presumably, one can argue that the names for the written symbols for letters overlap with a phonological representation to a greater extent than names for the written symbols for numbers. For example, the letter name for the orthographic symbol “K” /**k**ai/ encapsulates the phoneme it represents (i.e., /**k**/). This phonological overlap between symbol name and symbol explains, in part, why letter knowledge in Kindergarten is highly predictive of later reading ability (Scarborough, 2002). Digit names, on the other hand, have no symbol-sound association and can therefore be considered more “phonologically arbitrary” in comparison to letter names. Bowey et al. (2005) has suggested that both letter knowledge and phonological knowledge drive RAN's relationship with reading in younger children but once letters are over-learned and highly familiar, RAN's relationship to reading is specific only to phonology.

Stringer, Toplak & Stanovich (2004) explored the relationship between different stimulus items on RAN and found a double dissociation for naming colors vs. digits between children with ADHD and dyslexia. The reported that rapid naming of colors, but not digits, was impaired in ADHD, and rapid naming of digits, but not colors, was impaired in dyslexia. Because performance on tasks of executive functions (EF) predicted color naming, but not digit naming across groups, the color naming deficit in ADHD children was attributed to their central impairment in EF. Stringer et al. suggest that color names are more demanding of cognitive resources than digit names because 1) color names have vague boundaries and 2) colors do not exist in hierarchical categories. For example, retrieving the name for "red", which also invokes overlapping activation for the name "burgundy" is a more complex task in terms of semantic representation than retrieving the name for "duck" which invokes a distinct hierarchical semantic relationship with "bird." They suggest that reconciling competing activation from fuzzy vs. distinct semantic boundaries is impaired for children with EF deficits, whereas reconciling competing activation from fuzzy vs. distinct phonological boundaries is impaired for children with dyslexia. In sum, this explanation implies that digit naming speed is related to reading because both tasks are highly dependent on phonological rather than semantic representation.

Is Digit RAN Semantically Driven?

An opposing explanation suggests that, compared to colors and objects, arbitrary alphanumeric symbols are more difficult to retrieve because, comparatively, they are relatively weak in terms of their *semantic* specificity (Wiles & Browasky, 2004; Narhi, et al., 2005). However, because very little is known about the way abstract concepts are represented, it remains unclear whether or not verbal retrieval of arbitrary or abstract symbol names (such as digits) is subject to the same retrieval processes as naming other lexical items (e.g. words, colors, or objects). Additionally, while most researchers agree that symbolic notation of integers (e.g. Arabic numerals) automatically activates semantic representation (Ito & Hatta, 2003), this supposition has been challenged in recent years (Cohen, 2009). Moreover, Cohen (2009) recently questioned whether integers are abstract at all and has posited that retrieving names for digits is difficult because the distinctive visual features of the symbols are easily confused. This hypothesis implicates that digit RAN's relationship to reading involves semantic, rather than phonological representation that stems specifically from visual, rather than categorical representation.

Thus, explanations for the specific predictive power of digit naming represent two equally plausible but competing theoretical accounts of RAN. Moreover, both of these explanations focus entirely on explaining the relationship between reading and alphanumeric RAN in older children, leaving the equally predicative validity of non-alphanumeric RAN in younger children unaccounted for. Because there is currently no consensus regarding the extent to which RAN is phonologically-driven, these explanations are purely speculative and have been particularly difficult to reconcile theoretically.

Developmental Relationship between RAN and Reading

In the course of reading development, alpha-numeric RAN's strong relationship to reading emerges several years earlier in children learning more consistent orthographies (e.g. Italian, German) compared with children learning more complex, inconsistent orthographic systems (e.g. English, French). This well-established finding suggests that RAN's changing relationship to reading outcomes is more than age-dependent. Rather, RAN's predictive validity appears to be more highly associated with reading skill, specifically after the point at which rudimentary skills of accurate decoding are mastered (Share, 2008).

The process of reading is typically depicted as a model representing three distinct but interconnected processing modules: the meaning processor, the orthographic processor and the phonological processor (Seidenberg & McClelland, 1989). This classic parallel-distributed processing (PDP) model (Figure 1-2) underscores the prevailing perspective that reading is an interactive process and that skilled, effortless reading depends upon the integrity of each of the three modules as well as the strength of the connections, or pathways, between them.

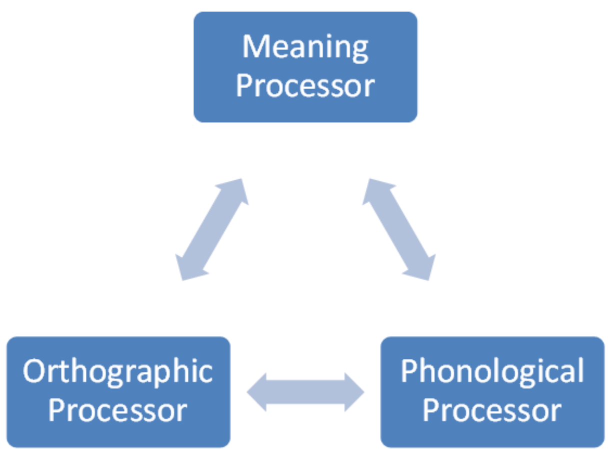

Figure 2-1. Parallel Distributed Processing (PDP) model. Siedenberg & McClelland, 1989.

Seidenberg and McClelland's (1989) connectionist model describes the task of word reading as a "division of labor" in which each pathway contributes cooperatively in a way that is most efficient for the demands of the task. For example, the demands of reading a frequent and familiar word requires less contribution from the phonological processor than the demands of reading an unfamiliar word or non-word. The general axiom is that skilled readers use a direct pathway from the orthographic processor to the meaning processor when they can, and recruit extra support from the phonological processor when they must.

Adams (1990) describes the development of automatic word reading in terms of these three modules. As children begin learning to read, phonological representations of the spoken language system are mapped onto orthographic representations of the written language system. With adequate reading instruction and experience with text, these phonologic and orthographic representations become “amalgamized” (Ehri, 1992) resulting in a combined graphophonemic representation that contains both phonologic and orthographic representations. It is precisely this amalgamation process, the tightly coupled mapping of phonological codes to orthographic codes that is the work of beginning readers and the key to skilled, effortless, automatic future reading. Before this amalgamation process is complete, however, beginning readers are thought to use an indirect route to accessing meaning. This indirect process, mediated by phonology, is less automatic and thus, more time consuming: Orthography (O)→Phonology(P)→Semantics (S). Through experience with reading, the amalgamized graphophonemic representation provides a means of direct access to meaning: O→S, which is faster but also more arbitrary (Siedenberg & McClelland, 1999).

Previous researchers have proposed that the process of directly accessing semantic information from orthography is shared between direct (O→S) and indirect processes (O→P→S) between the ages of 6 and 10 (Doctor & Coltheart, 1980). A recent study reported by Nation and Cocksey (2009), however, provides evidence that direct access to semantic information occurs quite early on in the development of reading. Using an embedded word paradigm, 7 year old children showed semantic interference effects when asked to make category judgments about words in which other words were inserted. For example, when asked *Is this a body part?*, children were slower to reject the word SHIP (containing HIP) than they were to reject CROW. Importantly, neither the position of the embedded word (initial or final part of the carrier word) nor similarity in pronunciation of the embedded word to the carrier word (i.e. PLUMP/PLUM vs. BUSH/BUS) affected response times. These results were consistent with those from a similar study using adult subjects and were interpreted as evidence that at least by age 7, semantic meaning can be accessed directly through orthography.

The present study explored whether or not changes in the predictive validity of specific stimulus sets used in RAN reflect a developmental interaction between lexical representations and the changing way in which the developing reading brain processes these representations. If RAN is indeed a "proxy" for reading, it would stand to reason that young children (< 7 years) process RAN stimuli through an indirect (O→P→S) route just as they do for reading word. As a result of emerging reading skill, orthography and phonology become tightly coupled and older children (> 7 years) increasingly employ a direct O→S route. At around the same age, and also in response to reading experience, newly established neuronal networks are forming, changing the way the brain processes linguistic information. Thus, changes in the way reading is processed also changes the relative contributions of phonological vs. semantic variables to the task. In essence, if children (and adults) “RAN” like they read, RAN speed may be more susceptible to variability in phonological representation in young children when their word reading is more reliant on phonological mediation; whereas, in older children, RAN speed may driven by variability in semantic representation because word reading is less reliant on phonological mediation.

Research Questions

The purpose of this study was to explore the direct effects of phonology on RAN using a novel experimental design and to test whether or not children change the way they perform RAN across the early years of reading development. A review of the literature review motivated the following experimental questions and predictions.

Question 1: Does RND have facilitative effects on object RAN?

Hypothesis 2: Because RND facilitates confrontation picture naming speed, a similar effect will be found for Object RAN such that words from high density neighborhoods will be named faster than words from low density neighborhoods.

Question 2: Does RND have facilitative effects on digit RAN?

Hypothesis 2: If digit RAN predicts reading because it is phonologically driven, the phonological variable RND will also have facilitative effects on digit RAN speed.

Question 3: Does acquisition of reading skill change the way children access words for rapid naming?

Hypothesis 3: If growth in reading skill changes the way children perform RAN, the effects of the phonological variable RND may be limited to the Kindergarten group because reading is more dependent on phonological mediation in novice readers than in more experienced readers.

Question 4: Compared to standard measures of RAN, how does manipulation of RND affect RAN’s relationship to various sub-skills of reading?

Hypothesis 4: If RAN is primarily phonologically driven, rapid naming of stimulus sets that are more highly specified in terms of phonology will predict reading better than either low density stimulus sets or standard (CTOPP) stimulus sets that are not controlled for phonology. As RAN is highly correlated with reading speed, it is predicted that high density RAN tasks will predict speeded measures of reading (Sight Word Efficiency and Phonemic Decoding Efficiency) better than the other stimulus sets.

CHAPTER 2
METHODS

Introduction

The primary purpose of this study was to test the effects of rime neighborhood density (RND) on children's rapid naming speed across two stages of reading development. Children in Kindergarten and 3rd grade completed two RAN experiments using different stimulus sets of objects and digits. Fourteen tasks of reading and reading related skills were also assessed. In this chapter, the methods of the study are described.

Methods

Setting

All of the children who participated in this investigation were recruited from one of two elementary schools in north central Florida. School A is a public school and School B is a charter school. As shown in Table 2-1, the percentage of minority students in identical to the state average for School B and somewhat lower in School A. The percentage of children who receive free or reduced lunch is higher than state averages. Eligibility for free and reduced lunch is based on federal poverty guidelines. Thus, socio-economic status (SES) for the student bodies at both schools is lower (i.e., poorer) than state averages. While neither SES nor minority status has been shown to influence RAN, both of these factors are high-risk indicators for reading difficulty. Whether increased risk of reading failure in these groups is due to environmental or educational opportunity is still debatable and beyond the scope of this investigation. Nevertheless, it should be noted that both of the sample schools have received passing grades in Florida's school accountability program for the past four years. These grades are based primarily on student performance on the Florida Comprehensive Achievement Test (FCAT). According to the Florida Department of Education School Accountability Report for school year 2008-2009 (http://schoolgrades.fldoe.org/default.asp), a large majority of the third grade children at both of these schools are meeting high standards in both reading and math and the percentage of children meeting these standards exceeds the state averages (http://fcat.fldoe.org/results/default.asp?action=statereport&report=State&years=&grades=&subjects). Thus, it is reasonable to expect that this sample's performance on RAN and reading measures yielded data that is minimally biased in terms of educational setting.

Table 2-1. 2008-2009 Demographics for sample schools compared to State of Florida averages

	Sample school 1	Sample school 2	State average
% Students from minority ethnic backgrounds	39	57	57
% Students on free or reduced lunch	75	67	58
% Students meeting high standards in reading	78	90	71
%Students meeting high standards in math	85	93	78

Participants

Permission slips were distributed to all students in four 3rd grade classrooms and two Kindergarten classrooms at the participating schools. Forty-four students returned signed permission slips. Following pre-determined exclusionary criteria, two students participating in the English Students of Other Languages (ESOL) program and two students participating in the Exceptional Student Education (ESE) program were excluded from participation, yielding a total of 40 general education students who were recruited for data collection. Data from one participant in Kindergarten was subsequently discarded due to voluntary withdrawal. Thus, data for 21 3rd graders (M_{AGE}

= 9.3 years) and 18 Kindergarten children (M_{AGE} = 6.14 years) were used in the final analyses. A total of 22 girls and 17 boys participated. Fourteen of the participants (36%) were from minority ethnic backgrounds (64% Caucasian; 15% African American; 5 % Hispanic; 15 % Other).

Measures

All students completed the same test battery and experimental protocol. The four experimental RAN tasks were interspersed among the 14 test measures so that subjects were asked to perform no more than two RAN procedures in succession. Tasks were presented in a fixed order. However, to control for possible order effects within the two experimental RAN procedures, presentation of high vs. low density sets was counterbalanced across subjects.

Data Collection

Procedure

Potential participants received an informed consent document describing to them and to their parents/caretakers the purpose of the study and the requirements of the participant. The document contained information regarding the confidentiality of those involved and statements citing that their role was completely voluntary and that they had the right to withdraw without penalty. A student was not allowed to participate in the study without a signed and returned IRB-2 approved parental consent form. A participant assent script was used prior to each assessment session to assure that the student was participating voluntarily. Copies of these forms are attached in the Appendix.

Data collection took place on site at the school during the months of April and May 2010. Students were tested individually in a quiet room in the school media center by the researcher or by a trained undergraduate research assistant. Each testing session took approximately 30 to 40 minutes to complete.

Instrumentation

All children were administered a test battery to assess the following components that were used in the analyses.

Verbal ability. The Verbal Analogies subtest from the Woodcock Johnson III Test of Cognitive Abilities (WJ-III-COG: Woodcock, McGrew, & Mather, 2001) was administered to assess student's verbal ability. This task required the participant to state a word to complete a two pair analogy (e.g., "*eye* is to *see* as *ear* is to ____").Three training items were administered prior to the test and testing was completed when a student missed three items in a row.

Phonological awareness. The Elision subtest from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) was administered to assess each participant's phonological awareness skills. The Elision subtest requires the participant to listen to and repeat a word, and then say the word without a specified syllable or sound (e.g, "say the word *spider* without saying *der*; say the word *split* without saying /p/). Testing was discontinued when the participant missed three items in a row. The score was recorded as the total number of all items answered correctly.

Rapid Automatized Naming (RAN) speed. A modified version (i.e., shortened: one rather than two trials) of the Rapid Automatized Naming subtests for colors, objects, letters and digits from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) was administered to measure each participant's rapid naming ability. In each of these tasks, 6 practice items were first named by the examiner and repeated by the participant. The participant was then given an 8 x 12 card showing the 6 items in 4 rows of 9 randomly repeated items and asked to name each stimulus item as quickly as possible without making any mistakes. The total time taken to name each stimulus set was timed with a hand-held digital stop watch and recorded and uncorrected accuracy errors were noted.

Word Reading Fluency. The Sight Word Efficiency (SWE) and Phonemic Decoding Efficiency (PDE) subtests from the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Roshotte, 1999) were used to measure each participant's ability to read real and pseudo- words fluently at the single word level. On the each of these subtests, practice items were presented and then the participant was given a series of real (SWE) or pseudo-words (PDE) and asked to read aloud as many as possible in 45 seconds. Inaccurate responses were deducted so that the final score reflected the total number of words correctly read within the given time frame.

Word Reading Accuracy. The Letter-Word Identification (LWI) and Word Attack (WA) subtests from Woodcock-Johnson III Tests of Achievement (WJ-III-ACH; Woodcock, McGrew, & Mather, 2001) were used to measure each participant's ability to read both real and pseudo-words without time limits. On the LWI subtest, the participant was asked to name letters, identify letter sounds, and read real words aloud from a list. Testing was continued until the six highest-numbered items administered were incorrect. The score was recorded as the total number of letters and words correctly read. On the WA subtest, the participant was asked to read or "sound out" pseudo-words aloud from a list. Testing was continued until the six highest-numbered items administered were incorrect and the score was recorded as the total number of psueduo-words correctly read.

Orthographic Knowledge. A timed orthographic knowledge task called “wordchains” (Kirby, 2003) was administered. In this pencil-paper task, subjects were given a 8 ½ x 11 sheet of paper that had 11 rows of increasingly longer word strings typed together with no spaces between the words (e.g. fatrunball, dollbirdhopseehe). Following a demonstration and three practice items, participants were instructed to insert a pencil slash marking word boundaries (fat/run/ball). Participants were given 30 seconds to complete the task. The total number of accurate responses was tallied to derive the total score, with no penalty for inaccurate responses. This unpublished test has been used in previous research (Georgiou, et al., 2009).

Processing Speed. The Decision Speed sub-test from the Woodcock-Johnson III Test of Cognitive Abilities (WJ-III-COG: Woodcock, McGrew, & Mather, 2001) was administered. For this task, the participant was given a 4 page booklet that showed 10 clearly delineated rows of 7 objects presented as black line drawings on each page. Participants were instructed to circle the two items in each row that were conceptually similar (e.g. dog and cat; watch and clock) as quickly as possible. Following a demonstration and three practice items, this task had a three minute time limit. The total score recorded was the number of matching pairs circled correctly within the given time frame.

Experimental RAN Tasks

In order to examine the influence of the independent variable, RND, on the dependent variable, RAN response times, four experimental RAN tasks were created:

Experiment 1 measured RND effects on rapid naming speed of objects while Experiment 2 measured RND effects rapid naming speed of digits.

Stimulus Item Selection. Stimulus items used in both of the experimental RAN tasks were contrasted for RND across two conditions (High Dense and Low Dense) such that one set of words from each experiment depicted words with significantly more rime neighbors than the other set. In order to isolate the effects of RND, mean lexical frequency of stimulus sets was matched across conditions in each experiment. Individual and mean RND and Log Frequency counts for stimulus items used in each experiment are shown below in Tables 2-2 and 2-3. RND measures were taken from the lexical data base of 4,086 monosyallbic words compiled by DeCara and Goswami (2002). The OVC (onset, vowel, consonant) metric for RND was used which is defined as the number of other monosyllabic words that share their underlying rime pattern with the target word. The frequency counts were originally derived from the HAL Corpus and refer simply to the number of times the word occurred within a collected 131 million spoken word corpus. The log transformed values, reported here, were taken from the English Lexicon Project database (Baloto, 2007).

Stimulus items for Experiment 1 were presented as black line drawings. For both conditions (high, low), 5 objects were selected and arranged on a single 8 ½ x 11 page in randomly repeating order in 4 rows of 9 objects for a total of 36 items. This presentation format and total number of items to-be-named was consistent with the CTOPP version of the RAN.

To control for possible spurious effects of phonology, none of the stimulus items were presented in immediate succession (e.g., nose-nose) and none of the items within each condition shared either onsets (e.g. **n**ose-k**n**ife) or rimes (e.g., n**ose**-r**ose**). Words selected were also matched across conditions for syllable structure such that 4 words depicted in each picture set were comprised of simple (VC or CVC) syllables and 1 word in each condition was comprised of a complex (CCVC) syllable with identical initial consonant clusters in the onset position (***tr**ain* in the high condition and ***tr**uck* in the low condition).

To control for possible spurious effects of semantics, all objects selected were concrete nouns with high (>530) imageability (M= 602.44, SD=24.41) and familiarity (M=568.22, SD=41.94) ratings (Coltheart, 1981). Additionally, stimulus pairs were selected from similar semantic categories across conditions, such that the five objects selected for each condition represented 1 natural kind (farm animal), 3 artifacts (1 kitchen item and 2 transportation items) and 1 facial feature.

Table 2-2. Experiment 1: Means and standard deviations for rime neighborhood density (RND) and log frequency counts of object stimuli

High Density Condition	RND	Log Frequency	Low Density Condition	RND	Log Frequency
Car	29	11.365	Truck	14	9.23
Train	38	10.059	Bus	9	10.485
Sheep	18	8.926	Pig	14	8.76
Bowl	27	9.280	Cup	4	10.233
Ear	33	9.334	Nose	8	9.541
Mean (SD)*	29 (7.44)	9.793 (0.97)	Mean (SD)*	9.8 (4.26)	9.649 (0.71)

*Difference in mean RND for high vs. low density conditions is significant (t=5.00; p<.001).
Difference in mean Log frequency for high vs. low density condition is ns. (t=0.26; p=.797).

Stimulus items for Experiment 2 were typed in 48 pt Calibri (body) font, consistent with the CTOPP version of the RAN digit task. Because only the monosyllabic digit names were used in the experimental task, each condition presented only 4 digits repeatedly arranged on a single page in random order in 4 rows of 9 digits for a total of 36 items.

An independent samples t-test showed a significant difference in RND means across conditions (*t*= 3.56; *p*<.05). Due to the constraints of using only eight stimulus items, control for other variables could not be planned, as it was in Experiment 1. However, syllable structure and log frequency counts were serendipitously found to be quite well matched. Differences in mean log frequencies of words across conditions were non-significant (*t*=-0.06; *p*=.95) and each set contained one complex syllable and three simple syllables. Phonological overlap was also minimal within sets, with the exception of a shared nucleus (five and nine) in the low condition.

Table 2-3. Experiment 2. Means and standard deviations for rime neighborhood density (RND) and log frequency counts of digit stimuli

High Density Condition	RND	Log Frequency	Low Density Condition	RND	Log Frequency
Two (2)	60	13.031	One (1)	17	14.172
Three (3)	40	12.015	Five (5)	11	12.015
Four (4)	56	11.353	Six (6)	8	10.685
Eight (8)	26	9.768	Nine (9)	24	9.597
Mean (SD)	45.5 (15.60)*	11.54 (1.36)	Mean (SD)	15 (7.07)*	11.61 (1.96)

*Difference in mean RND for high vs. low density conditions is significant (*t*=3.5596; *p*=.012).
Difference in mean Log frequency for high vs. low density condition is ns. (*t*=-.0625; *p*=.9522).

Procedure. The protocol for administering both of the experimental RAN tasks was identical to the CTOPP version of the RAN. To ensure accurate responses, prior to each task, stimulus items used in each RAN were first named by the examiner in an untimed practice row and participants were asked to name each item independently. RTs for naming each set of 36 items were recorded in seconds to the nearest one hundredths using a handheld digital stop watch. Accuracy errors that were not self-corrected were tallied. RTs for participants who made more than three accuracy errors were planned to be discarded from the analysis; however, none of the participants exceeded the 3 error limit.

CHAPTER 3
RESULTS

Data Preparation and Preliminary Analysis

All 39 participants completed a battery of 18 tasks. Data for all RAN tasks were visually examined and found to be somewhat positively skewed. To create a more normalized distribution, response times for outliers with scores ± 2 SD from the group means were replaced using a winsorization process (Tabachnick & Fidell, 2001). This process, which has been used in previous RAN research (Georgiou, et al., 2009) replaces outliers with the next highest, non-outlier score, plus one unit (i.e., one second), thus, preserving the rank of the score within the distribution. As a result, in the experimental RAN tasks, two data points were replaced in the Kindergarten group and four data points were replaced in the 3rd grade group. Additionally, in the Kindergarten group, one score in each of the CTOPP picture, color and letter RAN tasks was replaced. These cleaned data were used in all of the following analyses.

To ensure that order of presentation, which was counterbalanced across subjects, did not result in systematic bias, independent *t* tests were conducted to test for spurious order effects. In this procedure, group means for both of the experimental RAN tasks were compared across conditions of order (high dense before low dense vs. low dense before high dense). Results from each of these analyses were non-significant. Therefore, order of presentation had no significant effects on RAN times.

An independent samples *t* test was also conducted for each of the 14 non-experimental tasks to determine if the two groups performed differently. As expected, large group differences were revealed ($p<.0001$) for all tasks. Group means for these tasks are presented in Table 3-1.

Table 3-1. Descriptive statistics for reading and non-reading measures

	Kindergarten (n=18)			3rd Grade (n=21)			
Measure	Range	Mean	SD	Range	Mean	SD	*t****
Age (mos)	67.7-78.3	73.74	2.43	104.7-126	111.71	6.83	-23.78
CTOPP Picture RAN	34.03-55.00	44.37	7.79	22.84-44.10	31.88	5.97	6.07
CTOPP Color RAN	31.09-59.37	46.38	9.58	21.4-44.72	31.3	6.64	6.05
Analogies	0-6	3.39	1.79	0-9	6.33	1.90	-4.95
Decision Speed	4-24	16.17	5.21	15-35	25.90	5.10	-5.88
Letter Word Identification	15-37	21.94	5.90	35-64	50.05	6.80	-13.67
Word Attack	3-21	5.94	4.32	6-32	20.38	6.60	-8.19
CTOPP Letter RAN	26.12-57.90	40.85	20.49	12.12-24.81	18.55	3.30	7.67
CTOPP Digit RAN	23.68-56.47	35.55	8.52	13.81-26.50	19.07	5.19	7.81
Elision	0-17	4.61	3.96	5-20	11.62	4.78	-4.94
Word Chains	0-14	4.00	3.45	9-31	18.38	6.037	-9.28
TOWRE Sight Word Efficiency	0-50	9.11	13.73	34-80	64.05	10.94	-13.91
TOWRE Phonemic Decoding Efficiency	0-29	3.44	7.19	7-45	30.29	11.76	-8.73

***Group difference for all measures were significant at p<.0001 level (2 tailed).
Scores for RAN tasks are reported as response times in seconds. Scores reported for all other tasks represent the total number of items correct for each task.

Data Analysis

The effects of the independent variable (RND) on the dependent variable (RAN RTs) were examined for each experiment using a paired samples *t* test. A *t* test was chosen as the most appropriate test of significance due to the small sample size. Use of this analysis is supported by Newton & Rudestam (1999) who write:

> If you are using an ANOVA design, Rosenthal & Rosnow (1991) advise you to plan *t* tests that are of interest to you prior to data collection and conduct those *t* tests whether or not the overall *F* test is significant. In fact, one need not compute an overall *F* test at all… (p. 234)

These *t* tests were used to answer Experimental Question 1: *Does RND have facilitative effects on object RAN?* and Experimental Question 2: *Does RND have facilitative effects on digit RAN?*

A 2 (Group: Kindergarten, 3rd Grade) X 2 (density: low, high rime neighborhood density) mixed factor ANOVA was also conducted. In this analysis, the individual subject's RAN naming times for each list were the dependent variables, with rime neighborhood density (low, high) as the within-group variable and Group (Kindergarten, 3rd Grade) as the between group variable. Additionally, ANCOVAs controlling for variables of developmental maturation (age, processing speed) and variables of developmental reading skill (orthographic knowledge and sight word efficiency) were conducted. These analyses were used to answer Experimental Question 3: *Does acquisition of reading skill change the way children access words for rapid naming?*

Pearson Correlation Coefficients were also calculated to measure the strength of the relationships between the experimental RAN tasks and each of the reading and non-reading measures. These analyses addressed Experimental Question 4: *Compared to standard measures of RAN, how does manipulation of RND of the stimulus items* *affect RAN's relationship to various sub-skills of reading?* For continuity and ease of reading, results from these analyses are presented below in order of the experimental questions and not in the order that the analyses were conducted.

Experiment 1: Object RAN Task

Significance Tests

***t* Test**. In this analysis, a significant effect of RND was obtained for the 3rd grade group, $t(20) = -2.776$, $p = .012$, but not for the Kindergarten group, $t(17) = -.102$, $p = .920$. Thus, when small sample statistics were used, a significant effect of RND was found for picture RAN in the older group.

ANOVA. Mean response times for younger children were slower than older children in both conditions. Thus, there was a significant main effect of group, $F(1,37) = 43.257$, $p < .0001$ with a large effect size ($\eta^2 = 0.539$). For 3rd grade, high density objects were named faster than low density objects; 3rd: $M_{HD}= 31.375$, SE=1.680 < $M_{LD}=34.228$, SE=1.803) while RTs for Kindergarten children were virtually identical across conditions (K: $M_{HD} = 48.159$, SE= 1.815 < $M_{LD}= 48.35$, SE= 1.948). The 2 x 2 factorial ANOVA revealed no main effect of density, $F(1,37)=2.182$, $p =.148$, $\eta^2 = 0.056$, indicating no significant difference in RTs across high density ($M_{HD} = 39.767$, SE =1.237) and low density ($M_{LD}=41.289$, SE=1.327) conditions. A main effect of group, $F(1,37) = 43.257$, $p < .0001$ was obtained with a moderate effect size ($\eta^2 = 0.539$). No interaction between group and density was found, $F(1,37) = 1`.668$, $p = .205$, $\eta^2 = 0.043$.

ANCOVAs. Because processing speed and orthographic knowledge1) improve as children mature and 2) have been argued to contribute to RAN, the main effect of group was further explored by controlling for age, decision speed, and word chains in three separate analyses. When individually controlled, none of these covariates, including age, $F(1,37)=6.750$, $p=.013$, $\eta^2=.158$, significantly reduced the main effect of group. When only Sight Word Efficiency (SWE) was entered as a covariate, the group difference was eliminated, $F(1,37)=.039$, $p=.844$, $\eta^2=.001$. Results from these ANCOVAs indicate that neither developmental maturation nor orthographic knowledge could account for the large differences between Kindergarten and 3rd grade performance. Instead, group differences were found to be solely accounted for by efficiency of word reading skill.

Correlations

Object RAN x Reading Measures. Table 3-2 shows Pearson correlations between the object RAN tasks and the reading measures for Kindergarten. In this analysis, all of the RAN tasks were significantly correlated with each other, as were all of the reading tasks. However, none of the RAN tasks were significant correlates of

Table 3-2. Kindergarten: Correlations between object RAN and reading measures

	Object RAN			Untimed Reading		Timed Reading	
	Low Dense	High Dense	CTOPP	Let Wdld	Wd Attack	SWE	PDE
Low Dense	---	.685**	.693**	-.341	-.285	-.496*	-.360
High Dense		---	.688**	-.253	-.110	-.363	-.244
CTOPP			---	-.224	.034	-.223	-.075
LetWdld				---	.751**	.850**	.835**
Wd Attack					---	.810**	.920**
SWE						---	.911**

LtWdId=Letter Word Identification, WdAtt=Word Attack, SWE=Sight Word Efficiency, PDE=Phonemic Decoding Efficiency
**Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

reading, with the exception of the significant correlation between the low density objects and SWE. Generally, these results are consistent with existing research which finds that, at least by the end of 1st grade, object RAN is a poor predictor of reading.

Table 3-3 shows correlations between object RAN and reading measures for 3rd grade. Consistent with the findings from Kindergarten, the 3rd grade group's performance on all RAN tasks correlated significantly with each other, as did all of the reading tasks. Similarly, a relationship between SWE and tasks was found for both the low density set (r=-.502), and high density stimulus set (r=-.592). The finding that the CTOPP Object RAN task did not correlate with any of the reading measures in either group suggests that the stimuli used in the Experimental RAN tasks capture some shared variability with reading that the CTOPP RAN stimuli do not.

Table 3-3. Third grade: Correlations between object RAN and reading measures

	Object RAN			Untimed Reading		Timed Reading	
	Low Dense	High Dense	CTOPP	LetWdld	Wd Attack	SWE	PDE
Low Dense	---	.676**	.792**	-.009	-.027	-.502*	-.143
High Dense		---	.684**	-.191	-.065	-.592**	-.265
CTOPP			---	.011	-.027	-.331	-.013
LetWdld				---	.825**	.639**	.875**
Wd Attack					---	.526*	.831**
SWE						---	.798**

LtWdld=Letter Word Identification, WdAtt=Word Attack, SWE=Sight Word Efficiency, PDE=Phonemic Decoding Efficiency
**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Object RAN x Non-Reading Measures. Table 3-4 shows correlations between Object RAN and non-reading measures in Kindergarten. In this analysis, RAN was found to be unrelated to every non-reading measure. The only significant correlation revealed in the analysis was between elision and word chains. This finding is consistent with the assertion that phonological awareness and orthographic knowledge develop in a reciprocal fashion during the early stages of reading acquisition.

Table 3-4. Kindergarten: Correlations between object RAN and non-reading measures

	Object RAN			Phoneme-Grapheme		Non-Phonological	
	Low Dense	High Dense	CTOPP	Elision	Wd Chain	Dec Speed	Analogies
Low Dense	---	.685**	.693**	-.295	-.450	.030	-.318
High Dense		---	.688*	-.215	-.148	.148	-.089
CTOPP			---	-.157	-.131	.081	-.042
Elision				---	.794**	-.225	.197
Wd Chain					---	-.085	.162
Dec Speed						---	.246

** Correlation is significant at the 0.01 level (2-tailed).

Table 3-5 shows correlations for Object RAN and non-reading measures for 3rd Grade. Consistent with the results from the Kindergarten group, no significant relationship was found between any of the object RAN and non-reading measures. This indicates that phonological awareness, orthographic knowledge, processing speed and verbal ability are generally unrelated to object RAN performance in both novice and experienced readers.

Also consistent with the Kindergarten group, orthographic knowledge was the only task that correlated with another non-reading measure. In Kindergarten, orthographic knowledge correlated strongly with phonological awareness (r=.794) but not processing speed (r=-.085). However, in the 3rd grade group, this relationship was reversed such that orthographic knowledge was weakly correlated with phonological awareness (r=.283), yet strongly correlated with processing speed (r=.711). This finding is interpreted to mean that by 3rd grade, the speed at which high frequency word forms are recognized in print is largely independent of explicit phonological awareness skill. The strong relationship between the orthographic knowledge task, word chains, and the processing speed measure, decision speed, may reflect the shared multi-component demands of the tasks (i.e., visual scanning, pencil marking) as well as more domain general speed of processing demands.

Table 3-5. Third Grade: Correlations between object RAN and non-reading measures

	Object RAN			Phoneme-Grapheme		Non-Phonological	
	Low Dense	High Dense	CTOPP	Elision	Wd Chain	Dec Speed	Analogies
Low Dense	---	.676**	.792**	.378	-.244	-.153	-.146
High Dense		---	.684**	.128	-.230	-.156	.025
CTOPP			---	.372	-.182	-.016	-.225
Elision				---	.343	.283	-.073
Wd Chain					---	.711**	-.012
Dec Speed						---	.101

**Correlation is significant at the 0.01 level (2-tailed).

Experiment 2: Digit RAN Task

Significance Tests

t Test. In contrast with the results from Experiment 1, the paired samples t-test revealed no significant effect of RND in either the Kindergarten $t(17) = -.752$, $p = .462$ or the 3rd grade group $t(20) = -.300$, $p = .767$. From these data, it can be concluded that RND has no effect on digit RAN speed in either novice or experienced readers.

ANOVA. As expected, mean response times for younger children were slower than older children in both the high dense condition ($M_K = 32.662$, SE = 1.238 > $M_3 = 17.000$, SE = 1.146) and the low dense condition ($M_K = 33.329$, SE = 1.219 > $M_3 = 17.170$, SE = 1.129). Consistent with the results for Experiment 1, the ANOVA for the digits tasks revealed a powerful main effect of group, $F(1,37) = 99.602$, $p = .000$; $\eta^2 = .729$. In the combined group analysis, participants were slightly faster naming digits in the high density condition ($M_{HD} = 24.831$, SE=.843) compared to the low density condition ($M_{LD} = 25.249$, SE = .831), but these differences did not reach significance, $F(1,37) = .670$, $p = .418$; $\eta^2 = .018$.

ANCOVAs. The main effect of group was again explored by covaryng the following three measures individually: age, processing speed, and orthographic knowledge. Consistent with the results from the object RAN ANCOVA, this analysis failed to eliminate group differences. This was also the case even when all three variables were partialled out simultaneously, $F(1,37) = 5.223$, $p = .029$, $\eta^2 = .133$. Also consistent with the findings from Experiment 1, when SWE alone was entered as a covariate, group differences were reduced to non-significant levels $F(1,37) = .398$, $p = .532$, $\eta^2 = .011$.

Correlations

Digit RAN X Reading Measures.Table 3-6. shows Pearson Correlations between Digit RAN and reading measures for Kindergarten. All of the digit RAN tasks

Table 3-6. Kindergarten: Correlations between digit RAN and reading measures

	Digit RAN			Untimed reading		Timed reading	
	Low dense	High dense	CTOPP	LetWdld	Wd attack	SWE	PDE
Low Dense	---	.848**	.891**	-.513*	-.534*	-.586*	-.509*
High Dense		---	.718**	-.485*	-.586*	-.594**	-.515*
CTOPP			---	-.532	-.519*	-.607**	-.523*
LetWdld				---	.751**	.850**	.835**
Wd Attack					---	.810**	.920**
SWE						---	.911**

LtWdId=Letter Word Identification, WdAtt=Word Attack, SWE=Sight Word Efficiency, PDE=Phonemic Decoding Efficiency
*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

were strong correlates, as were all of the reading measures. All of the digit RAN tasks were also moderate to strong correlates for all of the reading measures. This was the case for both timed and untimed measures of reading.

Table 3-7 shows correlations for digit naming and reading measures for 3rd Grade. All of the reading tasks were correlated. In contrast to the results from Kindergarten, which found a significant relationship between all digit RAN tasks and all reading tasks, correlations from the 3rd grade group revealed no significant relationship between digit RAN and untimed measures of reading; however, a strong relationship with timed measures was found. All of the digit RAN tasks, including the CTOPP, correlated with SWE; only high RND set correlated with PDE. Thus, while RTs for digits did not seem to be affected by RND, the high density digits proved to have a stronger and more consistent relationship with reading speed than either the low density digits or the CTOPP digits.

Table 3-7. Third grade: Correlations between digit RAN and reading measures

	Digit RAN			Untimed reading		Timed reading	
	Low Dense	High Dense	CTOPP	Let Wdld	Wd Attack	SWE	PDE
Low Dense	---	.693**	.629**	-.055	-.024	-.547*	-.260
High Dense		---	.764**	-.308	-.175	-.785**	-.549*
CTOPP			---	-.036	.015	-.546*	-.268
Let Wdld				---	.825**	.639**	.875**
Wd Attack					---	.526*	.831**
SWE						---	.798**

LtWdId=Letter Word Identification, WdAtt=Word Attack, SWE=Sight Word Efficiency, PDE=Phonemic Decoding Efficiency
**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Digit RAN x Non-Reading Measures. Table 3-8 shows Correlations between digit RAN and non- reading measures for Kindergarten. These results show that neither of the Experimental digit RAN tasks correlated with any of the non-reading measures. However, a moderate relationship between the CTOPP digit RAN and orthographic knowledge (r=.565) was revealed. Because digits are the last orthographic codes to be learned, this correlation may reflect the fact that recognition of both digits and word forms have only recently been acquired.

Table 3-8. Kindergarten: Correlations between digit RAN and non-reading measures

	Digit RAN			Phoneme-Grapheme		Non-Phonological	
	Low Dense	High Dense	CTOPP	Elision	Wd Chain	Dec Speed	Analogies
Low Dense	---	.848**	.891**	-.298	-.396	-.338	-.096
High Dense		---	.718**	-.242	-.274	-.252	-.175
CTOPP			---	-.355	-.565*	-.140	-.159
Elision				---	-.794**	-.225	.197
Wd Chain					---	-.085	.162
Dec Speed						---	.246

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table 3-9 shows correlations between digit RAN and non- reading measures for 3rd Grade. Results from this analysis were consistent with those found in the Kindergarten group. The only exception was that the significant relationship between orthographic knowledge and the CTOPP digit RAN found in Kindergarten (r= -.565) was non-existent in 3rd grade (r=-.001). Taken together with results from Experiment 1, it can be concluded that phonological awareness, orthographic knowledge, processing speed and verbal ability were poor predictors of RAN, regardless of stimulus type or group.

Table 3-9. Third Grade: Correlations between digit RAN and non-reading measures

	Digit RAN			Phoneme-Grapheme		Non-Phonological	
	Low Dense	High Dense	CTOPP	Elision	Wd Chain	Dec Speed	Analogies
Low Dense	---	.693**	.629**	.213	.190	.297	.047
High Dense		---	.764**	.074	-.136	-.139	.084
CTOPP			---	.320	-.036	-.080	.058
Elision				---	.343	.283	-.073
Wd Chain					---	.711**	-.012
Dec Speed						---	.101

** Correlation is significant at the 0.01 level (2-tailed).

CHAPTER 4
DISCUSSION

Addressing the Experimental Questions

This study was designed to address four primary goals: 1) to test whether RND facilitates or inhibits response times (RTs) of rapid automated naming (RAN), 2) to determine if the effects of RND are consistent across stimulus types 3) to determine if the effects of RND are consistent across two levels of reading skill/experience and 4) to explore relationships between RAN and reading skills when RAN stimuli are controlled for strength of phonological representation according to lexical restructuring theory.

The effects of RND on object and digit RAN speed were tested in 39 children in Kindergarten and 3rd grade. Fourteen measures of reading and reading related sub-skills and four experimental RAN tasks, each contrasted for high and low RND, were used to test the effects of picture and digit RAN speeds within and across groups.

The Effects of RND on RAN

The first goal of this study was to explore whether or not strength of phonological representation (measured in this study by experimentally manipulating the phonological similarity variable RND) has facilitation or inhibition effects on RAN speed. Previous research has reported that increased RND exerts an inhibition effect--resulting in slower RTs--on some tasks (e.g., lexical decision), but exerts a facilitation effect --resulting in faster RTs--on other tasks (e.g., confrontation naming and reading). Because RAN is also a naming task and correlates highly with reading speed, it was predicted that RTs for words from high dense neighborhoods would be faster than those from low dense neighborhoods in both experiments.

In the combined group ANOVA, means for RAN speed were slightly faster, though not significantly so, in the high dense condition in Experiment 1, $M_{HD} = 38.4 < M_{LD} = 40.59$, and virtually identical across conditions in Experiment 2, $M_{HD} = 24.3 = M_{LD} = 24.0$. The within groups analyses also found RTs for naming high dense words to be either faster or identical to RTs for naming low dense words: Object RAN: Kindergarten: $M_{HD}= 48.16 = M_{LD}=48.35$;3rd Grade: $M_{HD}=31.38 < M_{LD}= 34.23$; Digit RAN: Kindergarten: $M_{HD}=32.66 < M_{LD}= 33.33$; 3rd Grade: $M_{HD}= 17.00 = M_{LD}= 17.17$. Again, differences in means were not statistically significant but the trend provides no indication that high RND exerted an inhibition effect on RAN. Comparing the means using a t test, however, revealed a significant processing advantage in the 3rd grade group for the picture RAN task. Consistent with the prediction that words from high dense neighborhoods should be easier to access because the strength of connections is stronger for words with finer grain differentiations, this study provided some direct evidence that RND has a facilitative effect on RAN; however, this effect appears to be dependent upon both stimulus choice and group selection.

RND Effects on RAN Across Two Stimulus Types

The second goal of the study was to examine whether or not the effects of RND on RAN are consistent across alphanumeric and non-alphanumeric stimuli. Previous research finds that for older children, RTs for digit RAN are more strongly related to reading than RTs for picture RAN. Some researchers have hypothesized that digits are more difficult to access because they are lacking in semantic representation, while others suggest that digits are more difficult to access because they are lacking in phonological representation. To explore the latter hypothesis, the effects of RND on digit RAN speed were tested in Experiment 2. It was predicted that if access to digits is related to underspecified phonological representations, older children should show a processing advantage for naming digits that reside in dense neighborhoods. This hypothesis was not supported because mean RTs for digit naming speed across high and low RND conditions were virtually identical in both the kindergarten and 3rd grade groups. Hence, no evidence was found to support the prediction that variability in underlying phonological representation affects naming speed of digits.

RDN Effects on RAN Across Two Stages of Reading Development

The third goal of this study was to assess whether or not acquisition of reading skill changes the way children access words in a serial naming task, such as RAN. Based on the developmental hypothesis that word reading is phonologically mediated in younger but not older children, and the hypothesis that RAN is highly predictive of reading because serial naming taps the same underlying constructs as word reading, it was predicted that RND would have stronger effects on RAN RTs for children in Kindergarten than for children in 3rd grade.

The ANOVA found no interaction between group and density. However, *t* test results from Experiment 1 (object stimuli) showed that RND had significant facilitation effects on RAN RTs for older, but not younger children whereas results from Experiment 2 (digit stimuli) showed no effects of RND on RAN. Hence, in stark contrast to the predicted outcome, these data indicate that phonology plays a mediating role in object naming speed for children who are reading (3rd graders) but not for emergent readers (Kindergarteners).

RANs Relationship to Reading and Reading Related Skill

The final goal of the study was to explore RANs relationship to reading and other reading-related measures. Two questions were of particular interest. The first was determining if the experimental RAN tasks correlated more strongly with other sub-skills of reading (i.e., word identification, decoding) when compared to typically employed (CTOPP) RAN tasks. The second was to determine if these relationships are consistent across emergent and more experienced readers. Because all of the non-reading measures correlated poorly with RAN across groups, the following section focuses on summarizing pertinent findings regarding RAN’s specific relationship to the reading measures.

Experiment 1: Object RAN’s Relationship to Reading. Consistent with existing research, all of the Object RAN tasks proved to be poor predictors of reading accuracy across groups. This finding was true for both of the experimental object RAN tasks used in Experiment 1, as well as for the object RAN task taken from the CTOPP.

In terms of reading speed, correlations between PDE (i.e., timed decoding) and Object RAN were consistently weak across groups; this was the case for both the CTOPP and experimental RAN tasks. Correlations between SWE (i.e., timed, exception word reading) and Object RAN stimuli were also consistently weak across groups when the CTOPP RAN was used. However, when the experimental Object RAN tasks (i.e., low and high RND stimuli) were used, a moderate correlation with SWE was revealed in the older, but not younger group. These results were unexpected because the relationship between object RAN and reading speed has previously been shown to dissipate after 1st grade. In addition, there was a strong linear relationship between high density RAN and SWE.

The finding that the experimental RAN tasks were better predictors of reading speed than the CTOPP Object RAN task is interpreted as supporting evidence that phonology plays an important role in both rapid object naming and in rapid word naming and that this relationship strengthens as children gain reading experience. Further, because the experimental RAN tasks correlated with SWE and not PDE, the relationship between phonology and reading speed appears to be most evident in tasks that tap automatic access of sight words, rather than in tasks that tap sub-skills in phonemic decoding.

Experiment 2: Digit RAN's Relationship to Reading. In the Kindergarten group, Digit RAN proved to be a broad and moderate predictor of all measures of reading. This was the case irrespective of the digit set used (i.e., high or low RND). In the 3rd grade group, digit RAN's relationship to reading was found to be much more specific to measures of reading speed.   Comparing the CTOPP RAN to the two Experimental RAN stimuli in the 3rd grade group, all three RAN tasks correlated significantly with SWE; however this relationship was stronger for the high density digits, which also correlated significantly with PDE. Thus, while no significant difference in RTs was found between the low and high density conditions for actual naming speed, the high density digits, those with presumably stronger phonological representations, appear to have an edge over those stimuli with weaker phonological representations in predicting reading speed. This was confirmed by finding a strong linear relationship between high RND RAN performance and SWE.

In summary, findings from the correlational analyses generally showed that naming speed for digits is a stronger and more consistent predictor of reading in both groups than naming speed for objects. Findings from this study are consistent with previous reported longitudinal research (Georgiou, et al. 2009): concurrent correlations between RAN and reading accuracy appear to decrease with reading experience while concurrent correlations between RAN and reading speed appear to increase. In addition, across stimulus types, naming speed for high density stimuli predicted reading speed better than the either low density stimuli or typically employed CTOPP RAN tasks.

General Discussion

Is RAN Phonological?

This study revealed a number of findings regarding the phonological underpinnings of RAN and its relationship to reading. By manipulating the phonological variable RND, phonological strength of representation was found to exert a facilitation effect on RAN response times for objects, but not digits, in older, but not younger, children. While RAN is theorized by many researchers to reflect the integrity of a phonological access mechanism, empirical evidence for a phonological explanation for RAN has been hard to come by. Indeed, a large and growing research base converges to find that phonology, specifically measured on tasks of phonological awareness, fails to predict RAN. Consistent with previous research, results from the present study also found the correlational relationship between phonological awareness and RAN to be weak, at best. However, controlling for the phonological density of the experimental stimuli in this study, the direct effects of phonological representation on RAN were examined.

Several researchers have suggested that individual variability across phonological awareness and RAN performance may arise because the cognitive demands of the two tasks differ so greatly (Breznitz, 2006; Ramus, 2001; Share, 2008). It has been also been theorized that the development of phonological representation occurs at two levels

(Seymour, 2005; Gombert, 1992; Metsala & Walley, 1998): the primary level of representation supports the development of listening and speaking and is implicitly learned through spoken language experience, while the secondary level supports the development of reading and writing and is explicitly learned though literacy instruction. Because phonological awareness is operationally defined as explicit awareness of the phonological structure of oral language that develops in tandem with learning orthographic codes, finding a phonological relationship between RAN and RND, but not phonological awareness, may be explained by the considering that RND and phonological awareness reflect variability in phonology at two different levels of representation: RND at the primary level and PA at the secondary level. The supposition that PA reflects phonology of the secondary level of representation has been implicated by Ramus, (2001). It can be argued, then, that RAN is particularly sensitive to implicit phonological representation that develops at the primary level, but not to phonological representation that develops at the secondary level. Thus, experimental manipulation of the implicitly formed phonological variable RND may prove to be a better means of measuring the integrity of a phonological access mechanism than the standard method of correlating explicit measures of phonological awareness (e.g., elision) with a phonologically uncontrolled RAN (e.g., CTOPP RAN tasks), especially among older readers.

Do Children "RAN" like they Read?

Because young children are more dependent on phonology for reading, it was predicted that, compared to older children, younger children's RAN performance would be more affected by variability in phonological representation. Results from this study found no evidence that phonological representation affected RAN speed in

Kindergarten. Considering the previous discussion regarding primary vs. secondary levels of phonological representation, it clearly stands to reason that phonology mediates beginning reading at the secondary level of representation, related to the acquisition of letter-sound correspondences and that the effects of this level of phonology would not extend to the retrieval of object names. This explanation is consistent with Share's (2008) assumption that phonological awareness is best construed as a developmental sub-skill of reading, related to learning decoding strategies in the very beginning stages of reading.

In marked contrast with the initial prediction, several findings from the present study indicate that phonology, in fact, plays a larger role for older children than for younger children. Arguably the most noteworthy result in the present study was the finding that the large group differences in RAN speed were explained almost entirely by efficiency of sight word reading. So, while typically developing readers clearly do not "RAN" like they decode, they do appear to "RAN" like they retrieve sight words.

RAN's specific relationship to sight word reading was recently reviewed in longitudinal investigation which found that non-alphanumeric RAN performance in pre-readers predicted later reading speed and subsequent alphanumeric RAN performance (Lervåg & Hulme, 2009). The authors speculate that these relationships are mediated by a common neural mechanism that supports object recognition. Neuro-imaging studies find this area, the left mid-fusiform, is activated for both object naming and reading. In skilled readers, proficiency in automatic word identification is correlated with increased activity in this region. Thus, this region has been dubbed, but some researchers, as a pre-semantic visual word-form area (Sandak, et al., 2004). Lervåg & Hulme (2010) write:

> From a developmental perspective, it seems reasonable to argue that the left mid-fusiform area may start out as an object recognition area (an area involved in identifying objects prior to name retrieval), and that this system is then recruited to serve an analogous function in identifying written words (p. 1049).

That is, once an orthographic code is amalgamized with meaning, word naming is analogous to object naming and both of these tasks are highly dependent upon the integrity of the mid-fusiform area. Hence, while RAN has previously been construed as a proxy of reading, it may be more accurate to say, neurologically speaking and more specifically, that skilled reading of amalgamized words, (i.e., immediate word recognition involving simultaneous recognition of a word's pronunciation, spelling, and meaning) is a proxy of naming. Thus, RAN's ability to predict future reading and naming speed performance in pre-readers may lie solely in its ability to tap the integrity of the mid-fusiform area.

Support for this parsimonious explanation for RAN has also been forwarded in a recent investigation which found that, compared to non-dyslexic peers, compensated adult dyslexic readers had significantly slower response times for both object naming and object categorization (Jones, et al, in press). Further, RTs for the object naming task did not explain group differences beyond those accounted for by the object categorization task. Because the object categorization task employed in the study required no overt verbal response, the authors conclude that "naming speed deficits in dyslexia do not stem from a straight forward impairment in accessing phonological codes," but, rather, stem "from early stages of item processing associated with initial identification of the object (p. 12, Jones, Branigan, Hatzidaki, & Obregón., in press)."

Jones, et al. further suggest that RAN deficits in dyslexia involve disruption in either the mid fusiform area or in the connections between the mid fusiform area and areas responsible for name retrieval or semantic processing.

That being said, it is important to note that the effects of RND on RAN were found to be both group and stimulus dependent in the present study: RND exerted a facilitation effect on RAN response times for objects (but not digits) in older (but not younger) children. It is certainly possible that the limited number of stimuli used in Experiment 2 affected RTs for digits; however, researchers routinely vary the number of stimuli used across studies. Additionally, the finding that mean response times on the high vs. low density digits tasks were virtually identical within each group suggests that access to digit names is largely unaffected by variability in phonological representation.

The Curious Case of Digits

In the present study digit RAN correlated more strongly with reading than any other RAN task. In Kindergarten, a relationship between digit RAN and reading was found for both accuracy and speed of reading; however, in 3rd grade, digit RAN was related exclusively to the reading speed measures. In addition, in Experiment 2 RND had little, if no, effect on lexical access of digit names for either the younger or older children. Thus, synthesizing findings from Experiment 1 and Experiment 2, it can be concluded that 1) some variable other than phonology drives digit RAN speed and, perhaps by proxy, its strong relationship to reading, 2) the specific relationship between reading speed and digit RAN emerges in the very early stages of reading acquisition (at least by the end of Kindergarten) and 3) this specific relationship is maintained even as children garner several years of reading experience. If no effects of RND were found on any RAN task, we could easily conclude that phonology plays no role in RAN regardless of the stimulus type. However, this was not the case. Finding a significant effect of phonology on object naming speed in older children forces us 1) to reject the hypothesis that digits are more robust predictors of reading because they are less specified phonologically and 2) to consider the alternative hypothesis that digits are less specified semantically.

A semantic explanation for RAN can easily be extended to provide a plausible explanation for the diagnostic sensitivity of alphanumeric over non-alphanumeric stimuli. Recall that in the present study, RND failed to differentiate low vs. high digit naming speed in both groups and also failed to differentiate low vs. high object naming speed in the younger, but not older, group. From these results, we can infer that something about access to object names is different for emergent readers than for more experienced readers and, perhaps, something about accessing digit names is the same. If we attribute RAN performance to accessing semantic representations, it follows that, as children's vocabularies increase, conceptual knowledge deepens and semantic connections strengthen, thereby speeding access to lexical items that are both highly frequent and familiar. This reasonable assumption would lead to the prediction that naming highly frequent and familiar stimuli with strong semantic connections (e.g. common objects and colors) would be subject to vocabulary development which increases exponentially between kindergarten and 3rd grade (Anderson & Nagy, 1992). Thus, what may be different about accessing object names in younger vs older children is that older children—even children with dyslexia-- have stronger semantic representations for objects than younger children.

If improved object naming is attributed to developmental increases in vocabulary knowledge, it stands to reason that increases in mathematical knowledge would also improve digit naming speed. However, deJong & Vrielink (2004) found that while training 1st graders in addition facts resulted in improved mathematical computation speed, this training had no significant effects on digit naming speed. deJong & Vrielink (2004) concluded that "different factors affect increases in the speed of symbol-name retrieval and of addition speed (p. 85)." This supposition is supported by Dehaene's (1992) "triple code" model of number representation. According to this model, three different aspects of numeric knowledge are represented in three distinct areas of the brain: 1) *magnitude codes*, used for approximating numeric quantities, are associated with the left and right inferior parietal areas; 2) *verbal codes*, used for rote memorization of mathematical facts, are associated with the left angular gyrus; and 3) *visual codes*, used for identifying digits, are associated with the left fusiform gyrus, Thus, within Dehaene's (1992) model, there appears to be a neurological distinction between visual and verbal processing of numeric representation which could easily account for deJong & Vrielink's (2004) findings.

Regarding the specific relationship between digit RAN and sight word reading found in the present study, it is important to note that a large portion of "sight words" are, in fact, function words (e.g. *do, have, get, some*) which are arguably low in terms of imageability and poorly represented in terms of semantics. Hence, naming digits and function words may rely more heavily on lower level visual recognition skills while naming objects and content words may rely more heavily on higher level linguistic skills, tapping both semantic and phonological retrieval processes.

Implications for Dyslexia

Many researchers have posited that RAN deficits in dyslexia reflect a “lingering deficit” in phonological system (Shaywitz, et al., 2008). However, correlational studies have failed to find a link between phonology and RAN. In this study, naming speeds for words contrasted for low vs. high RND were compared. Words from high density neighborhoods are highly specified in terms of phonology while words from low density neighborhoods are poorly specified. Hence, this experiential manipulation allows for a two part discussion regarding 1) a causal relationship between weak or underspecified phonological representation and RAN performance in dyslexia and 2) a correlational relationship between reading and RAN when phonological representation of stimulus items is varied.

The first part of this discussion focuses on the manifestation of the naming speed deficit in dyslexia. In the present study, a causal relationship between phonological representation and RAN was clearly differentiated across stimulus types. Because RND had no effect on digit RAN in either group, one can conclude with some certainty that naming speed for digits is largely unaffected by phonological representation. Thus, it is reasonable to assume that weak or underspecified phonological representation in dyslexia does not cause their slow naming speed for digits.

On the other hand, RND did have significant effects on naming objects, but only for older children. Therefore, phonological representation appears to have different effects on different stimuli at different stages of reading development. It is unclear at the present time how this would play out in dyslexia; however, there is reason to conjecture that a dyslexic group would perform more like the Kindergarten group than the 3rd grade group.

Support for this comes from neuro-imaging studies which find remarkable similarities in the reading circuits of both novice and dyslexic readers. Most notably and pertinent to the present argument, both novice readers and compensated adult readers with childhood histories of dyslexia show hypoactivation of occipital-temporal region of the left hemisphere (Chiarello, Lombardino, Kacinik, Otto, & Leonard, 2006; Perfetti & Bolger, 2004). Novice and dyslexic brains also use broad and diffuse circuitry including both hemispheres for the task of reading (Perfetti & Bolger, 2004). Over time, non-impaired readers develop more specific and efficient circuitry, specialized to the task of word reading while dyslexic readers do not. If dyslexic brains are similar to novice reader's brains, it is plausible that, like the Kindergarten group in this study, phonological representation is causally unrelated not only to digit naming speed, but also to picture naming speed.

The second part of this discussion turns from causal to correlational findings. Results from the present study found a clear and consistent relationship between SWE and reading speed. Importantly, this relationship was especially strong when RAN stimulus items were highly specified in terms of phonological representation (i.e., high RND) and this was the case for both object and digit stimuli. So, in contrast with finding little evidence of a causal relationship between phonological representation and RAN, there does appear to be a very strong correlational relationship between phonological representation and reading speed: reading speed is highly related to naming speed in general and this relationship is strongest when RAN stimuli have strong phonological representations. Because individuals with dyslexia have poorly specified phonological representations, it may well be the case that in dyslexia, phonology underlies RAN's relationship to reading but does not, in and of itself, cause persistently slow RAN performance.

A critically important but largely ignored finding in the literature is that while digit naming speed is more diagnostically sensitive to reading disability (Breznitz, 2006), dyslexic readers, even into adulthood, continue to be slower than normal readers on all RAN tasks, regardless of the stimulus type used (Jones, et al., in press; Ramus, et al. 2003). In essence, this finding implies that what is slow about RAN in dyslexia is not the same thing that predicts reading. The finding that digit naming is more predictive of reading than object naming has generally been construed as evidence for a common orthographic coding deficit between RAN and reading (Wolf, Bowers & Biddle, 2000). This orthographic explanation, however, does not explain why non-alphanumeric picture RAN, also slow in dyslexia, fails to predict reading.

If we return to the arguments presented by both Jones, et al.(in press) and Lervåg & Hulme (2009)--that RAN is primarily reliant on the integrity of the mid fusiform area--we can attribute a general cause for slow RAN performance in dyslexia to a underlying deficiency in object recognition that affects both digit and picture naming speed. If we extend this argument to include the supposition that digits and pictures differ in terms of semantic representation it follows that digits--low in semantic representation-- require more input from the phonological system while objects--high in semantic representation--require less input from the phonological module. Hence, retrieving the names of items that are weakly represented in the semantic system demands a high level of cooperation from the phonological system. Therefore, in the case of dyslexia, I would speculate that deficits in both digit and object naming are *caused* by a primary deficit in object recognition, but only alpha-numeric naming *predicts* reading because poor semantic representations of these stimuli tap the integrity of the phonological system, which is inherently weak in this population.

Limitations and Future Directions

Acknowledging that a semantic hypothesis for RAN veers drastically from previous and widely-studied explanations, results from this investigation will need to be replicated in a large-scale study. Indeed, one of the major limitations of the present study is the small sample size, leaving open the increased possibility of Type 1 errors. The correlations are also likely to be affected by the small sample size. Thus, these results should be interpreted with caution.

This semantic explanation forwarded here also demands further study regarding the semantic representation of digits. Such research would further our understanding of the relationship between digit naming speed and reading, and also contribute to our understanding of specific learning disabilities in math (i.e. dyscalculia). Dyscalculia affects 3-6% of school aged children and is more prevalent in girls than boys (Shalev, Auerbach, Manor & Gross-Tsur, 2009). Of profound interest to the present study, Fletcher, Lyon, Fuchs and Banes (2007) report that, when compared to non-disabled children, children with primary disabilities in mathematical computation perform more poorly on rapid naming tasks than children with primary disabilities in reading.

Extending this research to include subject groups with different types of reading disabilities (e.g. poor comprehenders vs. poor decoders) will also help disentangle the effects of semantic and phonological representation on RAN. Inclusion of readers of different languages is also indicated. Importantly, the rime unit is far more salient in English than in any other language (Zeigler & Goswami, 2005). Because smaller grain size units are emphasized in more shallow orthographies, the effects of RND reported in the present study may not extend to other languages (i.e. Spanish and Italian).

Additional considerations regarding stimulus variables should also be explored in future studies. For example, there is a high level of overlap between RND and phonotactic probability (Storkel & Morrissette, 2002; Vitevitch, 2002). Phonotactic probability describes the relative frequency that a certain sound sequence occurs within a specific language and words with common sound sequences are named faster than words with more uncommon sound sequences. Because words with high phonotactic probabilities tend to reside in high density phonological neighborhoods (and words with low phonotactic probabilities tend to reside in low density phonological neighborhoods), it is possible that the facilitation effects of RND reported here actually reflect a high phonotactic advantage. Therefore, future research should attempt to control for this possible confound.

Additionally, semantics was controlled in this study by matching sets of loosely defined semantic categories, which is probably less than ideal. There are many, more precise ways to define semantic “richness” or representational strength, such as semantic neighborhood, number of features, and contextual dispersion. Importantly, different metrics used to define semantic representation appear to have differential effects according to task demands (Pexman, Hargreaves, Siakaluk, Bodner & Pope, 2008). Exploring the effects of different metrics of semantic representation on RAN can be used to test the semantic hypothesis of RAN implicated here. It may well be the case that because digits are semantically related only to other digits, the processes involved in retrieving digit names are less susceptible to phonological competition than for noun class objects, which are arguably semantically related to many more case members. This would predict that retrieval of digit names would be unaffected by changes in RND in any naming paradigm. However, this remains an empirical question.

Also, there are several limitations regarding some of the tasks used in this study. First, several of the measures were prone to floor effects. The timed reading tasks from the TOWRE, which is normed for children as young as 6-0, proved to be quite difficult for the Kindergarten children. Seven children had scores of zero on the SWE subtest and ten children had zeroes on PDE subtest. In order to capture the full range of reading abilities in this group, these scores were included in the analysis but, obviously, this may have impacted the final results. Several children also performed at floor levels for the verbal ability task (analogies). This included two Kindergarten children and also one 3rd Grader. The analogies task was chosen over more commonly used expressive vocabulary tasks because it presumably measures vocabulary depth (i.e., semantic relationships). It was assumed that vocabulary depth might capture more variability in verbal ability in this typically developing group of children. Considering that it is the accumulation of the number of words in the mental lexicon that is implicated in lexical restructuring, using an expressive vocabulary test which captures the breadth of vocabulary knowledge, may have, in retrospect, been a better alternative.

Finally, it is noteworthy that PA failed to correlate with any of the reading measures, even in the Kindergarten group. Previous research has found that while PA and RAN make independent contributions to reading, contributions tend to be shared in the early stages of reading, even in shallow orthographies (Verhagan, et al., 2008). Finding no relationship between PA and reading in this Kindergarten group may be a testament to current teaching practices in the United States which have undergone dramatic reform in recent years. In response to recommendations made in the National Reading Panel Report (NICHD, 2000), federal legislation currently requires schools to include explicit phonics and phonological awareness instruction in their curricula beginning in Kindergarten. The results of this type instruction are clearly apparent in the present study. Thus, changing trends in teaching practices should be carefully considered when interpreting both previous and future research findings. It is likely that children learning to read English in the United States will begin to look more and more like children learning to read less complex orthographies. If so, we can look forward to a more universal explanation of RAN and its relationship to reading.

Conclusion

This study was conducted on the basis of three largely held assumptions: 1) word reading requires a division of labor between orthographic, phonological and semantic processing modules (Seidenberg & McClelland, 1989) 2) orthographic, phonological and semantic strength of representation affects the extent to which the process of word reading is automatic and efficient (Perfetti, 2004) and 3) RAN is highly predictive of reading because efficiency for retrieving names for stimulus items requires the same multi-component processes as efficiency for retrieving names for words (Breznitz, 2006). Because RAN is particularly predictive of dyslexia and dyslexia is attributed to a primary deficit in phonological representation, this study set out to explore how varying the phonological representation of different types of RAN items (objects and digits) would affect automaticity of naming speed in typically developing children at two different stages of reading development.

Three major findings were revealed. First and foremost, large differences in RAN speed between novice and more experienced readers were fully accounted for by differences in sight word reading efficiency. This is interpreted to mean that the division of labor between orthographic, phonological and semantic processing which contributes to automaticity of rapid naming closely mimics the division of labor for naming sight words.

Secondly, rapid naming of digits was a better predictor of word reading speed than rapid naming of objects. This finding, which was consistent across groups, is interpreted to mean that the division of labor for digit naming is a closer approximation of word naming that the division of labor required for naming objects.

Finally, rapid naming of digits was found to be virtually unaffected by differences in RND in either novice or more experienced readers. This is interpreted to mean that digit naming is relatively unaffected by phonological representation. Taken together, it can be argued that 1) if the processes required for digit naming approximate those for word naming and 2) digit naming is largely unaffected by phonological representation, then RAN's relationship to reading cannot be solely attributed to variability in phonological representation. In sum, while high RND was correlated highly with word reading ability, results from this study found little support for causal relationship between phonological representation and RAN speed. Whether semantic representation underlies this relationship remains an empirical question that clearly warrants further study.

APPENDIX
IRB APPROVED PROTOCOL AND PARENTAL CONSENT FORM

UFIRB 02 – Social & Behavioral Research **Protocol Submission**	
Title of Protocol: Phonological Effects on Rapid Automatized Naming (RAN)	
Principal Investigator: Linda J. Lombardino	**UFID #:** XXXXXXXXX
Degree / Title: PhD/Professor **Department:** Special Education, School Psychology and Early Childhood Studies	**Mailing Address:** PO Box 117420 336 Dauer Hall University of Florida Gainesville, FL 32611-7420 **Email Address & Telephone Number:** **llombard@ufl.edu** 352.392.2113 ext 285
Co-Investigator(s): Rebecca Wiseheart	**UFID#:** 5689-7401
Supervisor: NA	**UFID#:** N/A
Degree / Title: M.A./ Doctoral Candidate	**Mailing Address:** 405 SE 2nd Ave #28 Gainesville, FL 32601 **Email Address & Telephone Number:** wisehart@ufl.edu 352.514.8809
Date of Proposed Research: Mar 1, 2010 thru Feb 28, 2011	
Source of Funding *(A copy of the grant proposal must be submitted with this protocol if funding is involved):* None.	
Scientific Purpose of the Study: Rapid automatized naming (RAN) requires participants to name an array of repeating stimuli (colors, pictures, letters or digits) across a page. This simple task is a remarkably robust and stable predictor of reading disability and is highly correlated with reading speed. As such, RAN has become a mainstay in reading research and is also routinely used in test batteries for diagnosing developmental dyslexia. However, the precise processes that contribute to RAN are currently inconclusive. Some researchers posit that RAN reflects a deficit in phonological (speech sound) processing while others contend that RAN is primarily independent of phonology. In addition, numerous investigations report that the strength of RAN's relationship to reading changes over the early course of reading development, depending on the type of RAN stimuli used: while rapid naming of both pictures and symbolic (letters, digits) stimuli predict reading in Kindergarten, only symbol naming predicts reading after 1st	

grade. The goals of the study are 1) to investigate the extent to which phonological representation, measured by rime neighborhood density, affects the speed of rapid automatized naming of pictures and 2) to test whether or not this relationship differs among readers from Kindergarten vs. 3rd grade. In order to address these goals, the proposed study will manipulate the phonological structure of picture stimuli on two experimental picture naming RAN tasks. Response times for completing these tasks will be compared across two age groups: Kindergarten and 3rd grade. In addition, the relationship (s) between RAN speed and various measures of reading, processing speed, and orthographic (letter) knowledge will be examined. Results from this study will forward the theoretical debate regarding the phonological underpinnings of RAN. Results may also aid future researchers in developing more efficient and efficacious treatment strategies for reading difficulties in older children and may also provide a means for detecting and, subsequently, preventing reading disabilities in very young children, prior to 1st grade.
Describe the Research Methodology in Non-Technical Language: *(Explain what will be done with or to the research participant.)* See Methods Section, attached.
Describe Potential Benefits and Anticipated Risks: (*If risk of physical, psychological or economic harm may be involved, describe the steps taken to protect participant.*) There are no potential benefits or anticipated risks to participants.
Describe How Participant(s) Will Be Recruited, the Number and AGE of the Participants, and Proposed Compensation: A total of 60 native English speakers (30 Kindergarten students, ages 5-6 and 30 3rd graders, ages 8-9) will be invited to participate. Participants for will be recruited from Anthony Elementary School in Marion County Florida. Pending IRB approval, prior permission for recruitment of participants and use of school facilities during regular instructional hours has been granted by the school's principal, Mr. Jerome Brown. Participants will not be compensated for participation.
Describe the Informed Consent Process. Include a Copy of the Informed Consent Document: Participants will not be assessed without a signed and dated parental consent form. Prior to testing, all children will be read an assent statement. (see attached)

Principal Investigator(s) Signature:	**Supervisor Signature:**
Department Chair/Center Director Signature:	**Date:**

RESEARCH METHODOLOGY

All participants will be tested individually in a quiet room in the school's media center either by the co-investigator or by a trained undergraduate research assistant. Responses will be digitally recorded for verification purposes.

A. Standardized Measures

<u>Semantic Knowledge</u>

Verbal Ability Two subtests from the Woodcock Johnson III Test of Cognitive Abilities (WJ-III-COG: Woodcock, McGrew, & Mather, 2001) will be administered to assess student's verbal ability: Picture Vocabulary and Verbal Analogies. The Picture Vocabulary task requires the participant to name pictured objects. The Verbal Analogies task requires the participant to state a fourth word to complete a three-word analogy. Testing is completed when a student misses six items in a row.

Verbal Fluency Two tasks of verbal fluency will be administered. The first task asks participants to name as many words beginning with the letter "S" as they can within a one-minute time limit. The second task asks them to name as many animals as they can within a one-minute time limit.

<u>Phonological Processing</u>

Phonological Awareness The elision subtest from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) will be administered to assess participant's phonological awareness skills. The Elision subtest requires the participant to listen to and repeat a word, and then say the word without a specific sound that is removed from either initial, medial, or final position of the word. The score is recorded as the total number of all items answered correctly. Testing is completed when a student misses three items in a row.

Rapid Automatized Naming (RAN) Speed The RAN subtest from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) will be administered to assess participant's will be used to measure participant's rapid naming ability. The test for children of Kindergarten age consists of objects and colors. The test for children in 3rd grade consists of letters and digits. The participant is asked to name each stimulus item as quickly as possible without making any mistakes on all tests. Scores are based on the amount of time that is required to name all stimuli on each test.

<u>Reading Performance</u>

Timed Word Reading The Sight Word Efficiency (SWE) and Phonemic Decoding Efficiency (PDE) subtests from the Test of Word Reading Efficiency (TOWRE; Wagner, Torgesen, & Roshotte, 1999) will be used to measure participant's ability to read real and non-real words fluently at single word level with time limits. On the SWE subtest, the participant is given a series of real words and asked to read aloud as many as he/she could in 45 seconds. The score is the total number of words correctly read. On the PDE subtest, the participant is given a series of non-real words and asked to read aloud as many as he/she could in 45 seconds. The score is the total number of words correctly read. This task will be time with a hand held stop watch.

Un-timed Word Reading The Letter-Word Identification (LWI) and Word Attack (WA) subtests from Woodcock-Johnson III Tests of Achievement (WJ-III-ACH; Woodcock, McGrew, & Mather, 2001) will be used to measure participant's letter recognition and sight word vocabulary and unfamiliar printed words without time limits. On the LWI subtest, the participant is given to name letters and read real words aloud from a list. Testing is continued until the six highest-numbered items administered are incorrect and the score is recorded as the total number of letters and words correctly read. On the WA, the participant is given to read nonwords or low-frequency words aloud from a list. Testing is continued until the six highest-numbered items administered are incorrect and the score is recorded as the total number of letters and words correctly read.

Orthographic Knowledge

Word Parsing A timed orthographic knowledge task called "wordchains" will be administered. In this pencil-paper task, subjects are given a paper that has strings of words typed together with no spaces between the words (e.g. hurtunderworkafterofldsopengold). The object of the task is for participants to mark a pencil slash marking word boundaries. This task is timed with a stopwatch and inaccurate responses are deducted from the total score. This task has been used in previous research (Georgiou, Parrila & Kirby, 2009).

Processing Speed

Two sub-tests from the Woodcock-Johnson III Test of Cognitive Abilities (WJ-III-COG: Woodcock, McGrew, & Mather, 2001) will be administered. For each of these tasks, the student is given a booklet that shows rows of either pictures or numbers. On the Decision Speed subtest, students are asked to circle the two items in each row that are conceptually similar (e.g. dog and cat) as quickly as possible. On the Visual Matching subtest, students are asked to circle two identical numbers in each row as quickly as possible. Each of these subtests has a three minute time limit. The total score is the number of matching pairs circled correctly within the time frame.

B. Experimental RAN Tasks

In order to examine the influence of the underlying phonological sound structure on naming speed, stimulus items used in the two experimental RAN tasks vary in terms of the number of other words that share their underlying sound pattern. One page of pictures includes words that have many neighbors (high dense condition) while the other page of pictures includes words that have few neighbors (low dense condition).

Words for this experimental task will be selected from the lexical data base of 4,086 monosyallbic words compiled by DeCara and Goswami (2002). Pictures for the RAN task will be presented as black line drawings. Reliability of picture names will be established prior to the experiment. The experimental RAN task is adapted from the CTOPP RAN (Wagner, Torgesen, & Rashotte, 1999) and requires individuals to name in rapid succession a series of 5 pictures which are randomly repeated for a total of 36 items. Pictures used in each RAN will first be named by the examiner. Participants will then be instructed to name the pictures as quickly as possible. Participants will be given five items to practice the procedure.

Department of Communicative Disorders
University of Florida
Gainesville, FL 32600-0000

Parental Consent

Dear Parent/Guardian,

I am a doctoral student in the Department of Communicative Disorders at the University of Florida, conducting research on children's reading development under the supervision of Dr. Linda J. Lombardino. The purpose of this study is to compare students' reading and picture naming skills in Kindergarten and in 3rd grade. The results of the study will help researchers better understand the relationship between early picture naming and future reading skill. These results may also help researchers design better reading programs for young children who are at-risk for future reading difficulties, even before they begin to struggle. These results may not directly help your child today, but may benefit future students. With your permission, I would like to ask your child to volunteer for this research.

Participating children will be asked to complete 14 short tasks that measure spelling, reading, and vocabulary ability, as well as, picture matching and picture naming speed. Many of the tasks take less than one minute to complete. The procedure will be presented by a trained research assistant from the University of Florida during the school hours. The 30-minute procedure will take place during March, April, or May of this school year. With your permission, your child's responses will be audiotaped. The digital audio recording will be available only to the research team for verification purposes. At the end of the study, the tape will be erased. Although the children will be asked to write their names on the test forms for matching purposes, their identity will be kept confidential to the extent provided by law. We will replace their names with code numbers. Results will only be reported in the form of group data. Participation or non- participation in this study will not affect the children's grades or placement in any programs.

You and your child have the right to withdraw consent for your child's participation at any time without consequence. There are no known risks or immediate benefits to the participants. No compensation is offered for participation. Group results of this study will be available in August, 2010 upon request. If you have any questions about this research study, please contact me at 352-514-8809 or my faculty supervisor, Dr.Linda Lombardino, at 352-273-3732. Questions or concerns about your child's rights as research participant may be directed to the IRB02 office, University of Florida, Box 112250, Gainesville, FL 32611, (352) 392-0433.

Rebecca Wiseheart, MA, CCC-SLP
Doctoral Candidate
Department of Communicative Disorders
University of Florida

I have read the procedure described above. I voluntarily give my consent for my child,

____, to participate in Rebecca Wiseheart's study of reading and picture naming development. I have received a copy of this description.

____________________________ ___________
Parent / Guardian Date

Sample assent scripts

[3rd Grade children]

Hello *[child’s name]*. My name is *[examiner’s name]* and I am a student at the University of Florida. I am trying to learn about how children learn to read. I will be working with several students here at Anthony Elementary. If you decide to participate, you will be asked to do a series of activities, including some reading, vocabulary and picture naming tasks. Many of the activities will be timed so that we can see how fast children can perform these tasks. We will spend about a half-hour working on these activities individually. There are no known risks to participation, and most students actually enjoy the tests. You do not have to be in this study if you don’t want to and you can quit the study at any time. Other than the researchers, no one will know your answers, including your teachers or your classmates. If you don’t like a question, you don’t have to answer it and, if you ask, your answers will not be used in the study. I also want you to know that whatever you decide, this will not affect your grades in class. Your [parent / guardian] said it would be OK for you to participate. Would you be willing to participate in this study?

[Kindergarten children]

Hi, my name is [examiner's name], and I'm from the University of Florida in Gainesville. I'd like to ask you to do some reading activities with me. Your *[teacher / mom]* said it was OK. We'll do it in the media center, and it takes about thirty minutes. Would you like to come do this?

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BIOGRAPHICAL SKETCH

Rebecca Maulden Wiseheart graduated from the University of Florida in 1988 with a bachelor's degree in English. In 1993, she received her Master of Arts degree in speech-language pathology. Her Master's thesis, *A Linguistic-Specific Approach to Complex Sentence Production Treatment in Agrammatism*, was chaired by Dr. Linda Lombardino. Rebecca has worked as a school-based speech-language pathologist since 1993 and has also maintained a private practice, specializing in the diagnosis and treatment of developmental dyslexia, since 2004. In 2006, she returned to the University of Florida to pursue doctoral studies in the Department of Communication Sciences and Disorders with an interdisciplinary focus on developmental reading disorders. She received her Ph.D. from the University of Florida in the summer of 2010.