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Eye Movements and Semantic Processing in Rapid Automatized Naming

Implications for Semantic Knowledge in Dyslexia

Master's thesis in Master of Philosophy in English Linguistics and Language Acquisition
Supervisor: Mila Dimitrova Vulchanova and Joel B. Talcott
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Abstract

This study examines the well-established relation between rapid naming and reading. Rapid Automatized Naming has a long reputation for being a strong predictor of reading abilities. Despite extensive research spanning over 4 decades, this robust relationship and their underlying causes remain a subject of inquiry. In our study, we are particularly interested in the role of eye movements and semantic processing as the two potential components that contribute to the RAN-reading relationship. Our original sample consists of 42 undergraduate students at a British university. The participants speak English as their L1 and have neither reading nor spelling difficulties, together with neither auditory nor visual impairments. The materials used in the study included a word reading task, two conventional rapid naming tasks (object and digit), and two RAN-like categorization tasks. Results obtained from paired t-test suggested that semantic processing is not a component that rapid naming taps upon, which implies that semantic deficits in dyslexia are a consequence of phonological deficits, rather than difficulties with semantic processing itself. Besides, hierarchical multiple regression analyses revealed that oculomotor control remains an integral part that accounts for variance in RAN and reading performances, after other factors have been controlled. Taken together, this suggests that RAN and reading are correlated because both require rapid and accurate retrieval of phonological representations of the visual stimuli or symbols and stable coordination of eye movements across a surface or a printed page. As long as there are demands for phonological retrieval and serial processing to a certain extent, this RAN-reading relationship is existent.

Keywords: rapid naming, eye tracking, reading, semantic processing, eye movement, dyslexia

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"*Aerodynamically, the bumblebee should not be able to fly, but the bumblebee does not know it, so it goes on flying anyway*" – Mark Kay Ash

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Chapter 1: Introduction

Rapid Automatized Naming (RAN) is known to be a robust predictor of both concurrent and future reading abilities in pre-literate children, graders, and even adults in some studies. In a conventional RAN task, a participant is required to name aloud all the visual stimuli (e.g. digits, colors, letters, and objects) on a grid as rapidly as possible. The speed at which a participant is able to finish naming all of the stimuli in the grid is found to be highly correlated with his or her reading ability (Aarnoutse et al., 2005; Bowers & Swanson, 1991; Georgiou et al., 2009, Hu & Catts, 1998; Oakhill & Cain, 2012; Schatschneider et al., 2004; Tan et al., 2005, Wolf & Bowers, 1999). RAN today is one of the most reliable reading assessment tools that are widely used in literacy research and dyslexia diagnosis because of its merits in a vast array of settings: (a) It predicts literacy abilities in both typical readers and individuals with reading difficulties. Correlations as high as $r = .55$ were reported between typical preschool performance in RAN and second grade decoding (Bowers & Swanson, 1991). Additionally, 60% to 75% of individuals struggling with reading are found to exhibit RAN deficits (de Groot et al., 2015; Katzir et al., 2008; Waber et al., 2004, Wolf et al., 2002). (b) This predictive power of RAN appears to maintain until adulthood. Some studies reported correlations as high as $r = .53$ between performance in RAN and reading for adults aging from 36 to 65 (Van den Bos et al., 2002). (c) More significantly, this correlation between RAN and reading remains strong across different languages. RAN is shown to be predictive of reading regardless of the orthography depth and in both alphabetic and non-alphabetic languages (Georgiou et al., 2015; Georgiou et al., 2008; Moll et al., 2014; Tan et al., 2005). (d) Rapid naming itself is a highly efficient task in terms of clinical applications since it takes less than 5 minutes to administer, which saves a great deal of time and resources. These merits altogether make understanding the underlying processes that render RAN and reading similar a significant object of literacy research.

The question of why and how RAN can predict reading, however, remains an open debate. In order to investigate this strong relationship, our best approach may be to find out the similar linguistic and cognitive processes that are both present in rapid naming and reading. However, researchers do not see eye-to-eye on why there is a strong correlation between RAN and reading. One of the earliest and most well-known hypotheses is that rapid naming tasks require accurate and rapid retrieval of phonological units from the mental lexicon (Bowers & Swanson, 1991); this places considerable demands on the process of orthographical-phonological activation and co-ordination. Thus, RAN deficits among atypical readers (e.g. dyslexics) are a strong indicator of core phonological processing deficits (Pennington, Cardoso-Martins, Green, & Lefly, 2001; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997). Under this view, RAN is seen as another construct of phonological processing, and efficiency in rapid naming performance simply relies on speed and accuracy of access to familiar lexical items and their phonological representations. Recent studies have indicated that rapid naming tasks actually tap upon many different non-phonological mechanisms and more general cognitive processes, such as attention, visual detection and integration (Norton & Wolf, 2012). Therefore, the argument that RAN is simply a simulation of phonological processing cannot be maintained. According to Wolf & Bowers (1999), there are seven different sub-components that may in reality contribute to fluent and consistent performance in RAN:

a) Attentional processes to the stimulus
b) Bihemispheric visual processes responsible for feature detection, visual discrimination, and pattern identification

c) Integration of visual features and pattern information with stored orthographical representations
d) Integration of visual and orthographic information with stored phonological representations
e) Access and retrieval of phonological labels
f) Activation and integration of semantic and conceptual information with all other input
g) Motoric activation leading to articulation

To date, extensive research has investigated each sub-component of RAN; and yet, there is still no general consensus in the RAN-reading relationship. Norton & Wolf (2012) attempts to resolve the on-going debate by conceptualizing RAN as a "microcosm or mini-circuit of the later developing reading circuitry". To that end, RAN is predictive of reading because it involves a conglomeration of linguistic and perceptual processes that are required in reading, such as phonological, orthographic, and semantic representations, integrating visual information and allocating working memory. Performance in RAN reflects the ability to co-ordinate these interfaced processes fluently and accurately. There is nothing wrong with their perspective. However, our goal in investigating the RAN-reading relation is not only to pinpoint the exact underlying components but also to measure their contributive weight and the extent to which each component can contribute to defining the RAN-reading relationship.

Our study returns to examining one specific component of RAN that has received little attention: the activation and integration of semantic and conceptual information with all other input. To the best of our knowledge, the importance of semantic and conceptual integration and activation in RAN is not systematically investigated in any study. There is one study by Jones et al. (2010) that looks into semantic processing deficits among dyslexic readers. Evidence from this study reveals that dyslexic groups had both difficulties in conventional object-naming and object-categorization tasks. They hypothesized that this deficit could be due to either phonological or semantic retrieval from the visual stimuli. Further analyses indicated that dyslexic groups experienced comparable difficulties in tasks that emphasize semantic processing (e.g. giving verbal responses to different types of objects), as they would do in naming aloud tasks. Jones and colleagues concluded that RAN deficits are partly due to difficulties in semantic processing, which also implies that semantic processing is an integral component that establishes the relations between RAN and reading. Studies that examine semantic processing in rapid naming on typical and healthy populations are scant. Because of this, we are motivated to investigate this component in greater depth. We adopt the logic of Georgiou et al. (2012): "If X is the process that is responsible for the RAN-reading relationship, then increasing or decreasing the demands of X should result in an increase or decrease in the RAN-Reading relationship". In this study, X is semantic processing and conceptual integration of information.

In order to testify this hypothesis, we tracked and recorded participants' eye movements during word reading and in both conventional rapid naming tasks of objects and digits, as well as in categorization tasks of the same stimuli. By doing so, we can also re-assess the hypothesis that fluent oculomotor control is a significant factor that accounts for variance in RAN and reading. Our populations of interest are undergraduate university students who have no reading disabilities, cognitive deficits, nor severe visual impairments. We intentionally use the sets of objects and digits on adult readers to see whether different types of RAN vary in their sensitivity according to the maturity of participants. In summary, our project consists of three research questions:

R.Q 1: To what extent does the activation and integration of semantic processing contribute to defining the RAN-reading relationship? (If semantic processing has a significant contribution, we expect to see a substantial difference in processing time for animate objects and inanimate objects in the RAN grids in normal naming-aloud conditions)

R.Q 2: Do the grids of objects and digits have equivalent predictive power of word reading performances in adults? (If yes, we expect to see an equivalent amount of correlations in eye movements between RAN Object and word reading and between RAN Digit and word reading)

R.Q 3: In what ways are eye movements in rapid naming tasks similar to those in the word reading task? (If they are highly correlated, we expect to see that eye movement variables in all the RAN-related tasks account for a large variance in word reading efficiency)

Our goal in this project is not only to provide some insights into the nature of RAN and reading relationship and locate the role of semantic processing in this relationship but also to suggest some implications for semantic knowledge in dyslexic readers. The following chapter (**Chapter 2**) will provide a brief overview of literacy development and the role of semantics during the process of reading fluency development. On the basis of that theory of literacy acquisition, we will discuss the importance of Rapid Automatized Naming as a strong predictor of reading abilities. Because of its popular application in literacy research, insights into RAN has been divided into many dimensions. According to our research questions, we will only limit our concerns to the reason why RAN predicts reading (**Chapter 3**) and how this predictive value varies according to the different types of RAN and the age of participants (**Chapter 4**). **Chapter 5** reviews some important theoretical perspectives on dyslexia. The subsequent chapters (**Chapter 6** and **Chapter 7**) will explain the execution of our experiments and the results before we discuss these findings in greater depth in **Chapter 8.** All the instruments and tools used for testing can be found in the **Appendices**.

Chapter 2: Literacy Acquisition and the Role of Semantics

Literacy is considered to be an essential asset in human societies because of its importance in communication, academic training, professional development, and social integration. According to Pinker (1997), children are born "wired" for language, "but print is an optional accessory that must be painstakingly bolted on". Unlike spoken language, literacy acquisition cannot take place naturally and subconsciously, but it requires explicit and effortful instruction. Literacy emerged so recently in the evolutionary history of human beings that innate biological processes for reading do not exist in the minds of human babies (Norton & Wolf, 2012). Rather, infants are born with a well-established neural repertoire in place to facilitate the acquisition of spoken language, which functions as a prominent platform for written language (Norton & Wolf, 2012).

Substantial evidence suggests that specific brain regions are activated in response to sounds and structures of language from infancy (Pena et al. 2003, Minagawa-Kawai et al., 2011). On the other hand, literacy must be developed using brain areas that are intended for other purposes (e.g. language, vision, and attention) (Dehaene, 2009). In order for reading acquisition to be successful, one must rapidly integrate a vast circuit of brain areas with both great accuracy and remarkable speed. This "reading circuit" consists of several neural systems that lend support to every layer of language – phonology, morphology, syntax, and semantics – as well as "visual and orthographic processes, working memory, attention, motor movements, and higher-level comprehension and cognition" (Norton & Wolf, 2012). Indeed, literacy acquisition in reality is an extremely complex process that is often taken for granted in modern human society.

An abundant flow of scientific research has been dedicated to investigating the processes and variables that influence the development of reading accuracy and fluency since the 1970s. Despite extensive research spanning decades, many inquiries into how literacy is acquired remain unanswered. The general consensus is that reading acquisition seems to occur in stages. However, the number of stages and mechanisms involved in each stage vary considerably according to different models (Marsh et al., 1980; Frith, 1985; Ehri, 1992; Seymour, 1997). Duncan & Seymour (2000) suggested a reading model that seems to be well-recognized among linguistics, known as “dual foundation model”, as in **Figure 1**:

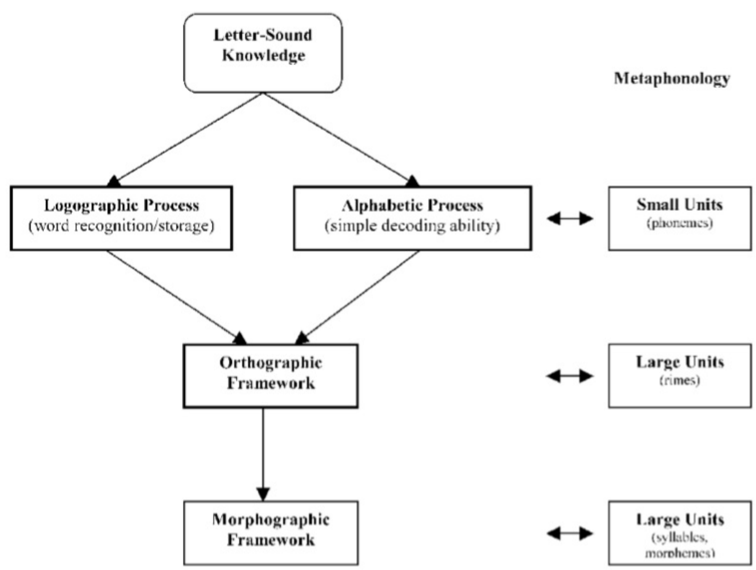

Figure 1. Schematic representation of the dual foundation model of orthographic development (from Duncan & Seymour, 2000).

Under this model, the stages that a child learns how to read can simply be understood as follows: In order to become literate, a child must first understand how visual symbols on a page (e.g. letters) represent units of sounds (e.g. phonemes) in the language he is acquiring. For example, the letter “D” in the word “dog” can make a “duh” sound while the letter “T” in “tooth” makes a different sound “tuh”. With this foundational knowledge in letter-sound relation in place, a child can learn to decode and store familiar words in his mental lexicon so that he can later recognize words he has learnt in written texts. The early stages of reading development rely heavily on the acquisition of mappings between phonology and orthography. This requires that children need to be aware of the sound structure in their language. Therefore, phonological awareness – the ability to identify, manipulate, and segment sounds within words – is a crucial component at the early stages of learning to read. Because of this, reading failures tend to be a consequence of core phonological processing deficits, as substantial evidence has suggested (Vellutino et al., 1996). Once a child has succeeded in decoding simple and familiar words, he can reach an "automaticity stage" when he can recognize words without ease and read without extreme efforts (Bishop & Snowling, 2004; Nation & Snowling, 2004).

The development of reading fluency involves not only word decoding but also comprehension. Reading process engages a nexus of orthographic, phonological, and semantic properties of words (Colheart et al., 2001; Seidenberg & McClelland, 1989). In order to become a proficient reader, a child must acquire high quality lexical representations and lexical processing is most successful only when the three components of a word (i.e. phonology, orthography, and semantics) are fully specified – known as the Lexical Quality Hypothesis (Perfetti, 2007). When one of these components is inadequate or not fully retrieved, comprehension is compromised. For this reason, rapid naming is considered as one of the strongest predictors of reading abilities because RAN functions as a miniature of reading: successful performance in rapid naming tasks require rapid and effective retrieval of phonological, orthographical, and semantic features of the stimuli (Norton & Wolf, 2012).

The role of semantics in literacy acquisition and word decoding appears to be overlooked in literacy research, compared with its companions (i.e. phonology and orthography). Successful reading development requires the interplay between phonology, orthography, and semantics of words in the mental lexicon. However, we still do not know whether semantic properties of words are activated at a later stage after their phonological or orthographic representations, or three components occur simultaneously. Recent studies have suggested that there is a reciprocal relationship between phonology and semantics in our mental lexicon (Li, Farkas, & MacWhinney, 2004). Moreover, the growth of semantics may encourage the development of phonological capacities (Van Goch, McQueen, & Verhoeven, 2014). The benefits of semantic knowledge towards word decoding efficiency has so far received little attention in the literature.

Recently, Rijthoven et al. (2018) found that strong semantic abilities compensate for underdeveloped phonological skills in dyslexic children. They also discovered a considerable impact of semantic abilities on both word decoding efficiency and pseudoword decoding efficiency. However, further regression analyses showed that semantic skills only predicted word decoding and pseudoword decoding indirectly via phonological awareness and rapid naming. This implies that enhanced semantic skills may actually contribute to better phonological processing skills and word decoding as a result, but semantics itself may not be a part of either word decoding efficiency or rapid naming.

Chapter 3: RAN as a Predictor of Reading

Rapid Automatized Naming (RAN) is shown to be one of the best predictors of both concurrent and future reading abilities. In a standard RAN task, participants are shown a grid of visual stimuli that represent common objects, colors, alphanumeric or numeric symbols and are asked to name (usually aloud) each item in the grid in a sequential order row by row as quickly as possible. Several empirical studies have shown that there is a strong correlation between the speed at which a participant is able to name all of the items in the grid and his reading ability. Correlations high up to r= .55 have been reported between kindergarten RAN performance and second grade decoding (Bowers & Swanson, 1991). Substantial evidence has suggested that poor performances in RAN tasks later result in reading difficulties and failures. RAN is now perceived as a robust predictor of reading ability in both alphabetic and non-alphabetic writing systems. Moreover, RAN-reading relationship seems to persist into adulthood (Van den Bos, Zijlstra & Lutje Spellberg, 2002). Several studies have also indicated that RAN is a stronger predictor of reading than phonological awareness in some orthographies (e.g. Urdu) (Farukh & Vulchanova, 2014; Vulchanova & Farukh, 2018). RAN is considered to be one of the best and universal precursor of reading abilities across all known orthographies (Georgiou et al., 2008). Neurolinguistic studies even indicated that RAN predicts reading independently of age (Cohen et al., 2018).

The critical question then is: “Why does rapid naming predict reading?”. Literacy researchers differ their perspectives on this; much controversy existing in the field mostly centers around whether RAN simply simulates mechanisms that are also existent in phonological processing tasks or whether rapid naming makes a distinct contribution to reading on its own. Some researchers advocate that RAN is a test that takes phonological processing as a main component (Vellutino et al., 1996; Wagner et al., 1993). Children who have phonological processing deficits experience immense difficulties in rapid naming tasks. However, many studies have refuted this perspective. Evidence against this view has come from a variety of sources. One of the most influential theories that have challenged the PA-RAN relation is the "Double Deficit Hypothesis", first suggested by Bowers and Wolf (1993). According to this hypothesis, children with reading disabilities can be categorized into three distinct groups: those with phonological processing deficits only, those with rapid naming deficits only, and those with deficits in phonological processing and rapid naming simultaneously. Wolf & Bowers (1999) reported that individuals with deficits in both phonological processing and rapid naming tasks exhibited the most severe reading impairments, compared with those with only deficits in either phonological processing or naming, and several subsequent studies in the literature have confirmed this. In addition, Swanson et al. (2003) conducted a meta-analysis on samples from 49 independent studies and reported low-to-modest correlations between phonological awareness and rapid naming in both skilled and poor readers. Recently, technological advances have also enabled psycholinguists to implement genetic and neuroimaging studies that have found different biological foundations for RAN and PA abilities (Norton & Wolf, 2012).

Some researchers, on the other hand, proposed that it is the similarity in orthographic processes between RAN and reading that strengthen their relation. The logic underlying this argument is based on the fact that slow letter identification compromises the quality of the orthographic representations, which deteriorates reading fluency and accuracy (Bowers & Wolf, 1993). It is well-established that RAN predicts both concurrently and prospectively variance in word-reading fluency, reading comprehension, and passage reading speed (Manis et al., 1999). However, RAN becomes a somewhat weaker independent precursor of word identification accuracy and a poor predictor of nonword-reading accuracy (Badian, 1993; Bowers, 1995; Cornwall, 1992; Torgesen et al., 1997). This implies that by nature RAN is a multi-faceted measure of many subskills required for reading, rather than just simply a construct of phonological processing skills. Several studies revealed that RAN is strongly correlated with tasks that stress orthographic knowledge. For example, Bowers et al. (1994) found that first to third graders with slower digit naming speeds were less sensitive to letter patterns of words than individuals with faster digit naming speeds. This result was also found in Sunseth & Bowers (1997)'s study, where they examined naming speeds in third graders by two measures of orthographic awareness, a word-likeness judgement task using regular and irregular letter strings, and a task requires correct spelling selection from a pair of homophones. Taken together, deficits in rapid naming tasks (slow and inaccurate naming) may be a consequence of weaknesses in phonological-orthographic processing skills.

It now appears to many that rapid naming is a complex conglomeration of linguistic, perceptual, and cognitive processes. More recent research has switched attention from language predictors (e.g. phonological awareness, orthographic knowledge) to more general cognitive variables in explaining contribution of RAN to variance in reading ability. One particular interest concerning cognitive and perceptual aspects of RAN that has received much attention is the role of eye movements. Research into this direction is grounded on the fact that visual scanning and serial processing of continuous RAN grid are similar to the same oculomotor programming involved in text reading (Kuper & Van Dyke, 2011). Hence, RAN is predictive of reading because both involve serial processing and the ability to co-ordinate eye movement across a written page or a grid (Georgiou, Parrila, Cui, & Papadopoulos, 2013). Evidence in support of this comes from two main streams of research. First, several studies have shown that the RAN-reading relationship is reduced or nearly non-existent when the items on the grid are presented isolated instead of in a serial manner (discrete RAN) (Bowers & Swanson, 1991; Jones, Branigan, & Kelly, 2009; Logan, Schatschneider & Wagner, 2011; Stanovich, 1981; Torgesen, Wagner & Rashotte, 1994; Wagner et al., 1994; Wagner, Torgesen, Laughon, Simmons & Rashotte, 1993). Second, research from the eye tracking literature found that rapid naming times are strongly linked to individual differences in eye movements during word or text reading (Kuperman et al., 2016). Results from these studies have revealed that longer naming times in RAN tend to be aligned with greater fixation rates, smaller saccades, increased refixation rates, and more frequent regressive saccades (Hawelka & Wimmer, 2005; Jones et al., 2009; Rayner, Slattery & Belanger, 2010). Most importantly, Kuperman & Van Dyke (2011) found that rapid naming times are a strong predictor of all domains of per-word eye movement recorded during sentence reading. A significant correlation between RAN performance and the percent of fixations and regressions during text reading was also found in a study by Doyle (2005). Altogether, these results indicate that: more fixation and regression rates in rapid naming are associated with increased fixation and frequent regressions in word or text reading. Eye movements in rapid naming are analogous in many respects to those which are existent during reading process.

Chapter 4: RAN across Different Stages of the Life Span

Predictors of reading appear to evolve through age: phonological awareness (PA) is the best precursor of reading abilities in the early stages of reading acquisition, whereas Rapid Automatized Naming (RAN) becomes a better reading predictor in more accurate and fluent readers (typically around 9-10 years old) (Cohen et al., 2018). For example, Denckla & Rudell (1976) found that the gap between typical readers and dyslexic individuals was greatest somewhere between 9 and 10 years, suggesting that rapid naming becomes a more reliable predictor of reading abilities in more experienced readers. This is because during the process of learning to read, a child must develop two different pathways: non-lexical route and the lexical route. The non-lexical (or indirect) pathway is in charge of grapheme-to-phoneme mappings and therefore facilitates reading of sight words and pseudo words. With explicit training and intensive practice, the repetitive pattern of decoding words results in the development of the lexical pathway. This route allows the child to identify familiar words correct and rapidly, regardless of whether they are consistent or not (Cohen et al., 2018). This pathway is most frequently used by more experienced readers (Ehri, 2014). At the early stages of reading development, reading depends heavily on grapheme-to-phoneme mapping, phonological awareness (PA) is therefore a robust predictor of literacy skills in early ages. With training and practice, reading gradually turns to the lexical route, where rapid access to phonological information from orthographic representations. This access is considered to be highly similar to those cognitive processes registered during a RAN task. Hence, RAN appeared to be a more efficient predictor of reading outcomes in older individuals (Parrila et al., 2004).

There are four different RAN tests that present four different categories of visual stimuli to participants: objects, colors, digits, and letters. Studies show that correlations between reading and rapid naming vary significantly according to the RAN stimulus types used. There is evidence that rapid naming scores for digits and letters are more strongly correlated with reading scores than those of objects and colors (Blachman, 1984; Cornwall, 1992; Maya et al., 2004). However, several other studies reported signification correlations between rapid naming performance on color and object grids and reading (Pauly et al., 2011; Albuquerque, 2012; Caravolas et al., 2012). In other studies, picture RAN was shown to be stronger predictor of reading than alphanumeric RAN in some studies (Arnell et al., 2009).

Different versions of rapid naming tasks are also shown to vary in their sensitivity in line with the age groups of participants. Some research has shown that all versions of RAN (objects, colors, letters, and digits) are good predictors of reading in pre-school children, but the object and color RAN versions lose their predictive ability for first and second graders (Badian, 1996; Semrud-Clikeman et al., 2000; Wolf et al., 1986). In contrast, naming-speed performance on letter and number formats RAN continues to be highly correlated with word reading abilities in more experienced readers (Bowers, 1993; Wolf et al., 1994; Wolf et al., 2000). This age effect has been observed in both typical readers and individuals with reading disabilities. For example, Semrud-Clikeman et al. (2000) reported that all RAN versions discriminate between poor readers and typical readers in young participants, but only letter and digit RANs do so for older children. Likewise, Badian (1996) found that while object naming speed accounted for variance in first graders' word reading and reading comprehension, this effect was not existent in second grade.

Chapter 5: Dyslexia and RAN Deficits

Developmental dyslexia is a learning disability that hinders the development of age-appropriate reading fluency despite normal intelligence, adequate educational provision, and no neurological pathology (Rutter & Yule, 1975). It is estimated that dyslexia affects approximately between 5% to 10% of the world population (Shaywitz, 2003). Nowadays, dyslexia is one of the most prevalent learning disabilities. Dyslexic individuals have great difficulties learning to spell and read letters and words. The source of reading disabilities in dyslexia remains an open subject of debate for both neuroscientists and psycholinguists. The general consensus is that reading disabilities found in dyslexic individuals are a result of phonological processing deficits (Vellutino et al., 1996). Phonological processing skills include a number of sub-types of skills, such as phonological awareness and verbal short-term memory. Phonological awareness is a type of meta-linguistic awareness that refers to the ability to manipulate sounds as units of language. For instance, children with good phonological awareness understand that the word "cat" is made up of three distinct phonemes (/c/, /a/, and /t/); replacing the initial phoneme /k/ in "cat" with /b/ makes a totally different word that means another kind of animal. Dyslexic children tend to perform poorly on tasks that require such high demands on phonological awareness (Vellutino et al., 1996).

Together with deficits in phonological processing tasks, dyslexic children are shown to be behind their peers in rapid naming tasks. RAN deficits tend to be longer latencies and greater inaccuracies in naming aloud the visual stimuli they see in a grid. Dyslexic kids also struggle and make many mistakes when reading words aloud from a word list. Early hypotheses attributed this observed difficulty to inadequate skills and knowledge in phonological processing, suggesting that RAN deficits are the consequences of core phonological deficits. However, Bowers and Wolf (1999) reported that a minority of dyslexic participants in their experiment exhibited phonological deficits but their RAN performances were comparable to the control group. The converse was observed in another group who struggled with rapid naming but had normal phonological abilities. In the same study, they found a third group who demonstrated both deficits in RAN and phonological processing; individuals with both deficits had the worst performance on reading-related tasks, which Bowers and Wolf (1999) formulated as the "Double Deficit Hypotheses". This evidence has led many neuroscientists and language researchers to believe that rapid naming tasks also tap upon several non-phonological processes. The idea that rapid naming is a measure of phonological processing cannot be maintained.

Recent studies have indicated that dyslexics may experience language problems beyond reading fluency, such as difficulties in interpreting figurative language, pragmatic incompetence, semantic deficits, and several emotional problems like low self-esteem. Still, decoding problems and reading disabilities remain the exemplary manifestations of dyslexia. In recent years, advances in research methodology and interdisciplinary research have enabled us to examine more general cognitive problems in dyslexia. For example, with improved knowledge in neuroscience, dyslexic individuals are shown to exhibit subtle deficits in executive functioning. In addition, eye-tracking data also indicated that less proficient readers and dyslexics tend to experience systematic decreases in the uptake of foveal and parafoveal information when performing RAN-related or reading tasks (Jones et al., 2013; Pan et al., 2013; Yan et al., 2013; Veldre & Andrews, 2014). These decreases may be the cause of (a) increased difficulties in visually examining and detecting the fixated stimulus (e.g. either a word or a symbol), (b) reduced efficiency or accuracy in coordinating saccades between two items, and (c) less fluent parafoveal preview of the upcoming stimulus (Kuperman et al., 2016). All of these problems together weaken the pre-activation of phonological and orthographic properties of the stimulus, inhibiting recognition as a result (Kuperman et al., 2016). These findings suggest strong similarities in the nature of eye-movement control and visual uptake between rapid naming and reading, which supports the hypothesis that visual scanning plays an essential role in establishing the RAN-reading connection (Kuperman et al., 2016).

Chapter 6: Methodology in the Current Study

Participants

A total of 42 undergraduate Aston Psychology students between 18 – 25 years-of-age took part in the study for research credits (n=42). The participants were recruited from SONA Research Participation System at Aston University. All participants speak English as their first languages and have normal or corrected-to-normal vision. None of the participants have historical records of diagnosed cognitive impairments, reading disabilities, and hearing difficulties. Some of our participants are bilingual people who speak another language as their first language alongside English. All participants completed the same tasks in two RAN experiments.

Materials and designs

The study consisted of a Test of Word Reading Efficiency (TowRe) and two sets of serial RAN (Modified Object and Digit grids). The two RAN grids were used in Experiment 1 and Experiment 2. Both experiments took place at a Recording and Observation room in Aston Psychology Lab

Test of Word Reading Efficiency

The TowRe test was adapted from the original version of Torgesen et al. (2011) to fit the resolution and picture format of the Tobii eye-tracker's computer screen. This digital version of TowRe consisted of 40 words in total, with 10 words divided into 4 columns. This test had a mixture of sight words and less frequent words. Less common words with more complex phonemic structure (two or more than two syllables) concentrated in the third and fourth column. Each column has a balanced mixture of word categories (**e.g.** nouns, verbs, and adjectives). The actual TowRe in the study can be found in the **Appendices.**

Serial Object Rapid Automatized Naming

The Object-RAN grid set included a total of 36 visual stimuli, with 9 objects on a row (9x4 size). The visual stimuli were categorized into two different groups: animate objects and inanimate objects. All the visual stimuli were designed on computer apps. We intentionally avoided using picture drawings for RAN. Some studies found that participants respond more rapidly to painted computer RAN images because they depict realistic shapes and vivid patterns of the objects in real life. In order to partition semantic processes towards living and non-living objects, we replaced "boat" and "star" with "chicken" and "frog". The RAN grid then had an even number of animate entities (chicken, frog, fish) and inanimate entities (pencil, key, star). The same Object RAN grid was used in both **Experiment 1** and **Experiment 2** (see **Appendices**)

Serial Digit Rapid Automatized Naming

The Digit-RAN grid consisted of 36 digits, with 9 digits on a row (9x4 size). The grid contained a mixture of even numbers (2, 4, 8) and odd numbers (3, 5, 7). The idea was to compare its performances with the Object RAN grid. The same Digit RAN grid was used in both **Experiment 1** and **Experiment 2**.

Experiment 1 – Conventional Naming Aloud Task

In Experiment 1, the participants were required to name aloud all the visual stimuli on the grid as rapidly as possible. Their eye movements were recorded by the Tobii eye tracker.

Experiment 2 – Object Categorization Task

Experiment 2 aimed to strip away phonological processing components, so the participants do not have to name aloud the stimuli. Alternatively, they scanned their eyes through the grid examining every stimulus and gave verbal responses by saying yes/no. For the Object-

RAN grid, they said yes whenever they saw a living object and said no whenever they saw a non-living object. For the Digit-RAN, they said yes whenever they saw an even number and said no if they saw an odd number (see **the Appendices**).

In Experiment 2, we intended to observe whether semantic processing is unique to processes involved in non-alphanumeric RANs only.

We focused on fluency and speed in RAN rather than accuracy. Therefore, only participants' eye movements were recorded during all testing sessions and experiments. There was neither voice nor video recording in our study.

Procedure

We recruited participants via the SONA Psychology Research Participation System at Aston University. The participants chose the time slots at their own convenience to take part in the study. All the testing sessions took place at the Aston Psychology Lab (MB640). We met participants in the lab lounge and led them to a recording room. The participants were told to read terms and guidelines on our PIS (Participant Information Sheet). The PIS mentioned our study purposes, participants' benefits, eligibilities, project descriptions, and how we would make use of the data. All the participants had to sign the consent form before the experiments began.

Every participant completed the Test of Word Reading Efficiency (TowRe) in 3-5 minutes before the RAN tasks. In Experiment 1, the participants had to name aloud the visual stimuli on the RAN grids. They finished the Object grid first and then proceeded with the Digit grid. In Experiment 2, the participants had to examine the visual stimuli and give verb response yes/no to our specific questions. For the Object grid, the participants had to say yes if the visual stimulus they were seeing was a living object and say no if it was not. For the Digit grid, they had to say yes if the digit was an even number and say no if it was not. Because our study is a within-subject design, half of our participants did the Conventional Naming Task (Experiment 1) first, and the other half did the Object Categorization Task (Experiment 2) first. We intended to counter-balance the order effects. The whole experiment took each participant approximately 20-30 minutes to complete the testing session. We gave every participant the debrief forms at the end of the experiments in order to thank and notify them about the intentions of each task. Should participants have any questions or inquires, they would contact us via our given correspondences.

Variables in the study

There are 5 variables of interests in our study: (a) Total Naming Time, (b) Total Fixation Duration, (c) Time for Making Saccades, (d) Total Fixation Duration for Animate Objects, (e) Total Fixation Duration for Inanimate Objects. Many previous studies also paid attention to Regressions and Skipping Rates, but the two variables do not belong to our interests because our samples showed little regression and skipping rates were negligible. The variables were measured per participant (n=42) and across 5 tasks in the experiments (TowRe, RAN Object Naming, RAN Digit Naming, RAN Object Categorization, RAN Digit Categorization). All timing variables were measured in seconds. **Table 1** summarizes the variables in the study and indicates how we measured those variables in our eye-tracking experiments.

We are particularly interested how the eye movement variables in word reading test will be correlated with those recorded in four rapid naming tasks. We expect to see a high correlation between fixation duration per item and time amount for making saccades between the two consecutive stimuli in the grid in rapid naming tasks and those of the word reading efficiency test. In addition, we pay specific attention to the fixation latencies that our participants spent on assigned AOI (areas of interests), whether they belong to animate or inanimate objects, and even or odd digits.

Table 1: Variables in the study, their interpretation and method of measurement (all in seconds)

Name of the variable	Interpretation of the variable	Method of measurement
Total Naming Time	The total amount of time that a participant needed to name aloud all the visual stimuli they saw on a grid in a trial	We measured this variable by subtracting the end time at which a participant finished naming the last stimulus in the grid with the onset time at which a participant was shown the first stimulus.
Total Fixation Duration	The total amount of time that a participant fixated on all the visual stimuli on a grid	Total Fixation Duration is the summed duration of all fixations landing on the targets in a trial
Time for Making Saccade	The total amount of time that a participant spent on making saccades and coordinating their eyes across the stimuli in a trial	We calculated Time for Making Saccade by subtracting Total Fixation Duration from the Total Naming Time
Total Fixation Duration for Animate Objects	The total amount of time that a participant fixated on animate targets in a trial	Total Fixation Duration for Animate Objects is the summed duration of all fixations landing on targets that were classified as "animate" in a trial
Total Fixation Duration for Inanimate Objects	The total amount of time that a participant fixated on inanimate targets in a trial	Total Fixation Duration for Inanimate Objects is the summed duration of all fixations landing on targets that were classified as "inanimate" in a trial

Chapter 7: Data Analysis and Results

The unit of eye movement analysis for both the RAN conditions and the TowRe was a symbol on a grid: a digit, a word, or an object. Our original sample consisted of 42 participants. However, we eliminated 5 participants from our samples due to technical failures or participants' unstable performance during the test. The exclusion criteria are: (a) either the participants looked out of too many areas of interests and/or (b) either the participants did not keep their heads still during reading. These unstable recordings of data were similar across all the rapid naming tasks and word reading performance for the 5 participants. Only 37 participants were included in the final analyses. All the analyses performed were run on these 37 samples (n=37). In order to obtain the desired results, we performed a number of tests with SPSS. The final analyses in the study include the paired sample t-test, correlation analysis, and regression analysis. All the figures are rounded to two digits. **Table 2** illustrates the descriptive statistics for all the variables in the study across RAN-related tasks and the Word Reading task (TowRe):

Table 2: Descriptive statistics for all the variables in the study (n=37) (all measured in secs)

Condition	Measure	Min	Max	Mean	SD
TowRe (Word Reading)	Total Naming Time	19.04	47.27	27.29	5.70
	Total Fixation Duration	9.67	33.81	19.45	5.19
	Eye Movement Time	3.46	17.77	7.84	3.30
RAN Object Naming	Total Naming Time	16.83	42.75	24.85	4.58
	Total Fixation Duration	10.50	29.00	18.31	4.60
	Eye Movement Time	2.82	18.90	6.54	3.61
RAN Digit Naming	Total Naming Time	9.95	20.70	14.03	2.27
	Total Fixation Duration	3.46	14.82	9.59	2.40
	Eye Movement Time	1.64	13.58	4.44	2.36
RAN Object Categorization	Total Naming Time	13.53	26.72	19.25	3.11
	Total Fixation Duration	8.77	19.63	14.10	3.15
	Eye Movement Time	2.44	12.81	5.14	2.48

RAN Digit Categorization	Total Naming Time	15.00	35.25	21.96	4.40
	Total Fixation Duration	9.65	24.95	15.52	4.07
	Eye Movement Time	2.35	12.69	6.44	2.74

We conducted two paired-sample t-tests to compare the means of fixation lengths for animate stimuli and that of inanimate stimuli in the two RAN Object tasks; and fixation durations for even digits and odd digits in the two RAN Digit tasks. The results corresponded to our expectations. For the conventional rapid naming tasks where a participant had to name aloud the visual stimuli, there were no statistically significant differences between two AOI groups that were intended to induce a contrast that demands semantic activation. This difference is only observed in modified naming tasks where participants had to categorize the visual stimuli only by giving verbal yes/no responses. These results illustrate that participants were conditioned to capitalize on their semantic processing abilities only in categorization tasks. However, in a conventional rapid naming task where participants name aloud the grid items, they tended to pay little or no attention to the semantic properties of the stimuli. As a result, rapid naming tasks may mainly require rapid and accurate retrieval of phonological representations from the visual symbols.

Table 3: Paired sample t-test for total fixation duration (measured in seconds) on animate-inanimate object and even-odd digits.

Task	**Animate**		**Inanimate**		**T-test results (Animate vs Inanimate)**		
	Mean	**SD**	**Mean**	**SD**	**df**	**t**	**Sig.**
RAN Object Naming	9.24	2.45	9.08	2.35	36	.728	.472
RAN Object Categorization	6.58	1.79	7.53	1.61	36	-4.403	.000*
	Even		**Odd**		**T-test results (Even vs Odd)**		
	Mean	**SD**	**Mean**	**SD**	**df**	**t**	**Sig.**
RAN Digit Naming	4.76	1.36	4.83	1.18	36	-.535	.596
RAN Digit Categorization	7.33	2.10	8.19	2.21	36	-3.600	.001*

* significant at $p < 0.05$

Table 4 reports all Pearson correlation coefficients between eye movement variables in the RAN conditions and those in TowRe. These analyses revealed that there are strong correlations between several eye movement variables in RAN-related tasks and in reading: longer reading times, greater fixation latencies, and shorter time for making saccades in TowRe are associated with longer name times, greater fixation latencies, and shorter time for making saccades in the RAN-related tasks. These correlations remain strong across all the RAN tasks, including the categorization tasks where participants do not need to name aloud the visual stimuli.

Table 4: Pearson's correlation between naming times and eye movement variables in RAN-related tasks and naming times and eye movement variables in word reading task (TowRe)

Condition	Measure	Reading Time in TowRe	Fixation Duration in TowRe	Eye Movement Time in TowRe
RAN Object Naming	Naming Time	0.59**	0.50**	0.21
	Fixation Duration	0.30	0.57**	-0.37*
	Eye Movement Time	0.36*	-0.08	0.74**
RAN Object Categorization	Naming Time	0.60**	0.56**	0.16
	Fixation Duration	0.49**	0.62**	-0.14
	Eye Movement Time	0.14	-0.08	0.38*
RAN Digit Naming	Naming Time	0.54 **	0.32**	0.41*
	Fixation Duration	0.04	0.24	-0.31
	Eye Movement Time	0.47**	0.06	0.71**
RAN Digit Categorization	Naming Time	0.64**	0.68**	0.03
	Fixation Duration	0.46**	0.62**	-0.17
	Eye Movement Time	0.34*	0.17	0.32

Note: *p < .05. **p < .01

As shown in **Table 5**, we also calculated correlations between eye movement variables and naming times within the same RAN tasks. These results are aligned with many previous studies in the literature: longer naming times in RAN are correlated with longer fixation durations and smaller saccades.

Table 5: Pearson's correlation between naming times and eye movement variables within the same RAN-related tasks.

Condition	Measure	Naming Time	Fixation Duration	Eye Movement Time
RAN Object Naming	Naming Time	-	0.69**	0.38*
	Fixation Duration		-	-0.40*
	Eye Movement Time			-

RAN Object Categorization	Naming Time	-	0.68**	0.38*
	Fixation Duration		-	-0.40*
	Eye Movement Time			-
RAN Digit Naming	Naming Time	-	0.49**	0.46**
	Fixation Duration		-	-0.54*
	Eye Movement Time			-
RAN Digit Categorization	Naming Time	-	0.79**	0.42**
	Fixation Duration		-	-0.21
	Eye Movement Time			-

Note: *p < .05. **p < .01

Table 6, Table 7, and **Table 8** indicate correlation coefficients of different types of eye movement variables among the four types of RAN conditions. Overall, these measured variables are associated with one another, suggesting that when a participant was slow in naming aloud the visual symbols in one RAN condition, he or she tended to be slow in all other RAN conditions. The same pattern was also observed for fixation duration and saccade time. When a participant had longer fixation latencies in one RAN task, he or she also had longer fixation latencies in all other RAN tasks. Likewise, a participant tended to make shorter saccades in all the RAN-related tasks if he or she made shorter saccades in one RAN condition.

Table 6: Pearson's correlations of total naming times recorded across all the RAN-related tasks

	RAN Object N	RAN Object C	RAN Digit N	RAN Digit C
RAN Object N	-	0.576**	0.468**	0.476**
RAN Object C		-	0.256	0.657**
RAN Digit N			-	0.272
RAN Digit C				-

Note: **p < .01

Table 7: Pearson's correlations of fixation durations recorded across all the RAN-related tasks

	RAN Object N	RAN Object C	RAN Digit N	RAN Digit C
RAN Object N	-	0.704**	0.484**	0.496**
RAN Object C		-	0.441**	0.737**
RAN Digit N			-	0.249
RAN Digit C				-

Note: **p < .01

Table 8: Pearson's correlations of saccade time recorded across all the RAN-related tasks

	RAN Object N	RAN Object C	RAN Digit N	RAN Digit C
RAN Object N	-	0.596**	0.579**	0.432**
RAN Object C		-	0.424**	0.477**
RAN Digit N			-	0.282
RAN Digit C				-

Note: **p < .01

In order to examine the impacts of four different versions of RAN tasks on TowRe reading speed, we performed four sets of hierarchical multiple regressions (**Model 1-4** in **Table 9**). In **Model 1** and **Model 3**, we examined the effects of eye movement variables in conventional serial RANs (i.e. object grids and digit grids) on word reading speed. In **Model 2** and **Model 4**, we examined the effects of eye movement variables in modified serial RANs (i.e. categorization tasks using the same object and digit grids in **Model 1** and **Model 3**) on word reading speed. Results from regression analyses show that a combination of fixation duration and eye movements is a good predictor of word reading speed, accounting for nearly 36.2% and 35.2% of variance in conventional rapid naming conditions: the RAN object naming and the RAN digit naming respectively. In categorization tasks where there is no demand for phonological retrieval, eye movement variables in RAN still explains 33.8% and 41.7% in RAN object categorization and RAN digit categorization respectively.

Table 9: Multiple hierarchical regressions for selected eye movement variables in Rapid Automatized Naming and total reading time in TowRe

Predictors added	R^2	B	Beta	Sig.
Model 1: Object Naming				
Step 1				
Fixation Duration	0.092	0.38	0.30	0.69
Step 2				
Fixation Duration		0.657	0.530	0.001
Eye Movement		0.895	0.567	0.001
Fixation Duration + Eye Movement	0.362			0.000
Model 2: Object Categorization				
Step 1				
Fixation Duration	0.235	0.878	0.455	0.002
Step 2				
Fixation Duration		1.182	0.652	0.000
Eye Movement		0.943	0.410	0.009
Fixation Duration + Eye Movement	0.338			0.000
Model 3: Digit Naming				
Step 1				
Fixation Duration	0.002	0.101	0.042	0.803
Step 2				
Fixation Duration		1.012	0.426	0.014
Eye Movement		1.709	0.705	0.000
Fixation Duration + Eye Movement	0.352			0.001
Model 4: Digit Categorization				
Step 1				
Fixation Duration	0.214	0.649	0.463	0.004
Step 2				
Fixation Duration		0.785	0.560	0.000
Eye Movement		0.959	0.460	0.002
Fixation Duration + Eye Movement	0.417			0.000

Chapter 8: Discussion and Implications for Dyslexia

In this study, we aim to examine semantic processing and eye movements as two components that are mostly responsible for establishing the relationship between rapid naming and reading. We hypothesized that semantic activation is not a sub-component that conventional rapid naming taps upon because a participant is only required to name aloud the visual stimuli. Thus, rapid and accurate performances in conventional rapid naming tasks should be the result of rapid and efficient retrieval of phonological units from the mental lexicon. Our hypothesis contradicts the view that rapid naming tasks may activate the lexical retrieval, rather than just simply phonological retrieval. In order to testify this further, we use RAN grids that consist of visual stimuli that are a mixture of living and non-living objects. The number of living objects is equal to the number of non-living objects in our grid. We used this design to see whether there is a significant difference between fixation durations on living objects and non-living objects. In principle, the mental distinction between animate and inanimate has been well-documented and recorded since early infancy (Caramazza & Shelton, 1998). Recognition and activation of semantic properties are argued to be exclusive to human cognitive processes. Should rapid naming tasks also activate semantic processing, we expect a considerable difference in fixation latencies between animate stimuli and inanimate stimuli. In other words, a participant may fixate longer on clusters of non-living objects than living objects because the inanimate group is comprised of a greater number of subordinates and neighborhoods. Denser neighborhoods result in greater competition among words with similar initials (Caramazza & Shelton, 1998).

Another thing we wish to see in this study is to what extent the role of eye movements contributes to the relations between RAN and reading. Several studies in the literature have found that Ran-related tasks tap upon nonphonological and more general cognitive processes, such as executive functioning, parafoveal coordination. Our focus in this study is the importance of eye movements. According to the visual scanning hypothesis, RAN accounts for a large proportion of variance in reading since eye movement patterns in rapid naming are similar to those registered during reading. RAN and reading are related because both involve the ability to coordinate eye movements across different stimuli on a printed page, ideally in left-to-right conditions. We expect that longer fixation durations and shorter saccades will also be linked to longer fixation durations and shorted saccades in reading tasks. Many previous studies use sentence and paragraph reading as a measure to investigate oculomotor control. However, we use word reading tasks primarily for two reasons: (1) word reading is a purer measure of decoding words and therefore should exhibit stronger effects with RAN. Sentence and paragraph reading involve not only word decoding but also language comprehension, inferences, and world knowledge. (2) In the word efficiency reading (i.e. TowRe), a participant has to read words in columns and in top-to-bottom direction instead of left-to-right manner. It is therefore interesting to see whether eye movements between RAN and reading are still similar in such case. If this is true, the visual scanning hypothesis should be revised: the coordination of eye movements establishes the relation between RAN and reading, and this coordination is independent of directions.

The results reported here in this study in general confirm our hypotheses. We did not see a significant difference in fixation latencies between animate and inanimate objects in conditions where phonological retrieval exists. We can conclude that semantic processing is not a component of conventional rapid naming tasks. This contradicts the view that semantic integration and activation of the stimuli also play a role in defining the relationship between RAN and reading (Wolf & Bowers, 1999). In this respect, RAN is predictive of reading because it mainly tests how rapidly and accurately a person is able to retrieve the phonological representations to name a targeted symbol. As a result, RAN becomes the strongest predictor of reading abilities when it comes to word decoding. Text reading requires several additional processes, apart from word recognition, such as syntactic processing, discourse analysis, inferential logic, world knowledge, semantic skills, working memory, and so on (Kuperman et al., 2016). Therefore, studies that use sentence or paragraph reading tend to report lower variance in reading explained by RAN than those that use word reading tasks. Together with results reported here, this suggests that rapid naming tasks bear a more direct correlation with word reading, which mostly requires pure phonological processing, but a more indirect correlation with language comprehension, such as in sentence and paragraph reading. We cannot conclude that RAN cannot predict abilities to comprehend a passage or make inferences from a text since word decoding and recognition facilitates language comprehension.

Norton & Wolf (2012) conceptualized RAN as a "microcosm or mini-circuit of the later developing reading circuitry". Under this view, RAN is a strong predictor of reading because it involves a nexus of so many cognitive and linguistic processes that are also found in reading. However, our results reported here have weakened their claim. Semantic processing is an integral component of word reading, sentence reading, and paragraph reading. According to our results, rapid naming tasks appear not to require their participants to activate their semantic memories. Therefore, RAN and reading may be similar in many respects, from eye saccades to working memory to the connecting of orthographic and phonological representations, but not integration and activation of semantic properties of written symbols or stimuli.

On the flip side, we also found that eye movement patterns in RAN and reading are so similar. Longer fixations and shorter saccades in RAN are associated with longer fixations and shorter saccades in word reading task. As previously mentioned in the literature, eye movement variables were found to be highly correlated with those in sentence reading tasks (Kuperman & Van Dyke, 2011), in paragraph reading tasks (Doyle, 2005; Kuperman & Van Dyke, 2011), and now in our word reading task, even with categorization tasks that do not require explicit articulation of symbol names. Some studies have found that eye movement patterns between rapid naming and reading remain similar when participants are asked to read backward from the right to left (Protopapas et al., 2013). Taken together, these results are a call for modifications to the visual scanning hypothesis. As long as participants have to name symbols in a serial manner, eye movements between RAN and reading are still strongly related, regardless of whether it is left-to-right, right-to-left, or top-to-bottom directions.

Like previous studies in the literature, our study still has some limitations that affect our results. Because of time pressure and insufficient resources, we did not record the number of words that were read correctly and incorrectly in the word reading test (TowRe). At the time of data collection, we could not get a version of the word reading test that is compatible with the resolution and the screen size of the Tobii eye tracker studio. We were initially interested in fluency, speed, and eye movement variables, rather than accuracy. This decision, however, turned out to be a mistake: (a) we failed to examine if the subsets of colors and objects lose its predictive value of reading accuracy in adults, and (b) we could not see whether the RAN categorization tasks are still related to the participants' reading score in the TowRe to a significant extent. At the beginning of our experiment, we predicted that the categorization tasks may not predict participants' accuracy scores well. An array of studies in the RAN-reading literature found that articulation alone does not account for variance in reading abilities. For example, Georgiou et al. (2013) found that RAN Cancellation and RAN Yes/No did not predict reading abilities in their participants. Therefore, we conclude that oral production of the names of the symbols on RAN grids is exclusive to the RAN-reading relationship, and articulation alone does not explain that strong relation.

Finally, our study has yielded one important implication for semantic deficits in dyslexia. According to the Lexical Quality Hypothesis, semantics is among the vital components that contribute to efficient and successful retrieval of words from the mental lexicon. Previous studies recorded semantic deficits in dyslexic readers because of their impaired performances on modified rapid naming tasks (e.g. saying yes/no to animate/inanimate objects), suggesting that this type of deficit is unique to dyslexia (Jones et al., 2010). However, as our results have demonstrated, semantic deficits in dyslexia are actually an indirect consequence of phonological processing deficits. One possible explanation for semantic processing problems in dyslexic readers may lie in the association of form (phonology and orthography) and meaning (which is integrated and consolidated knowledge in adult dyslexic readers. Problems with accessing the phonological representations of words alone may lead to breakdowns with the bundle as a whole. Our findings are aligned with the Lexical Quality Hypothesis by Perfetti (2007) and results reported in Rjthoven et al., (2018). Still, this explanation may be valid for alphabetic languages where there is a close association between orthographical information and phonological representations of words. In some non-alphabetic languages, such as Chinese or Japanese, there is a stronger link between orthography (e.g. strokes or characters) and semantics (e.g. each character represents a certain meaning); phonology is learnt by rote, rather than with a systematic mapping. Semantic processing deficits warrant further investigation in such languages.

Chapter 9: Conclusion

In conclusion, we found that semantic processing is not a component that rapid naming tasks tap upon and eye movement variables in RAN and reading are highly comparable. Our results have suggested that the role of eye movements is partially responsible for strengthening the relationship between RAN and reading. Without seriality, such relationship is reduced or non-existent because there is no need for making saccades and coordinating eye movements across a grid or a printed page. Nevertheless, eye saccades alone cannot explain variance in reading. Our biggest contribution in this study is to discover that participants do not retrieve their semantic properties from their mental lexicon when naming the RAN stimuli. This suggests that we must take the componential approach in order to analyze the correlation between RAN and reading. The alternative approach that conceptualizes RAN as a mini version of reading does not work, since semantic processing is essential to reading, while in RAN it is not, as reported in our study.

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Appendices

Form B

2	7	4	5	3	8	4	2	5
8	3	7	2	8	4	3	5	7
4	8	2	7	5	3	5	2	8
3	4	7	3	2	5	8	7	4

cat	part	suite	colour
red	fast	without	intuition
no	shoes	garment	distress
we	money	hollow	transient
he	father	potent	absentee
the	river	collapse	prairie
and	timid	provide	confident
yes	cancel	postpone	persuade
of	collapse	qualify	recession
fast	empty	proposal	rigid
man	mountain	depress	extinguish

NTNU
Norwegian University of
Science and Technology

Aston University
Birmingham