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Rapid Automatized Naming and Reading Ability

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by

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Under the Direction of Robin D. Morris, Ph.D.

ABSTRACT

The Rapid Automatized Naming test (RAN) has been shown to be a strong predictor of reading ability (Katzir et al., 2006), however the nature of this relationship remains unclear. The purpose of this study was to evaluate the underlying components of RAN, and to then determine whether these components partially account for the relationship between RAN and reading ability. The sample consisted of 100 undergraduate students. The underlying components of RAN that were evaluated included, visual search and scanning, auditory and visual sequencing, discrete naming, confrontation naming, executive functioning and phonological processing. The findings suggest that visual search and scanning, auditory sequential processing, discrete naming and executive functioning are all significant underlying components of RAN. Additionally, the findings suggest that visual scanning and auditory sequential processing partially mediate the relationship between RAN and reading fluency.

INDEX WORDS: Reading, Rapid Automatized Naming, eye movements

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Acknowledgements/Dedication

For my parents, whose love and support have been a constant source of inspiration, and for Eric, whose patience, love and understanding has been a much appreciated comfort

And for Robin, I could not have accomplished this without tour mentorship, support and knowledge.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
ADHD	Attention-Deficit/Hyperactivity Disorder
ANOVA	Analysis of Variance
BNT	Boston Naming Test
CTOPP	Comprehensive Tests of Phonological Processing
ESL	English as a Second Language
GORT-4	Gray Oral Reading Test-4
in	inch
POR	Point of Regard
RAN	Rapid Automatized Naming
ms	millisecond
SD	Standard Deviation
sec	second
Word ID	Word Identification
WJ-3	Woodcock-Johnson III

Chapter 1: Introduction

Researchers and clinicians have known for years that the Rapid Automatized Naming test (RAN) is a strong predictor of early reading ability and that people who have poor performances on these tasks are expected to have difficulty reading fluently (Katzir et al., 2006; Wolf and Bowers, 1999). Although there are a number of hypotheses about why the continuous format of the RAN test is such a strong predictor of reading ability, there is little conclusive evidence that provides for a comprehensive understanding as to why it is such a good predictor. It appears that naming speed represents a complex integration of many cognitive, perceptual and linguistic processes (Denckla and Cutting, 1999). Of particular interest in the current study is the hypothesis that the visual scanning and sequential components of the continuous RAN format are similar to those same visual scanning and sequential processes required in reading, and that they account for some of the uniquely shared variance.

The History of RAN

The concept of RAN was first introduced by Geschwind and Fusillo (1966), who examined color-naming in an adult stroke patient suffering from alexia without agraphia. This patient could not name colors despite normal color matching and no evidence of color blindness. The authors concluded that the patient could access the pathway from visual and kinesthetic representations to spoken words, despite the fact that the patient could not read. This paper led Denckla and Rudel (1972) to examine color naming in first-grade children with unexpected reading failure. Although they found the children could name colors, they had longer latencies in retrieving the color names from memory and in rapidly naming colors, suggesting that these naming difficulties might be related to the children's problems with reading. Denckla and Rudel (1974, 1976) later developed 3 additional RAN tests using digits, letters and objects. As with the color naming, they similarly found that latency was more predictive than errors with these new stimuli. Since this initial work, other research groups have replicated the findings that the RAN test is a strong correlate of early reading development (Katzir et al., 2006; Georgiou, Parrila and Kirby, 2006; Manis, Doi, and Bhadha, 2000; Manis, Seidenberg and Doi, 1999).

Continuous versus Discrete Format

Since this early work, there has been a historical, methodological debate centered around whether RAN measures should be presented in the continuous format as it was originally developed, or whether it should be presented in a discrete format where each stimulus is presented individually. Wolf (1991) stated that advocates of the discrete-trial format have argued that it is a purer measure of RAN because it eliminates the processes of scanning, sequencing, motoric requirements, and any other extraneous sources of variance that are included in the continuous versions. Advocates of the continuous version argue that it is the very nature of the continuous format, including the scanning, sequencing, and eye movement requirements, that make RAN such a strong predictor of reading ability (Misra, Katzir, Wolf and Poldrack, 2004; Wolf, Bowers and Biddle, 2000; Wolf, 1997). Research has suggested that the continuous format may also place more demands on executive functioning than the discrete format (Denckla and Cutting, 1999).

There is conflicting older research on whether the discrete format is even predictive of reading ability. Several researchers have found that the discrete version is not a good predictor of reading ability (Perfetti, Finger, and Hogaboam, 1978; Stanovich, 1981), whereas, others have found that the discrete format can be predictive of reading ability (Bowers and Swanson, 1991). Although some researchers have found the discrete format to be predictive of reading ability, the continuous version appears consistently to exceed the discrete version in predictive ability.

Bowers and Swanson (1991) found that after first entering the discrete format of the RAN into a regression analysis, the continuous format still added uniquely to reading ability, surpassing the discrete format in predictive value. The research on the continuous version of RAN is more consistent in its finding that it is a good discriminator between good and poor readers (Grigorenko et al., 1997; Berninger et al., 1995), and such results have even been found among adults (Felton, Naylor and Wood, 1990).

Components of RAN

There has been another debate over whether RAN measures make a distinct contribution to predicting reading ability that is separate from other cognitive or language predictors, such as phonological awareness and working memory. Many researchers have believed that RAN makes a distinct contribution (Wolf, Bowers and Biddle, 2000; McBride-Chang and Manis, 1996). However, others have believed that RAN is a test that measures a component of phonological processing (Velluntino et al., 1996; Wagner et al., 1993). The arguments that the RAN test measures a separate process from phonological processing stem from the fact that RAN consistently makes a unique contribution to reading, and that poor readers can be subtyped into those with RAN deficits only, phonological deficits only, and those who have deficits in both phonological processing and RAN (Denckla and Cutting, 1999).

Wolf and Bowers (1999) presented a cognitive model for letter naming. The model starts with the initial attention to each letter that is required. From there, visual processes for feature detection, visual discrimination and letter identification are engaged. Next, the integrated visual information is compared to stored orthographic and then phonological information. Next, phonological labels are accessed and are integrated with semantic information. Finally, motor processes are activated for articulation of the letter. This model highlights the importance of serial eye movements. Serial eye movements must occur as the eye rapidly shifts attention from one letter stimulus to the next.

RAN and Neuroimaging

Misra, Katzir, Wolf and Poldrack (2004) used fMRI to investigate the activation patterns elicited by serial letter and object naming. For both RAN tasks, they found activation in neural areas associated with eye movement control and attention (basal ganglia and frontal eye fields), along with a network of structures that have been implicated in reading tasks. The reading networks activated in this study included the inferior frontal cortex, temporal-parietal areas, and the ventral visual stream. The authors concluded that the patterns of activation they observed during the RAN tasks, highlighted the role of sequential eye movements and attentional processes in these tasks as important processes underlying skilled reading.

RAN in Adult Readers

Cirino, Israelian, Morris and Morris (2005) evaluated the double-deficit hypothesis in a sample of college students with and without reading disabilities. The results of this study indicated that while phonological awareness and RAN contributed to performance on a variety of reading measures, their relative contribution was influenced by the nature of the reading task. Specifically, the results indicated that measures of phonological awareness were most predictive of reading performance on measures of untimed decoding of real words and nonwords. Measures of RAN were most predictive of time decoding of real words and equally predictive of timed decoding of nonwords. These findings suggest that RAN is most predictive of timed reading in adults. Additionally, the findings of this study supported a double-deficit model in adults with reading disabilities. Among the disabled readers, four subgroups emerged, those with primarily phonological deficits, those with primarily RAN deficits, those with both and those with neither.

This highlights the important role of RAN in the manifestation of reading disabilities in adult readers.

Eye movements and reading

When we read, we continually make eye movements called saccades. Saccades are rapid eye movements with velocities as fast as 500 degrees per second. Sensitivity to visual input is reduced during eye movements due to a phenomenon called saccadic suppression (Matin, 1974; Rayner, 1998). The reason for this saccadic suppression, or lack of new visual input or information during a saccade, is because the eyes are moving so quickly across the stable visual stimulus that only a blur would be perceived (Rayner, 1998; Uttal & Smith, 1968). Between the saccades, our eyes remain relatively still during fixations for about 200-300 ms. The eyes actually are never completely still because there is a constant tremor of the eyes called nystagmus. These tremors are small and it is often thought that they are related to perceptual activity, and help the nerve cells in the retina to keep firing (Rayner, 1998). Other, somewhat larger eye movements or tremors are called drifts and microsaccades. It is thought that the eyes occasionally drift, or make small slow movements, because of the imperfect control of the oculomotor system by the nervous system. When this happens, there is often a small microsaccade, or more rapid eye movements, to bring the eyes back to where they were. Most experimenters interested in reading assume that these small movements are just noise in the system and use scoring procedures to ignore them (Rayner, 1998).

Many researchers view eye movements as a valid measure of visual scanning of sequential stimuli, along with other cognitive processing abilities during reading (Starr & Rayner, 2001). A currently supported processing model that embodies this framework is the E-Z Reader (Reichle et al., 1998; 2000). The four processes included in the E-Z Reader are a familiarity check, the completion of lexical access, the programming of saccades, and the saccades themselves. When first fixating a word, the familiarity check begins. At the same time, lexical access or word recognition of the fixated word begins, but the familiarity check is completed first. Once the familiarity check is completed, an initial eye-movement program to the next word is initiated and the lexical access process continues. Finally, the lexical access is completed and the word is recognized (Starr & Rayner, 2001).

When reading English, eye fixations last about 200-250 ms, and the mean saccade size is 7-9 letter spaces. Letter spaces are the appropriate metric to use because the number of letters navigated by saccades is relatively stable when the same text is read at different distances (Morrison, 1983). Although visual acuity is very good in the fovea, it is not as good in the parafovea, and is even worse in the periphery, or region beyond the parafovea. We use saccades, or move our eyes, to place the fovea on the part of the visual stimulus that we want to see most clearly. Reading on the basis of only parafoveal or peripheral information is difficult if not impossible (Rayner, 1998; Rayner & Bertera, 1979). When reading words in text, some function words are skipped so that foveal processing of each word is not necessary. Content words are fixated about 85% of the time, whereas function words are only fixated about 35% of the time (Carpenter & Just, 1983; Rayner & Duffy, 1988). Function words are fixated less than content words because they tend to be short, and as the length of the word increases, the probability of fixating the word also increases (Rayner & McConkie, 1976).

Although most saccades in reading English are made from left to right, about 10- 15% of the saccades are regressions, or right-to-left movements along the line of text, or movements back to previously read lines. Many regressions are only a few letters long and could be due to the reader making too long of a saccade. When this happens, a short saccade to the left may be necessary in order for reading to proceed efficiently. Short, within-word regression may also be related to problems the reader has processing the currently fixated word. Longer regressions, those spanning more than 10 letter spaces back along the line of text, or onto another line, occur because the reader did not understand the text. In this instance, good readers are very accurate in sending their eyes to the part of the text that caused them difficulty (Murray & Kennedy, 1988; Rayner, 1988), whereas poor readers engage in more backtracking through the text (Murray & Kennedy, 1998). Eye movements are also influenced by level of textual difficulty. As the text becomes conceptually more difficult, fixation duration increases, saccade length decreases, and the frequency of regressions increases (Rayner & Pollatsek, 1989).

There are interesting developmental trends in eye movements as children learn to read. As reading skill increases, the number of fixations decreases, and the frequency of regressions decreases (McConkie et al., 1991). Poor readers and dyslexic readers, like beginning readers, make longer fixations, shorter saccades, more fixations, and more regressions than normal readers (Eden et al., 1994; Martos & Vila, 1990). Lefton et al. (1979) found that the normal developmental gains made by most children, such as decreased fixation duration, increased saccade length, and decreased frequency of regressions, are not seen in dyslexic readers.

Eye movements and visual scanning

The literature evaluating eye movements during more general visual scanning tasks is not as extensive as the reading literature. Eye movement studies using visual search tasks have included searches through text or text-like material (Rayner & Fisher, 1987), searches of pictorial stumili (Boersma, Zwanga, & Adams, 1989), searches of complex arrays (Carmody, Nodine, & Kundel, 1980), and searches of randomly arranged arrays of alphanumeric characters or objects (Zelinsky, 1996). Similar to the finding from reading research, task difficulty seems to influence eye movements in visual search. Several studies have shown that when the distracters are similar to the targets, fixation time increases, more fixations are made, and saccade size decreases (Noyes, 1980; Rayner & Fisher, 1987). Zelinsky and Sheinberg (1997) found that fixations were longer, saccades were shorter, and more eye movements were made in serial search tasks, where the participant was asked to locate a single O among Q-like distracters, than in a parallel search task, in which the participant was asked to find a single Q-like target among O distracters. To date, no studies have evaluated the relationship between eye movement performances in such non-reading tasks like the RAN to those found during reading in the same participants.

The Initial Study

An initial study was conducted within a sample of average undergraduate readers (Doyle, 2004). This study evaluated whether the visual scanning and sequential components of the continuous RAN format are similar to visual processes required in reading in normal adult readers. This study also evaluated whether the visual scanning and sequential processes of the continuous RAN format partially account for the relationship between RAN and reading. Fifty-seven undergraduate students read three short stories and the continuous versions of two RAN tasks (colors, letters) while eye movements were monitored. The study examined and compared the percent of regressions and fixations during both text reading and RAN tasks. The underlying components of the RAN tasks were evaluated using linear regression. In the first model, rapid color naming standard score on the standardized measure was the dependent variable and the predictors were measures of phonological processes, confrontation naming speed, and the number of fixations and regressions on the color naming task using eye movement monitoring. In the second model, the rapid color naming variables were replaced with the rapid letter naming variables. Both models explained significant portions of variance in RAN. The percent of fixations variable was the most significant predictor in both models. Pearson's r correlations evaluated the relationship between eye movements during the RAN and reading tasks. Percent of fixations in color and letter naming were significantly positively correlated with percent of fixations during the text reading tasks. Percent of regressions on the letter naming task and on the easy and average texts were significantly positively correlated. However, RAN standard scores were not found to consistently correlate with standardized reading scores in this sample. Results of the study suggested that the continuous RAN measured important visual scanning and sequencing processes that are similar to the visual scanning and sequencing processes required for reading. Sample limitations restricted the reading range and generalizability of the results. The majority of research documenting the relationship between RAN and reading ability states that although the RAN discriminates between good and poor readers, even among adults, RAN does not typically predict individual variation in word reading skills among normal readers past the elementary grades (Meyer, Wood, Hart, and Felton, 1998).

The Current Study

The purpose of the current study was to extend the scope of the initial study, by examining eye movement patterns during text reading and continuous RAN in a group of adults with a wider range of reading ability. There were two main aims for this study. First, to evaluate whether the scanning and sequential processes, that were found to be an important component for RAN in the initial study, would also be important predictors of RAN in a group of adults who demonstrate a relationship between RAN and reading. It was hypothesized that visual scanning and sequential processing would remain important predictors of RAN. The second aim of this study was to evaluate whether visual scanning and sequential processing would then help explain the relationship between RAN and reading ability. Again, it was hypothesized that visual scanning and sequential processing would at least partially mediate the relationship between RAN and reading ability. In this study, fixations during three types of tasks (reading text, RAN, visual search and scanning) were examined. Based on previous literature and the findings from the initial study, it was expected that fixations made during text reading and the continuous RAN tasks would be similar. Specifically, it was expected that less productive eye movement patterns, such as a greater number of fixations would be indicative of poorer scores on both the RAN measures and the text reading tasks.

Chapter 2: Methods

Participants

One hundred forty-four undergraduate students were recruited from introductory Psychology classes at Georgia State University and one was recruited from the Regents Center for Learning Disabilities, to participate in this study. Of the 145 participants, 22 students did not show for their scheduled experiment time, accurate eye data could not be obtained for 12 participants, 2 participants were color blind, 1 participant decided not to continue with the experiment and dropped out, and 8 participants were excluded due to their medical histories (1 was legally blind in the right eye, 1 significant drug abuse and dependence, 2 moderate traumatic brain injury, 2 epilepsy, 1 multiple sclerosis, and 1 diabetes with diabetic retinopathy causing significant problems with visual acuity). Of the final sample of 100 participants, there was a mean age of 21 years (SD = 4.4), and 79 participants were female (79%). The sample was comprised of 41 (41%) Caucasian, 46 (46%) African American, 4 (4%) Asian, and 5 (5%) Hispanic, 1 (1%) African, and 3 (3%) Biracial self-reported ethnic backgrounds. The mean self-reported grade point average for the sample was 3.15 (SD = .50).

For this study, a low reading achievement classification was used based on the criteria used in a study of college students with reading disabilities by Cirino, Israelian, Morris and Morris (2005). Low reading achievement was defined as a standard score of 85 or less on the WJ-III Basic Reading composite or TOWRE Reading Efficiency composite. A discrepancy based reading disability criteria could not be defined because an IQ measure was not given. Although only one reading impaired participant was recruited from the Regent's Center, 22 (22%) of the undergraduate participants met criteria for low reading achievement based on a score of 85 or less on either the WJ-III Basic Reading Composite or the TOWRE Reading Efficiency composite.

Participants were screened for both visual and auditory acuity at the time of testing. Each participant completed a background questionnaire. This questionnaire was used to help screen for neurological conditions and sequelae, current and past psychiatric conditions, learning problems and non-native English speakers. No participants with a history of serious neurological problems (Epilepsy, moderate to severe brain injury, Multiple Sclerosis) or psychosis were included in the study. Only native English speakers and simultaneous bilingual English speakers were included in the analyses. In this study, simultaneous bilingual was defined as anyone who learned English simultaneously with another language, either in the U.S. or in another country. Two participants met the simultaneous bilingual criteria. Both reported being more proficient in English and were fluent English speakers.

Each participant completed a Beck Depression Inventory (BDI-II; Beck, 1996) and a Beck Anxiety Inventory (BAI; Beck, 1990) to assess for current depression and anxiety. Of the final sample, 7 participants endorsed mild-moderate anxiety, 2 endorsed moderate anxiety and 2 endorsed moderate-severe anxiety. On the BDI-II, 1 participant endorsed mild, 4 endorsed moderate and 1 endorsed severe depression. They also completed an ADHD Behavior Checklist For Adults (Barkley, 1995) to assess for ADHD. Based on this questionnaire, 2 participants met criteria for ADHD Inattentive type, 1 met criteria for ADHD Hyperactive type and 3 met criteria for ADHD Combined type. Depression, anxiety and ADHD were not considered exclusionary criteria, given the high rates of commorbidity in this population. However, these disorders were considered in the analyses to control for potential confounding variables.

Apparatus

Eye movement and pupil dilation data was collected with an ISCAN (Burlington, MA) RK-726PCI eye tracker. The eye tracker consists of a camera and infrared light source, both mounted on an adjustable hat that fit on the participant's head. The camera and infrared light source were focused on the pupil to record eye movement and pupil size. The RK-726PCI also tracked the location of the cornea to separate small head movements from eye movements. The computer software calculated pupil size and the location of eye gaze after each subject was calibrated. The eye-tracker system imaged the participant's eye over a 10-in. monitor, and recorded pupil size and location of eye gaze with respect to the participant's surrounding environment. The system was calibrated at the beginning of each session for each participant by requiring them to fixate on a series of nine dots that appeared in random positions on the screen. The coordinates of visual gaze and pupil size were recorded by computer and were reported as the number of pixels on the visual display screen. Visual gaze was measured using the point of regard variable for vertical (POR vertical) and horizontal (POR horizontal) eye movements. The participants were tested using an IBM-compatible computer that was connected to an 18-inch color graphics monitor. This computer was used to present the visual text and processing speed stimuli that the participants read, as well as to record the eye movements and all related data. In contrast to the initial study, in which participants were not restrained, in the current study, participants placed their chin in a chin-rest, in order to reduce head movements and maintain a more accurate vertical POR reading.

Procedure

The undergraduate students received research credit for their Introductory Psychology class for participating in the study. The reading disabled participant from the Regent's Center for Learning Disabilities was compensated with $40. Each participant signed a consent form explaining the nature of the study and any risk involved. All participants participated in one experimental session at Georgia State University. The session lasted approximately 1 ½ hours. A brief informal interview was conducted by the experimenter to obtain a short background history for each participant, including information about possible learning disabilities, traumatic brain injuries, English as a second language (ESL), and grades repeated. Additionally, each student completed an ADHD Behavior Checklist For Adults (Barkley, 1995). This checklist is a series of 18 self-report questions regarding both current functioning and their functioning as a child. Each participant also completed a BDI-II and BAI to assess for current depression and anxiety.

All participants completed the eye movement portion of the experiment first. The eye movement measures consisted of the three GORT-4 stories of different difficulty levels, the continuous versions of two rapid automatized naming tasks (colors and letters), and two visual search and scanning tasks (letters and geometric symbols). Each participant was randomly assigned to complete either the GORT-4 stories or RAN tasks firsts, and subsequently completed the visual scanning tasks. The participants then completed related standardized tests of phonological awareness, reading ability, confrontation naming and executive function.

Eye Movement Variables

Fixations

Fixations were defined as two or more consecutive pixel coordinate values differing along the horizontal axis by no more than five pixels. In order to further differentiate fixations from saccades, at least two of the consecutive data points had to be the exact same horizontal value. The two fixation variables that were calculated in this study were number of fixations and average fixation duration. Number of fixations was calculated by summing the total number of eye movement sequences classified as a fixation. Average fixation duration was calculated by summing the number of samples per second within each eye movement sequence classified as a fixation and then dividing by the total number of eye movement sequences classified as fixations. This value was then multiplied by 16.67 to convert the value from samples per second (60 samples per second) into milliseconds. Figure 1 provides a visual example of this classification system. In this example, there are two eye movement sequences which are classified as fixations and the average fixation duration is 6 samples per second, which equates to 83.5 ms.

Forward Saccades

Forward saccades were defined as an increase in pixel coordinate value along the horizontal plane, not otherwise meeting criteria for a fixation. The two saccade variables that were used in this study were number of saccades and average saccade length. Number of saccades was calculated by summing the total number of eye movement sequences classified as a saccade. Average saccade length was calculated by calculating the number of pixels within each eye movement sequence classified as a saccade and then dividing by the total number of eye movement sequences classified as saccades. Figure 1 provides a visual example of this classification system. In this example, there is one eye movement sequence classified as a saccade, and the length of the saccade is 6 pixels. Given that each pixel on the horizontal axis is approximately 1.23 mm, the saccade in Figure 1 equates to approximately ¼ inch or 1 letter (since each letter is ¼ inch wide on the computer screen).

Regressions

Regressions were defined as a decrease in pixel coordinate value along the horizontal plane, not otherwise meeting criteria for a fixation. The total number of lines, minus one line of information, in the experimental stimulus display was then subtracted from the number of regressions. The reason for this subtraction was to distinguish legitimate decreases along the horizontal plane as the participants moved to the next line of to-be-read information from actual backtracking errors. The easy text had 10 lines of material, and so 9 was subtracted from the total number of regressions for each subject. The average text has 11 lines of material, and the hard text has 12 lines of material, so 10 and 11 were subtracted, respectively, from the total number of regressions in these conditions. Both the experimental naming tasks and visual scanning tasks had 4 lines of information and so 3 was subtracted from the number of regressions in each of these conditions.

The regression variable that was used in this study was number of regressions. Number of regressions was calculated by taking each participant's total number of regressions. In Figure 1, there is one eye movement sequence classified as a regression.

Eye Blinks

In order to calculate eye blinks, pupil diameter had to be calculated. Additionally, pupil diameter helped to distinguish between eye blinks and data error, as data error was recorded as horizontal and vertical values of 0 pixels while pupil dilation was normal, whereas blinks were recorded as horizontal and vertical values of 0 pixels while pupil dilation was 1 mm. Eye blinks were defined as anytime the horizontal and vertical readings were 0 pixels while the pupil dilation value was 1 mm. Following each eye blink, there was a period of un-usable data while the eye re-tracked the screen to get back to the same place it was before the eye blink. This period in the data was omitted from all the analyses as it was not relevant to the study. This was accomplished by discarding all data following an eye blink until the first fixation after that eye blink.

Measures

Table 1 provides a comprehensive list of the measures completed by each participant. Each measure is discussed in detail below.

Experimental Eye Movement Stimuli

Text Stimuli

The GORT-4 is a psychometric test designed to measure oral reading ability in children ages 7 to 18 years old (Wiederholt, and Bryant, 2001). The GORT-4 consists of two parallel forms, Form A and Form B, each containing 14 separate stories of different difficulty levels. The GORT-4 partitions reading into five components: rate, accuracy, fluency, comprehension, and overall reading ability. The GORT-4's fluency measure has good 2-week test-retest reliability (r = .93), and construct validity (detailed information on the psychometric properties of the GORT-4 are reported by Wiederholt & Bryant, 2001). Because the purpose of the present study was to evaluate the relationship between eye movements during reading and RAN fluency in adult readers, only stories 5, 10 and 13 from Form B were used. These stories were chosen because they range in difficulty of readability from a 7^{th} grade level to a fourth-year college level. Readability was determined using Gunning's Fog Index formula (Gray, 1975), where average sentence length (ASL) and percentage of hard words (PHW) were combined to determine school grade level of the text. All stories were presented in an unstandardized fashion on a computer screen for purposes of eye movement measurement. On the computer screen, each letter was ¼ inch wide and the space between each word was 3/8 inch wide.

Story 5 from the GORT-4 Form B was used as easy text. This text was determined to be at the 7th grade level for readability using Gunning's Fog Index formula (Gray, 1975). This story was modified to a shortened version for the purposes of this study. This was accomplished by using just the first 5 sentences of the original GORT-4 paragraph. Studies evaluating eye movements using text often use text of approximately 50-70 words because of the massive amounts of data that are collected (Behrmann, Shomstein, Black, and Barton, 2001; Lueck, Mendez, and Perryman, 2000). The truncated story used in the current study consisted of 68 words, with an average sentence length of 13 words and 7% hard words (defined as words with 3 or more syllables).

Story 10 from the GORT-4 Form B was used as average text. This text was determined to be at the 12th grade level for readability, using Gunning's Fog Index formula (Gray, 1975). This story was also modified to a shortened version for the purposes of this study. This was again accomplished by using just the first 3 sentences of the original GORT-4 paragraph. The truncated story that was used in the current study consisted of 65 words, with an average sentence length of 21 words and 11% hard words (defined as words with 3 or more syllables).

Story 13 from the GORT-4 Form B was used as difficult text. This text was determined to be at a 4th year college student level for readability, using Gunning's Fog Index formula (Gray, 1975). This story was also modified to a shortened version for the purposes of this study, by using just the first 3 sentences of the original GORT-4 paragraph. The truncated story that was used in the current study consisted of 63 words, with an average sentence length of 21 words and 25% hard words (defined as words with 3 or more syllables). There was some concern that this story may be too difficult for some of the participants. Given this concern, a ceiling of less than 50% of words read correctly on Story 10 was implemented. This means that any participant who could not read at least half of the words in the average text correctly, were not given the difficult text. None of the participants in this study met this criterion, and thus all of the participants were given the difficult story.

These experimental texts were validated in a previous study (Doyle, 2004), indicating statistically significant positive correlations between each of the three experimental text tasks and the standardized GORT stories irrespective of text difficulty. This was accomplished using Pearson's *r* analyses to evaluate the time to read each paragraph on both the computerized GORT texts (stories 5, 10 and 13 of Form B) and the standardized GORT texts of similar difficulty (stories 5, 10 and 13 of Form A).

Text difficulty was also established in a previous study (Doyle, 2004). Within-subject ANOVAs were performed to evaluate differences in eye movement results between the three difficulty levels of the experimental text reading tasks. Repeated measures ANOVAs were performed for each of the five eye movement variables used in that study (percent of regressions, saccades and fixations, and saccade and fixation duration) across the three text reading tasks (easy, average and hard). Statistically significant differences were found between the three levels of text difficulty and all five eye movement variables, with the exception of fixation duration between the average and hard text. These findings suggest that the three paragraphs did differ in text difficulty as designed.

Rapid Naming Stimuli

Rapid naming was measured using the Rapid Letter Naming and Rapid Color Naming subtests of the CTOPP (Wagner, Torgesen, and Rashotte, 1999). These stimuli were presented on the computer screen for purposes of eye movement measurement. Time to name each stimulus set was measured in seconds using a stop watch.

Rapid Letter Naming is a 36-item test that measures the speed with which an individual can name a continuous list of letters. Six randomly arranged lower case letters (a, t, s, k, c, and n) were presented in a series of four rows containing nine letters in each row. The participants were instructed to start at the top and name the letters from left to right as quickly as possible. On the computer screen, each letter was ¼ inch wide and the space between letters was 1 inch.

Rapid Color Naming is a 36-item test that measures the speed with which an individual can name a continuous array of colored squares. Six randomly arranged colored squares (blue, red, yellow, green, black, and tan) were presented in a series of four rows containing nine colors in each row. The participants were instructed to start at the top and list the colors from left to right. On the computer screen, each color box was ¾ inch wide and the space between color boxes was 3/8 inch.

These experimental naming stimuli were validated in a previous study (Doyle, 2004), indicating statistically significant positive correlations between the two experimental naming tasks (letter and color naming) and standardized naming times on the CTOPP naming tasks (letter and color naming).

Visual Scanning and Search Stimuli

Two visual scanning and search tasks were created and administered on the computer. Participants were asked to scan 4 rows of letters or symbols (/, \, +, -) from left to right and to search for a particular letter or symbol. Participants were instructed that they would be asked how many of a particular letter (a) or symbol (/) they saw at the end of the task. This was done to ensure that participants actually scanned the entire stimulus. On the computer screen, each letter or symbol was ¼ inch wide and the space between each letter or symbol was 1 inch.

<u>Standardized Measures</u>

Reading Measures

Reading ability was measured using the standardized version of the Letter-Word Identification and Reading Fluency subtests of the Woodcock-Johnson III Tests of Achievement (Mather and Woodcock, 2001), the standardized version of the GORT-4 Form A: Comprehension and Fluency (Wiederholt, and Bryant, 2001) and the standardized version of the TOWRE Sight-Word Efficiency and Phonemic Decoding Efficiency Form A (Torgesen, Wagner, and Rashotte, 1999).

Letter-Word Identification measures the participant's word identification skills as they read words of increasing difficulty without time limits. The portion of this task appropriate for adult participants requires the participants to pronounce single words correctly but does not require them to know the meaning of any words. The items become more difficult as the task progresses and the selected words appear less frequently in written English. The task has a median reliability of .94 in adults. A standard score was calculated to measure untimed single word reading. Additionally, performance on Letter-Word Identification and Word Attack (mentioned below) were combined to create an overall Basic Reading Composite score using the WJ-III norms).

Reading Fluency measures the participant's ability to read simple sentences quickly and to indicate whether the sentences make truthful or false statements by circling yes or no. The difficulty level of the sentences increases to a moderate level. The participant is instructed to complete as many items as possible within a 3-minute time limit. This task has a median reliability of .90 in adults. A standard score was calculated to measure reading fluency.

The GORT-4 measures both fluency (using number of errors and the time to read passages aloud) and comprehension of what has been read (using 5 multiple choice questions for each text of reading). The passages are read aloud, and the examiner records the time it takes to read the passage and any mistakes made during reading. Errors include repetitions, errors in pronunciations or words read incorrectly, self-correction, omissions, and insertions. The participant reaches a ceiling when a low score has been made on both comprehension and fluency. Standard scores were calculated for reading rate, reading accuracy, reading fluency (rate + accuracy) and reading comprehension. Additionally, an overall reading composite standard score was calculated by combining the fluency and comprehension scores. An additional measure of reading speed was collected by taking the total time to read story 10 for each participant (hardest story completed by majority of sample).

The Sight Word Efficiency subtest of the TOWRE assesses the number of real printed words that can be accurately identified within 45 seconds. This task has a test-retest reliability of .82 for adults. The Phonemic Decoding Efficiency subtest measures the number of pronounceable printed nonwords that can be accurately decoded within 45 seconds. This task has a test-retest reliability of .91 for adults. Standard scores were calculated for both Sight Word Efficiency and Phonemic Decoding Efficiency. An overall reading efficiency composite standard score was also calculated by combining the two subtest standard scores.

Rapid Naming Measures

Rapid naming was measured using the standardized Rapid Letter and Rapid Color Naming subtests of the CTOPP (Wagner, Torgesen, and Rashotte, 1999).

Rapid Letter Naming is a 36-item test that measures the speed with which an individual can name a continuous list of letters. Six randomly arranged letters (a, t, s, k, c, and n) are presented in a series of four rows containing nine letters in each row. The examinee is instructed to start at the top and name the letters from left to right. A standard score was calculated based on total time to name letters.

Rapid Color Naming is a 36-item test that measures the speed with which an individual can name a continuous array of colored squares. Six randomly arranged colored squares (blue, red, yellow, green, black, and tan) are presented in a series of four rows containing nine colors in each row. The examinee is instructed to start at the top and list the colors from left to right. A standard score was calculated based on total time to name colors.

The scaled scores for Rapid Letter Naming and Rapid Color Naming were added together and then an overall rapid naming composite standard score was calculated using the CTOPP manual norms.

Phonological Decoding and Awareness Measures

Phonological decoding and awareness were measured using the Word Attack subtest of the Woodcock-Johnson-III Tests of Achievement (Mather and Woodcock, 2001) and the Elision and Blending Words subtests of the CTOPP (Wagner, Torgesen, and Rashotte, 1999).

Word Attack measures a participant's skill in applying phonic and structural analysis skills to the pronunciation of 32 novel printed words. The nonwords become increasingly difficult as the test progresses. A basal is established when the participant correctly reads 6 consecutive nonwords beginning with the first word on a stimulus page. A ceiling is established when the participant incorrectly reads 6 consecutive nonwords ending with the last word on a stimulus page. This test has a median reliability of .95 in the adult range. A standard score was calculated and used as an untimed measure of single nonword reading.

Elision is a 20-item subtest of the CTOPP that measures the extent to which an individual can repeat a word, and then reconstruct what is left of the word after dropping designated phonemes and sounds from the original word. The individual is asked to listen to a word, repeat the word, and finally to say the new word that it created when a particular phonetic component of the original word is removed. This test has a test-retest reliability of .77 in adults. A scaled score was calculated and used as a measure of phonological processing.

Blending Words is a 20-item subtest of the CTOPP that measures the ability to combine sounds into words. The participant listens to a series of separate sounds on an audiocassette and is then asked to put the separate sounds together to make a whole word. This test has a test-retest reliability of .71 in adults. A scaled score was calculated and used as a measure of phonological processing.

The scaled scores for Elision and Blending were added together and then an overall phonological awareness composite standard score was calculated using the CTOPP manual norms.

Sequential Processing Measures

Visual sequencing was measured using the Spatial Span subtest from the Wechsler Memory Scales- 3rd Edition (Psychological Corporation, 1997). The Spatial Span subtest consists of two parts: Spatial Span Forward and Backward. For each part, the examiner taps a series of cubes at the rate of one cube per second. The participant responds by either tapping the same series in the forward task or the reversed series in the backward task. For both parts of the subtest, the test begins with a series of two cubes and continues to add cubes to each progressive series until a maximum of an eight cube series. Participants are given two trials of a series length, and the test continues until both trials of a series length are failed, or until they have completed every series. One point is awarded for each trial that the participant correctly answers. Test-retest reliability for the Spatial Span subtest is .84 for 20-24 year-olds. Overall standard score, as well as longest forward span (longest number of cubes correctly repeated forward) and backward span (longest number of cubes correctly repeated backward) were calculated.

Auditory sequential processing was measured using the Digit Span subtest from the Wechsler Memory Scales- 3rd Edition (Psychological Corporation, 1997). The Digit Span subtest consists of two parts: Digit Span Forward and Backward. For each part, the examiner says a series of numbers at the rate of one number per second. The participant responds by either repeating the same series in the forward task or the reversed series in the backward task. For both parts of the subtest, the test begins with a series of two numbers and continues to add numbers to each progressive series until a maximum of a nine number series for Digit Span Forward and an eight number series for Digit Span Backward. Participants are given two trials of a series length, and the test continues until both trials of a series length are failed, or until they have completed every series. One point is awarded for each trial that the participant correctly answers. Test-retest reliability for the Digit Span subtest is .90 for 20-24 year-olds. Overall standard score, as well as longest forward digit span (longest number of digits correctly repeated forward) and backward span (longest number of digits correctly repeated backward) were calculated.

Executive Function Measures

Cognitive flexibility or the ability to switch back and forth between alternating cognitive sets was measured using the Trail Making Test and Color-Word Interference Test from the Delis-Kaplan Executive Function Scales (D-KEFS; Delis, Kaplan, and Kramer, 2001).

The Trail Making Test of the D-KEFS consists of 5 conditions. The primary executive function task is the Number-Letter Switching condition. This condition measures flexibility of thinking in a visual-motor sequencing format. The four additional conditions allow the examiner to tease out several key processes needed to perform the switching task, including visual scanning, number sequencing, letter sequencing and motor speed. Standard score for the Number-Letter Switching condition was used as a measure of executive functioning.

The Color-Word Interference Test of the D-KEFS consists of 4 conditions. There are two primary executive function conditions. Condition 3 requires the participant to inhibit reading words denoting ink colors, in order to name dissonant ink colors in which the words are printed in. Condition 4 requires that the participant switch back and forth between naming the dissonant ink colors and reading the color words. This condition measures inhibition as well as cognitive flexibility. Two baseline conditions are also included to evaluate key component skills of the higher-order tasks. One of these conditions requires the participant to name color patches, while the other requires the participant to read words that denote colors printed in black ink. Standard scores for conditions 3 and 4 were used as measures of executive functioning.

Additional Experimental Naming Measures

Word Retrieval Measure

Non-continuous word retrieval was measured using a shortened version of the Boston Naming Test (Kaplan, Goodglass, and Weintraub, 2001). The Boston Naming Test is a confrontation naming test consisting of 60 pictures, ordered from easiest to most difficult. This task was presented on a computer screen so that a participant's latency of naming could be acquired for each item. The task was altered by using just the last 30 items from the original Boston Naming Test. The median latency in seconds across all items as well as percent correct (number correct/total number of items) for each participant were used as measures of word retrieval efficiency.

Discrete Naming Measure

Discrete rapid naming was measured using a modified version of the Rapid Color and Letter Naming subtests from the CTOPP (Wagner, Torgesen, and Rashotte, 1999). The tasks were altered from the standard forms described above, by presenting the stimuli one at a time on a computer screen. Stimuli remained on the screen until named by the participant, triggering a voice activated microphone which automatically removed the stimuli from the screen and brought the next stimuli to the screen. Using a voice activated microphone allowed for both a measure of overall naming latency, as well as mean and median latencies. Median latency in seconds was used as the measure of discrete naming.

Table 1.
List of Measures

Experimental Eye Movement Stimuli	Analog Standardized Measures
Text Stimuli	
Easy Text	GORT-4
Average Text	
Hard Text	
Rapid Naming Stimuli	
Letter Naming	CTOPP Letter Naming
Color Naming	CTOPP Color Naming
Visual Scanning and Search Stimuli	
Letter Scanning	VSAT
Symbol Scanning	
Additional Experimental Naming Measures	**Additional Standardized Measures**
Word Retrieval Measure	**Reading Measures**
Shortened and Computerized BNT	WJ-3 Letter-Word Identification
Discrete Naming Measure	WJ-3 Reading Fluency
Discrete Letter Naming	TOWRE Sight-Word Efficiency
Discrete Color Naming	TOWRE Phonemic Decoding Efficiency
	Phonological Decoding and Awareness Measures
	WJ-3 Word Attack
	CTOPP Elision
	CTOPP Blending Words
	Sequential Processing Measures
	WMS-3 Spatial Span
	WMS-3 Digit Span
	Executive Function Measures
	D-KEFS Trail Making Test
	D-KEFS Color-Word Interference Test

Note. GORT-4 = Gray Oral Reading Test- 4th Edition, CTOPP = Comprehensive Test of Phonological Processing, VSAT = Visual Search and Attention Test, WJ-3 = Woodcock Johnson Tests of Achievement- 3rd Edition, TOWRE = Test of Word Reading Efficiency, BNT= Boston Naming Test, WMS-3 = Wechsler Memory Scale- 3rd Edition, D-KEFS = Delis-Kaplan Executive Function Scales.

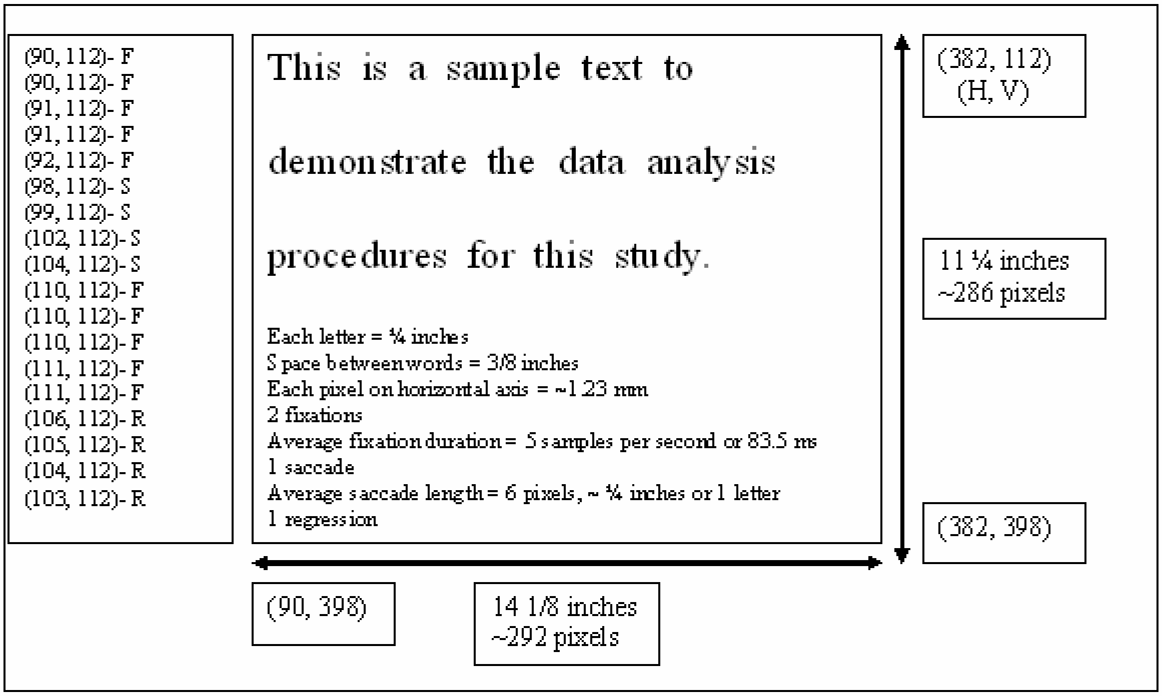

Figure 1. Example of eye movement classification system

Note. F = fixation, S = saccade, R = regression, H = horizontal, V = vertical

Chapter 3: Results

Description of Data

Descriptive statistics were run for all of the dependent and independent variables in this study. Results of these analyses are shown in Table 2. Demographic information about the participants was collected using a self-report questionnaire. There were five missing data points due to participants' neglect in filling in all of the information on this questionnaire, including four participant's grade point average and one participant's class year.

Data Cleaning

Outliers

The data were checked for outliers using z-scores and box plots. Outliers were defined as z-scores greater than 3.00 from the sample means. These outlier values were dropped from further analyses because of concern that the outliers would skew the distributions and interfere with the correlational analyses performed below. Table 1 in the Appendix provides a comprehensive list of all outliers removed. Additionally, the data for 4 participants on both the symbol scanning and letter scanning tasks was removed because it was observed during data collection that these participants were scanning both left to right and right to left (which would artificially increase number of regressions and decrease number of forward saccades).

Distributions

The distributions of the variables were evaluated using histograms. The majority of the variables appeared to be normally distributed. For those variables that visually appeared to be either positively or negatively skewed, further evaluation was conducted using a method that is detailed by Tabachnick and Fidell (2007). With this technique a skewness score is calculated by dividing the skewness statistic by the skewness standard error. Scores over 2.0 suggest that the distribution of a variable is significantly skewed. Eight of sixty seven variables were found to be significantly skewed. In situations in which variables are significantly skewed, Tabachnick and Fidell suggested transforming the data. The particular equation used to transform the data depends on the degree and direction of the skewness. The eight skewed variables were transformed using square root transformations. The relevant linear regression analyses were run both with the transformed variables and with the original non-transformed variables. No differences in significant results were found between the two sets of variables and so it was decided to use the original non-transformed variables. The benefit in using the original variables is that transforming variables often makes it difficult to interpret data.

Evaluation of Redundancy in Eye Movement Variables

In all, there were five eye movement variables (number of regressions, saccades and fixations, and saccade length and fixation duration) for each experimental condition (3 texts of different difficulty levels, rapid letter and color naming, visual scanning of letters and symbols). This was too many variables to include in the regression analyses below, as it would reduce the power of the analyses. Additionally, it was hypothesized that these variables would be highly correlated, creating redundancy and the threat of multicollinearity in further analyses. In order to evaluate the relationships between the different eye movement measures, correlation analysis using Pearson's *r* were performed using the five eye movement variables across the experimental RAN, scanning and 3 text tasks. As shown in Table 3a, there were statistically significant correlations between number of fixations on all three of the text reading tasks and all of the other eye movement variables. Table 3b demonstrates that on the rapid naming tasks, number of fixations was significantly correlated with all of the other eye movement variables for letter naming, but was only significantly correlated with number of regressions and number of saccades for color naming. Table 3c indicates that on the visual scanning tasks, the relationship between the eye movement variables was more variable, as number of fixations was only significantly correlated with number of saccades and saccade distance on these tasks. Because of the redundancy among measures, and to reduce possible type 2 error inflations, it was decided to use the number of fixations variable for primary analyses as it generally had the highest correlation with all the other variables, and seemed to best represent the eye movement measures across all tasks.

In order to better understand the relationship between the reading, naming and scanning tasks, correlation analyses were performed to evaluate number of fixations during these tasks. As shown in Table 2 of the Appendix, correlation analyses using Pearson's *r* established a statistically significant positive relationship between the number of fixations on all three text reading tasks, and the rapid naming tasks and visual search and scanning tasks. A significant relationship was not established between number of fixations during color or letter rapid naming, and the letter search and scanning task.

<u>Validation Analyses</u>

Establishment of Relationship Between Eye Movement Variables during Experimental Reading Tasks and Reading Performance on Standardized Measure

In order to help validate that the eye movement variables from the experimental text reading tasks were related to actual reading performances, the relationships between reading speed on one of the GORT-4 stories and number of fixations on the experimental text reading tasks was evaluated. As shown in Table 4, correlation analyses using Pearson's *r* established a statistically significant positive relationship (r = .65-.71) between number of fixations on each of the three experimental texts, and time to read GORT-4 story 10. This suggests that there was a strong relationship between how long it took to read this story and how many fixations they made on the experimental texts.

Establishment of Relationship Between Eye Movement Variables during Experimental Naming Tasks and Standardized RAN Scores

In order to help validate that number of fixations from the experimental rapid naming tasks were related to the actual performance on the CTOPP RAN subtests, the number of fixations on the experimental naming tasks were correlated with the CTOPP RAN standard scores. As shown in Table 4, correlation analyses using Pearson's *r* established a statistically significant negative relationship between number of fixations on both of the experimental naming tasks, and standard scores on the CTOPP Color and Letter Naming tasks. This suggests that lower standard scores were associated with more fixations on the experimental naming tasks, or higher standard scores were associated with fewer fixations. This was the expected relationship.

Establishment of Relationship Between Eye Movement Variables during Experimental Visual Search and Scanning Tasks and Performance on Standardized Visual Search and Scanning Measure

In order to help validate that the number of fixations from the experimental visual scanning tasks were related to performance on a standardized measure of visual search and scanning, the number of fixations on the experimental visual scanning tasks were correlated with the VSAT standard scores. As shown in Table 4, correlation analyses using Pearson's *r* established a statistically significant negative relationship between number of fixations on both of the experimental scanning tasks, and standard scores on the VSAT. This suggests that lower standard scores were associated with more fixations on the experimental scanning tasks, again the expected relationship.

This series of analyses all supported the validity of the experimental eye movement measures and the use of number of fixations, as useful analogues of the actual standardized measures.

Analyses Addressing Study Hypotheses

Establishment of Relationship Between Reading and Naming

An important, preliminary step in the analyses was to establish whether there was a relationship between reading and RAN in this sample. This relationship was necessary in order to proceed with further analyses evaluating why RAN is predictive of reading ability. A correlation analysis was performed using Pearson's *r* to establish the relationship between the standardized versions of the CTOPP RAN and GORT-4, WJ-3 and TOWRE. As demonstrated in Table 5, a statistically significant positive relationship was found between the RAN letter naming standard score and all of the reading standard score measures, with the exception of GORT-4 comprehension. A statistically significant positive relationship was also found between the RAN color naming standard score and all of the reading standard score measures, with the exception of WJ-3 Word Attack and GORT-4 comprehension. In addition, a statistically significant positive relationship was found between the composite RAN standard score and all of the reading standard score measures, with the exception of GORT-4 comprehension. Finally, a statistically significant negative relationship was found between all three of the naming variables and time to read GORT-4 story 10.

Predictors of Standardized Measures of Reading Ability

A series of linear regressions were preformed to evaluate the contributions of RAN and phonological processing in predicting reading ability on standardized measures. The predictor variables used for these analyses were the phonological processing composite standard score from the CTOPP and the RAN composite standard score from the CTOPP. Three separate regression analyses were preformed to evaluate the differences in the predictive value of RAN and phonological processing for timed connected text reading (time in seconds to read GORT-4 story 10), timed single word and nonword reading (composite standard score on TOWRE), and untimed single word and nonword reading (WJ-II Basic Reading composite standard score).

As shown in Table 6, RAN and phonological processing were significant predictors of reading ability, and the predictive value of each of these variables varied depending on the type of reading format. Specifically, RAN and phonological processing accounted for 51% of the variance in timed, single word and nonword reading ($F_{2,96}$=52.36, p < .01). Additionally, RAN and phonological processing contributed independently to the model. For timed, connected text reading, RAN and phonological processing accounted for 33% of the variance ($F_{2,93}$=23.96, p < .01). Both RAN and phonological processing contributed independently to the model. For untimed, single word and nonword reading, RAN and phonological processing accounted for 30% of the variance ($F_{2,96}$=21.69, p < .01). Both RAN and phonological processing contributed independently to the model.

Predictors of RAN

Before a model of predictors of RAN could be evaluated, it was necessary to further reduce the number of predictor variables by choosing one eye movement variable to include in the model. Pearson's *r* correlations were conducted between the number of fixations variables for the experimental naming (letters and colors), scanning (letters and symbols) and reading tasks (easy, average, hard text), and the standardized CTOPP RAN composite criterion variable. This was done to establish which eye movement variable should be included in the model for predictors of RAN. As shown in Table 7, the most significant relationship was found between the fixation variables for rapid letter and color naming and the RAN composite score. However, a conservative decision was made to not use these variables as they were known to be an analogue to the criterion variable. Thus, number of fixations on the hard text was chosen as the best representative eye movement variable for the prediction model because it demonstrated the most significant relationship with the RAN composite variable (secondary to the actual naming variables).

Next a series of hierarchical linear regressions were performed to evaluate the components of RAN. These analyses addressed a central hypothesis of the current study: the idea that the visual processes which were measured through eye-movement tracking, are an important component in understanding the complexity of continuous rapid naming abilities. For these analyses, the dependent variable was the overall RAN composite standard score from the CTOPP (which combined letter and color naming). The predictor variables were the measures of (1) phonological processing (the overall phonological composite standard score from the CTOPP which combined Elision and Blending Words), (2) cognitive flexibility and inhibition (Trail Making Test condition 4 standard score and Color-Word Interference condition 4 standard scores), (3) discrete naming (median latency in seconds for discrete color naming), (4) confrontation naming (BNT median latency in seconds for correct items), (5) sequential auditory processing (Digit Span standard score from the WMS-3), (6) visual search and scanning (number of fixations on hard text and VSAT standard score).

As shown in Table 8, a significant model emerged ($F_{8,85}$=9.75, $p < .01$). This model accounted for 43% of the variance in RAN. Confrontation naming speed and phonological processing did not appear to make a significant contribution to the model. Table 9 demonstrates that an equally strong model when confrontation naming speed and phonological processing were removed from the model ($F_{6,88}$=12.01, $p < .01$). This model also accounted for 42% of the variance. Table 3 in the Appendix provides a correlation matrix, indicating the relationships between these variables.

As shown in Table 4 in the Appendix, whether participants were average or low achievement readers did significantly predict performance on RAN, as expected. However, this factor did not significantly change the underlying predictive components of the RAN, nor significantly add additional variance to the overall prediction. Additionally, these analyses were run controlling for ADHD, BDI and BAI scores. This did not significantly change the underlying predictive components of the RAN. For this reason, none of these variables were included in the final model for predicting RAN.

Potential Mediators of the Relationship between RAN and Reading

A series of linear regressions were preformed to determine whether the relationship between RAN and reading is mediated by any of the significant predictors of RAN. These analyses were conducted using methodology described in Baron and Kenny (1986). Step one of this analysis involved establishing that RAN was a significant predictor of reading ability. Only timed measures of reading were evaluated in these analyses as it was demonstrated in Table 6 that RAN is a stronger predictor of reading for timed versus untimed reading. As shown in Table 10a, RAN accounted for 35% of the variance in timed, single word and nonword reading ($F_{1,97}$=53.77, $p < .01$), and accounted for 28% of the variance in timed, connected text reading($F_{1,94}$=37.30, $p < .01$). As documented above, Table 9 indicated that the discrete naming speed (discrete color naming), auditory sequential processing (digit span standard score), executive functioning (Color Word Interference condition 4) and visual search and scanning (hard text number of fixations) were the most significant predictors of RAN, thus these were the variable that were chosen as potential mediating variables.

Step two involved demonstrating that RAN is correlated with the proposed mediator variables. To evaluate this, the RAN composite standard score was entered as the predictor variable, and separate analyses were run using each of the four potential mediating variables as the dependent variable. Table 10b shows that RAN was a significant predictor of each of the four potential mediating variables. Specifically, RAN accounted for 22% of the variance in predicting discrete color naming ($F_{1,97}$=27.91, $p < .01$). RAN accounted for 14% of the variance in predicting digit span ($F_{1,95}$=16.15, $p < .01$). RAN accounted for 17% of the variance in predicting Color Word Interference condition 4 ($F_{1,95}$=20.30, $p < .01$). RAN accounted for 18% of the variance in predicting number of fixations on the hard text ($F_{1,97}$=21.96, $p < .01$).

Step 3 involved evaluating whether the potential mediating variables affected the outcome variable (reading ability). To do this, two sets of linear regressions were conducted (one evaluating timed connected text and one evaluating timed single word and nonword reading). For each set of regressions, each of the potential mediating variables and RAN were added as predictor variables, with reading ability (TOWRE and GORT-4) the dependent variables. As shown in Table 10c, for timed single word and nonword reading, digit span and fixations on the hard test significantly mediated the relationship between RAN and reading. Table 10d indicates that for timed connected text, a similar pattern emerged, with digit span and fixations on hard text again significantly mediating the relationship between RAN and reading. A Sobel test

(Sobel, 1988) suggested that the inclusion of digit span significantly decreased the strength of the association between RAN and timed, single word and non-word reading ($z = 2.14$, $p < .05$), such that the associated beta weight decreased from .60 to .52. Similarly, the inclusion of digit span significantly decreased the strength of the association between RAN and timed, connected text reading ($z = -3.14$, $p < .01$), such that the associated beta weight decreased from -.53 to -.41. The inclusion of fixations on hard text significantly decreased the strength of the association between RAN and timed, single word and nonword reading ($z = 3.56$, $p <.001$), such that the associated beta weight decreased from .60 to .39. Similarly, the inclusion of fixations on hard text significantly decreased the strength of the association between RAN and timed, connected text ($z = -3.85$, $p < .01$), such that the associated beta weight decreased from -.53 to -.29.

Table 2
Descriptive Statistics of Standardized and Experimental Measures

Standardized Measures

Variables	Mean	Standard Deviation	Range	Sample Size
WJ-3 Word ID SS	98.74	8.68	73.00-123.00	100
WJ-3 Fluency SS	105.73	12.65	83.00-136.00	99
WJ-3 Word Attack SS	93.64	10.39	72.00-118.00	100
WJ-3 Basic Reading SS	96.79	8.65	74.00-119.00	100
CTOPP Blending Words SS*	8.31	2.88	1.00-14.00	100
CTOPP Elision SS*	8.47	2.85	1.00-12.00	100
CTOPP Color Naming SS*	11.68	3.42	5.00-20.00	100
CTOPP Letter Naming SS*	10.55	2.66	1.00-17.00	100
CTOPP Rapid Naming Composite SS	107.18	14.73	76.00-151.00	99
CTOPP Phonological Awareness Composite SS	90.34	15.06	55.00-115.00	100
GORT Rate SS*	11.50	1.46	7.00-13.00	98
GORT Accuracy SS*	12.07	3.11	4.00-15.00	100
GORT Fluency SS*	12.95	3.41	3.00-16.00	100
GORT Comprehension SS*	7.78	2.25	3.00-13.00	100
GORT Reading Composite SS	102.61	13.02	70.00-127.00	99
GORT Story 10 Rate (Form A) sec	64.97	11.28	41.00-97.00	97
TOWRE Sight Word SS	99.20	11.37	66.00-113.00	100

TOWRE Phonemic Decoding SS	94.58	10.11	70.00-115.00	100
TOWRE Reading Composite SS	96.62	10.73	71.00-115.00	99
VSAT Composite SS	93.51	15.09	60.00-125.00	100
Digit Span Forward Actual Span	6.81	1.24	5.00-9.00	100
Digit Span Backwards Actual Span	4.89	1.40	2.00-8.00	100
Digit Span SS*	9.66	2.25	5.00-17.00	98
Spatial Span Forward Actual Span	5.88	1.04	4.00-8.00	100
Spatial Span Backwards Actual Span	5.44	0.97	4.00-8.00	99
Spatial Span SS*	9.99	2.41	4.00-15.00	99
D-KEFS Trail Making Test 1 SS*	12.05	1.51	8.00-15.00	99
D-KEFS Trail Making Test 2 SS*	11.49	2.05	1.00-15.00	100
D-KEFS Trail Making Test 3 SS*	12.26	1.69	5.00-15.00	100
D-KEFS Trail Making Test 4 SS*	10.76	1.80	6.00-14.00	100
D-KEFS Trail Making Test 5 SS*	12.27	0.99	9.00-14.00	100
D-KEFS Color Word Interference 1 SS*	11.39	2.09	5.00-16.00	100
D-KEFS Color Word Interference 2 SS*	11.60	2.02	3.00-15.00	100
D-KEFS Color Word Interference 3 SS*	10.76	2.23	5.00-15.00	99
D-KEFS Color Word Interference 4 SS*	11.40	2.09	5.00-15.00	98

Note. WJ-3 Word ID SS = standard score on WJ-3 Word Identification; WJ-3 Fluency SS = standard score on WJ-3 Reading Fluency; WJ-3 Word Attack SS = standard score on WJ-3 Word Attack; WJ-3 Basic Reading SS = composite standard score on WJ-3; CTOPP Blending Words SS = scaled score on CTOPP Blending Words; CTOPP Elision SS = scaled score on CTOPP Elision; CTOPP Color Naming SS = scaled score on CTOPP Color Naming; CTOPP Letter Naming SS = scaled score on CTOPP Letter Naming; CTOPP Rapid Naming Composite SS = composite Rapid Naming standard score on CTOPP; CTOPP Phonological Awareness Composite SS = composite Phonological Awareness standard score on CTOPP; GORT Rate SS = scaled rate score on GORT; GORT Accuracy SS = scaled Accuracy score on GORT; GORT Fluency SS = scaled Fluency score on GORT; GORT Comprehension SS = scaled Comprehension score on GORT; GORT Reading Composite SS= reading composite standard score on the GORT; GORT Story 10 Rate = raw rate score on GORT story # 10 (seconds); TOWRE Sight Word SS = standard score on TOWRE Sight Word reading efficiency; TOWRE Phonemic Decoding SS = standard score on TOWRE Phonemic Decoding efficiency; TOWRE Reading Composite SS = overall composite standard score on TOWRE test; VSAT Composite SS = overall composite standard score for VSAT; Digit Span Forward

Actual Span = longest forwards span on WMS-3 Digit Span; Digit Span Backward Actual Span = longest backward span on WMS-3 Digit Span; Digit Span SS = scaled score on WMS-3 Digit Span; Spatial Span Forward Actual Span = longest forwards span on WMS-3 Spatial Span; Spatial Span Backward Actual Span = longest backward span on WMS-3 Spatial Span; Spatial Span SS = scaled score on WMS-3 Spatial Span; D-KEFS Trail Making Test 1 SS = scaled score on D-KEFS Trail Making Test subtest 1; D-KEFS Trail Making Test 2 SS = scaled score on D-KEFS Trail Making Test subtest 2; D-KEFS Trail Making Test 3 SS = scaled score on D-KEFS Trail Making Test subtest 3; D-KEFS Trail Making Test 4 SS = scaled score on D-KEFS Trail Making Test subtest 4; D-KEFS Trail Making Test 5 SS = scaled score on D-KEFS Trail Making Test subtest 5; D-KEFS Color Word Interference 1 SS = scaled score on D-KEFS Color Word Interference subtest 1; D-KEFS Color Word Interference 2 SS = scaled score on D-KEFS Color Word Interference subtest 2; D-KEFS Color Word Interference 3 SS = scaled score on D-KEFS Color Word Interference subtest 3; D-KEFS Color Word Interference 4 SS = scaled score on D-KEFS Color Word Interference subtest 4.
*Scaled score mean = 10, std. = 3, all other SS = 100, std. = 15 unless otherwise noted.

Experimental Measures	Mean	Standard Deviation	Range	Sample Size
Easy Fixations	31.22	7.32	16.00-51.00	100
Easy Regressions	6.07	3.87	0.00-17.00	99
Easy Saccades	28.39	6.00	15.00-43.00	100
Easy Fixation Duration (ms)	168.37	19.70	125.02-221.71	100
Easy Saccade Length (pixels)	40.72 [a]	9.60	17.1-66.40	100
Average Fixations	43.73	10.54	20.00-71.00	99
Average Regressions	9.39	4.63	0.00-23.00	98
Average Saccades	37.75	7.43	23.00-59.00	100
Average Fixation Duration (ms)	186.87	20.52	143.36-240.05	100
Average Saccade Length (pixels)	36.12 [b]	7.53	19.60-54.20	100
Hard Fixations	56.39	12.08	34.00-86.00	100
Hard Regressions	13.98	6.39	1.00-33.00	100
Hard Saccades	46.09	8.12	30.00-66.00	100
Hard Fixation Duration (ms)	195.04	23.06	135.03-251.72	100
Hard Saccade Length (pixels)	30.18 [c]	5.97	13.90-45.00	100
Color Naming Fixations	43.94	7.06	26.00-64.00	98
Color Naming Regressions	3.49	2.47	0.00-12.00	98
Color Naming Saccades	31.33	3.20	22.00-38.00	98
Color Fixation Duration (ms)	306.39	65.18	180.04-533.44	96
Color Saccade Length (pixels)	12.13 [d]	2.54	5.40-19.00	100
Letter Naming Fixations	30.80	6.96	15.00-46.00	99

Letter Naming Regressions	2.21	1.49	0.00-7.00	96
Letter Naming Saccades	25.54	4.89	13.00-39.00	100
Letter Fixation Duration (ms)	208.04	32.51	133.36-300.06	99
Letter Saccade Length (pixels)	16.71 [e]	4.86	7.50-31.90	99
Letter Scanning Fixations	10.17	3.70	4.00-21.00	95
Letter Scanning Regressions	2.95	1.64	0.00-9.00	95
Letter Scanning Saccades	8.19	2.47	4.00-15.00	94
Letter Scanning Fixation Duration (ms)	164.70	32.51	100.02-263.39	95
Letter Scanning Saccade Length (pixels)	55.85 [f]	17.62	23.20-111.30	94
Symbol Scanning Fixations	11.93	4.10	5.00-24.00	95
Symbol Scanning Regressions	2.98	1.49	0.00-8.00	95
Symbol Scanning Saccades	9.83	3.18	5.00-19.00	96
Symbol Scanning Fixation Duration (ms)	292.06	160.87	133.36-996.87	92
Symbol Scanning Saccade Length (pixels)	55.85 [g]	15.36	23.20-111.30	94
BNT response time(ms)	1307.75	4290.08	837.00-2208.00	99
BNT % Correct	61.92	15.89	16.13-100.00	100
Discrete Letter Naming time (ms)	508.50	79.32	416.00-742.00	100
Discrete Color Naming time (ms)	571.02	76.47	346.50-692.50	100

Note. Easy Fixations = number of eye movements classified as fixations during easy text reading tasks; Easy Regressions = number of eye movements classified as regressions during easy text reading tasks; Easy Saccades = number of eye movements classified as saccades during easy text reading tasks; Easy Fixation Duration = average

fixation duration in ms during easy text reading task;; Average Fixations = number of eye movements classified as fixations during average text reading tasks; Average Regressions = number of eye movements classified as regressions during average text reading tasks; Average Saccades = number of eye movements classified as saccades during average text reading tasks; Average Fixation Duration = average fixation duration in ms during average text reading task; Hard Fixations = number of eye movements classified as fixations during hard text reading tasks; Hard Regressions = number of eye movements classified as regressions during hard text reading tasks; Hard Saccades = number of eye movements classified as saccades during hard text reading tasks; Hard Fixation Duration = average fixation duration in ms during hard text reading task; Color Naming Fixations = number of eye movements classified as fixations during color naming tasks; Color Naming Regressions = number of eye movements classified as regressions during color naming tasks; Color Naming Saccades = number of eye movements classified as saccades during Color Naming tasks; Color Naming Fixation Duration = average fixation duration in ms during color naming task; Letter Naming Fixations = number of eye movements classified as fixations during letter naming tasks; Letter Naming Regressions = number of eye movements classified as regressions during letter naming tasks; Letter Naming Saccades = number of eye movements classified as saccades during letter naming tasks; Letter Naming Fixation Duration = average fixation duration in ms during letter naming task; Letter Scanning Fixations = number of eye movements classified as fixations during letter scanning task; Letter Scanning Regressions = number of eye movements classified as regressions during letter scanning task; Letter Scanning Saccades = number of eye movements classified as saccades during letter scanning task; Letter Scanning Fixation Duration = average fixation duration in ms during letter scanning task; Symbol Scanning Fixations = number of eye movements classified as fixations during symbol scanning tasks; Symbol Scanning Regressions = number of eye movements classified as regressions during symbol scanning task; Symbol Scanning Saccades = number of eye movements classified as saccades during symbol scanning task; Symbol Scanning Fixation Duration = average fixation duration in ms during symbol scanning task; BNT response time(ms)= median time to respond in ms on the experimental confrontation naming task; BNT % Correct = percentage of correctly named pictures on the experimental confrontation naming task; Discrete Letter Naming time = median time to respond in ms on the experimental discrete letter naming task; Discrete Color Naming time = median time to respond in ms on the experimental discrete color naming task.
[a] = ~8 letters; [b] = ~7 letters; [c] = ~6 letters; [d] = ~1 color box; [e] = ~1 letter; [f] = ~2 letters; [g] = ~2 symbols

Table 3a

Correlations Between Text Eye Movement Variables

Eye Movement	# of fixations	# of regressions	# of saccades	Fixation duration	Saccade length (pixels)
			Average Text		
# of fixations	--	$.43_c$**	$.74_b$**	$.30_b$**	$-.60_b$**
# of regressions		--	$.68_c$**	$.10_c$	$-.30_c$**
# of saccades			--	$.20_a$*	$-.70_a$**
Fixation duration(ms)				--	$-.19_a$
			Easy Text		
# of fixations	--	$.32_b$**	$.72_a$**	$.37_a$**	$-.59_a$**
# of regressions		--	$.62_b$**	$-.14_b$	$-.23_b$*
# of saccades			--	$.04_b$	$-.73_a$**
Fixation duration(ms)				--	$-.13_a$
			Hard Text		
# of fixations	--	.46**	.74**	.56**	-.51**
# of regressions		--	.70**	.06	-.24*
# of saccades			--	.23*	-.62**
Fixation duration(ms)				--	-.24*

Table 3b

Correlations Between Naming Eye Movement Variables

	# of fixations	# of regressions	# of saccades	Fixation duration	Saccade length
		Letter Naming			
# of fixations	--	$.29_e$**	.87**	$.61_c$**	$-.62_c$**
# of regressions		--	$.24_e$*	$.10_f$	$-.02_f$
# of saccades			--	$.48_b$**	$-.66_b$**
Fixation duration(ms)				--	$-.48_c$**
		Color Naming			
# of fixations	--	$.42_e$**	$.49_e$**	$.10_g$	$-.13_c$
# of regressions		--	$.27_e$**	$-.05_g$	$.13_c$
# of saccades			--	$.19_g$	$-.35_c$**
Fixation duration(ms)				--	$.10_e$

Table 3c

Correlations Between Scanning Eye Movement Variables

	# of fixations	# of regressions	# of saccades	Fixation duration	Saccade length
		Letter Scanning			
# of fixations	--	$.17_f$	$.74_g$**	$.17_f$	$-.55_g$**
# of regressions		--	$.31_g$**	$-.06_f$	$-.03_g$
# of saccades			--	$.00_g$	$-.68_h$**
Fixation duration(ms)				--	$-.05_g$
		Symbol Scanning			
# of fixations	--	$.19_g$	$.83_f$**	$-.08_j$	$-.58_f$**
# of regressions		--	$.30_f$**	$-.00_j$	$-.15_f$
# of saccades			--	$-.08_i$	$-.71_e$**
Fixation duration(ms)				--	$.16_i$

Note. # of Fixations = number of eye movements classified as fixations during tasks; # of Regressions = number of eye movements classified as regressions during tasks; # of Saccades = number of eye movements classified as saccades during tasks; Fixation Duration = average fixation duration in ms during tasks; Saccade Length = average saccade length in pixels during tasks.
^{a}n = 100. ^{b}n = 99. ^{c}n =98. ^{d}n = 97. ^{e}n = 96. ^{f}n = 95. ^{g}n = 94. ^{h}n = 93. ^{i}n = 92. ^{j}n = 91.
*$p < .05$. **$p < .01$.

Table 4

Correlations between Number of Fixations on Eye Movement Experimental and Standardized Measures

Text	GORT-4 Story 10 Time
# of Fixations on Easy Text	$.65_c$**
# of Fixations on Average Text	$.70_c$**
# of Fixations on Hard Text	$.71_c$**
Naming	Letter Naming SS
# of Fixations on Letter Naming Task	$-.63_a$**
	Color Naming SS
# of Fixations on Color Naming Task	$-.54_b$**
Scanning	VSAT SS
# of Fixations on Letter Scanning Task	$-.23_d$*
# of Fixations on Symbol Scanning Task	$-.24_d$*

Note. # of Fixations on Easy Text = number of eye movements classified as fixations during experimental easy text reading task; # of Fixations on Average Text = number of eye movements classified as fixations during experimental average text reading task; # of Fixations on Hard Text = number of eye movements classified as fixations during experimental hard text reading task; GORT-4 Story 10 Time = time in ms to read GORT-4 story 10; # of Fixations on Letter Naming Task = number of eye movements classified as fixations during experimental letter naming task; # of Fixations on Color Naming Task = number of eye movements classified as fixations during experimental color naming task; Letter Naming SS = standard score on CTOPP Letter Naming task; Color Naming SS = standard score on CTOPP Color Naming task; # of Fixations on Letter Scanning Task = number of eye movements classified as fixations during experimental letter scanning task; # of Fixations on Symbol Scanning Task = number of eye movements classified as fixations during experimental symbol scanning task; VSAT SS = standard score on VSAT.

[a]n = 99. [b]n = 98. [c]n =97. [d]n =95

**p* < .05. ***p* < .01.

Table 5

Correlations between Standardized RAN and Reading Measures

	Letter Naming SS	Color Naming SS	RAN Composite SS
TOWRE Composite SS	$.52_b$**	$.49_b$**	$.60_b$**
WJ-3 Word ID SS	$.23_a$*	$.28_a$**	$.28_b$**
WJ-3 Word Attack SS	$.24_a$*	$.19_a$	$.22_b$*
WJ-3 Reading Fluency SS	$.21_b$*	$.42_b$**	$.40_c$**
WJ-3 Basic Reading SS	$.24_a$*	$.26_a$**	$.28_b$**
GORT-4 Rate SS	$.43_c$**	$.36_c$**	$.42_d$**
GORT-4 Accuracy SS	$.36_a$**	$.37_a$**	$.41_b$**
GORT-4 Fluency SS	$.40_a$**	$.41_a$**	$.45_b$**
GORT-4 Comprehension SS	$.14_a$	$.09_a$	$.08_b$
GORT-4 Story 10 Time	$-.45_d$**	$-.49_d$**	$-.53_e$**
GORT-4 Composite SS	$.34_b$**	$.32_b$**	$.34_c$**

Note. Letter Naming SS = standard score on CTOPP Letter Naming task; Color Naming SS = standard score on CTOPP Color Naming task; RAN Composite SS = standard score composite for CTOPP RAN tasks; TOWRE Composite SS = standard score composite on TOWRE tasks; WJ-3 Word ID SS = standard score on WJ-3 Word Identification subtest; WJ-3 Word Attack SS = standard score on WJ-3 Word Attack subtest; WJ-3 Reading Fluency SS = standard score on WJ-3 Reading Fluency subtest; WJ-3 Basic Reading SS = standard score on WJ-3 Basic Reading composite; GORT-4 Rate SS = standard score on GORT-4 Rate measure; GORT-4 Accuracy SS = standard score on GORT-4 Accuracy measure; GORT-4 Fluency SS = standard score on GORT-4 Fluency measure; GORT-4 Comprehension SS = standard score on nGORT-4 Comprehension measure; GORT-4 Story 10 Time = time in ms to read GORT-4 story 10; GORT-4 Composite SS = standard score for GORT-4 reading composite
^{a}n = 100. ^{b}n = 99. ^{c}n =98. ^{d}n = 97. ^{e}n = 96.
*p < .05. **p < .01.

Table 6

Linear Regressions for Predictors of Standardized Measures of Reading

	B	SE B	ß	Adjusted R^2
		TOWRE SS (n = 98)		.51**
Phonological Processing SS	.30	.05	.41**	
RAN SS	.38	.05	.52**	
		GORT-4 Time (n = 95)		.33**
Phonological Processing SS	-.18	.06	-.24**	
RAN SS	-.37	.06	-.49**	
		WJ-3 Basic ReadingSS(n = 98)		.30**
Phonological Processing SS	.29	.05	.49**	
RAN SS	.11	.05	.19*	

Note. TOWRE SS = Composite standard score on TOWRE; GORT-4 Time = Time in seconds to read GORT-4 story 10; WJ-3 Basic Reading SS = Basic Reading composite standard score on WJ-III; Phonological Processing SS = Phonological processing composite standard score on CTOPP; RAN SS = Rapid naming composite standard score on CTOP.
$*p < .05$. $**p < .01$

Table 7

Correlations between Eye Movement Variables, RAN and Reading

	RAN Composite SS	TOWRE Composite SS	WJ-III Basic Reading Composite SS	GORT-4 Time
Easy Text	$-.42_{b}$**	$-.59_{b}$**	$-.39_{a}$**	$.65_{d}$**
Average Text	$-.38_{c}$**	$-.50_{c}$**	$-.40_{b}$**	$.70_{d}$**
Hard Text	$-.43_{b}$**	-.65**	$-.52_{a}$**	$.71_{d}$**
Letter Scanning	$-.07_{g}$	$-.12_{g}$	$-.06_{f}$	$.15_{h}$
Symbol Scanning	$-.18_{g}$	$-.30_{g}$**	$-.21_{f}$*	$.17_{h}$
Letter Naming	$-.65_{c}$**	$-.49_{c}$**	$-.30_{b}$**	$.48_{e}$**
Color Naming	$-.60_{d}$**	$-.44_{d}$**	$-.17_{c}$	$.43_{e}$**

Note. RAN Composite SS = RAN composite standard score on CTOPP; TOWRE Composite SS = TOWRE composite standard score; WJ-III Basic Reading Composite SS = Standard score composite for WJ-III; GORT-4 Time = Time in seconds to read GORT-4 story 10; Easy Text = Number of fixations on easy text; Average Text = Number of fixations on average text; Letter Scanning = Number of fixations on letter scanning task; Symbol Scanning = Number of fixations on symbol scanning task; Letter Naming = Number of fixations on letter naming task; Color Naming = Number of fixations on color naming task.
[a]n = 100. [b]n = 99. [c]n =98. [d]n =97. [e]n =96. [f]n =95. [g]n =94. [h]n =92.
*p < .05. **p < .01.

Table 8

Hierarchical Linear Regressions for Predictors of Composite RAN (n = 92)

	B	SE B	ß	Adjusted R^2
Model 1				.21**
Discrete Color Naming (ms)	-.09	.02	-.46**	
Model 2				.20**
Discrete Color Naming (ms)	-.10	.02	-.50**	
BNT Time (ms)	.01	.01	.09	
Model 3				.28**
Discrete Color Naming (ms)	-.09	.02	-.47**	
BNT Time (ms)	.01	.01	.16	
Digit Span SS	2.00	.60	.31**	
Model 4				.39**
Discrete Color Naming (ms)	-.08	.02	-.41**	
BNT Time (ms)	.01	.01	.18	
Digit Span SS	1.88	.56	.29**	
Trail Making Test SS	.28	.80	.03	
Color Word 4 SS	2.34	.64	.34**	
Model 5				.39**
Discrete Color Naming (ms)	-.08	.02	-.41**	
BNT Time (ms)	.01	.01	.17	
Digit Span SS	1.98	.59	.30**	
Trail Making Test SS	.30	.80	.04	

Color Word 4 SS	2.41	.65	.35**	
Phonological Processing SS	-.05	.09	-.05	
Model 6				.43**
Discrete Color Naming (ms)	-.08	.02	-.42**	
BNT Time (ms)	.01	.01	.17	
Digit Span SS	1.49	.60	.23**	
Trail Making Test SS	.23	.78	.03	
Color Word 4 SS	1.87	.70	.27**	
Phonological Processing SS	-.06	.09	-.06	
Hard Text Fixations	-.29	.11	-.24**	
VSAT SS	.04	.09	.04	

Note. Discrete Color Naming = median latency in seconds on discrete color naming task; BNT Time = median latency in seconds on BNT naming; Digit Span SS = Standard score on Digit Span; Trail Making Test SS = Standard score on Trail Making test condition 4; Color Word 4 SS = Standard score on color word interference test condition 4; Phonological Processing SS = Phonological processing standard score composite on CTOPP; VSAT SS = Standard score on VSAT; Hard Text Fixations = Number of fixations on hard text.
**p* < .05. ***p* < .01

Table 9

Hierarchical Linear Regressions for Best Predictors of Composite CTOPP RAN SS (n = 96)

	B	SE B	ß	Adjusted R^2
Model 1				.21**
Discrete Color Naming (ms)	-.09	.02	-.47**	
Model 2				.27**
Discrete Color Naming (ms)	-.08	.02	-.40**	
Digit Span SS	1.78	.59	.27**	
Model 3				.38**
Discrete Color Naming (ms)	-.06	.02	-.34**	
Digit Span SS	1.65	.55	.25**	
Trail Making Test SS	.21	.80	.03	
Color Word 4 SS	2.31	.64	.33**	
Model 4				.41**
Discrete Color Naming (ms)	-.07	.02	-.35**	
Digit Span SS	1.15	.56	.18*	
Trail Making Test SS	.12	.78	.01	
Color Word 4 SS	1.79	.66	.26**	
VSAT SS	.04	.09	.04	
Hard Text Fixations	-.28	.11	-.24**	

Note. Discrete Color Naming = median latency in seconds on discrete color naming task; Digit Span SS = Standard score on Digit Span; % Trail Making Test SS = Standard score on Trail Making test condition 4; Color Word 4 SS = Standard score on color word interference test condition 4; VSAT SS = Standard score on VSAT; Hard Text Fixations = Number of fixations on hard text.
**p* < .05. ***p* < .01

Table 10a

Linear Regressions for RAN Predicting Reading

	B	SE B	ß	Adjusted R^2
		TOWRE SS (n = 98)		.35**
RAN SS	.44	.06	.60**	
		GORT-4 Time (n = 95)		.28**
RAN SS	-.40	.07	-.53**	

Note. TOWRE SS = Composite standard score on TOWRE; GORT-4 Time = Time in seconds to read GORT-4 story 10; RAN SS = Rapid naming composite standard score on CTOPP.
**p* < .05. ***p* < .01

Table 10b

Linear Regressions for RAN Predicting Potential Mediator Variables

	B	SE B	ß	Adjusted R^2
		Discrete Color Naming ms (n = 98)		.22**
RAN SS	-2.46	.47	-.47**	
		Digit Span SS (n = 96)		.14**
RAN SS	.06	.01	.38**	
		Color Word 4 SS (n = 96)		.17**
RAN SS	.06	.01	.42**	
		Hard Text Fixations (n =98)		.18**
RAN SS	-.35	.08	-.43**	

Note. Discrete Color Naming = Median latency in ms on discrete color naming task; Digit Span SS = Standard score on Digit Span; Color Word 4 SS = Standard score on Color Word Interference test condition 4; Hard Text Fixations = Number of fixations on hard text; RANSS = Rapid naming composite standard score on CTOPP.
*p < .05. **p < .01

Table 10c

Linear Regressions for Mediation of RAN and Single Word Reading

	B	SE B	ß	Adjusted R^2
		TOWRE SS (n = 98)		.35**
RAN SS	.46	.07	.63**	
Discrete Color Naming (ms)	.01	.01	.08	.
		TOWRE SS (n = 96)		.37**
RAN SS	.37	.06	.52**	
Digit Span SS	.94	.41	.20*	
		TOWRE SS (n = 96)		.35**
RAN SS	.37	.07	.51**	
Color Word Interference SS	.89	.46	.18	
		TOWRE SS (n =98)		.54**
RAN SS	.28	.06	.39**	
Hard Text Fixations	-.43	.07	-.49**	

Note. TOWRE SS = Composite standard score on TOWRE; Discrete Color Naming = Median latency in ms on discrete color naming task; Digit Span SS = Standard score on Digit Span; Color Word Interference SS = Standard score on Color Word Interference test condition 4; Hard Text Fixations = Number of fixations on hard text; RAN SS = Rapid naming composite standard score on CTOPP.
**p* < .05. ***p* < .01

Table 10d

Linear Regressions Mediation of RAN and Timed Connected Text

	B	SE B	ß	Adjusted R^2
		GORT-4 Time (n = 95)		.27**
RAN SS	-.40	.08	-.54**	
Discrete Color Naming (ms)	-.00	.02	-.01	
		GORT-4 Time (n = 93)		.36**
RAN SS	-.31	.07	-.41**	
Digit Span SS	-1.62	.44	-.33**	
		GORT-4 Time (n = 93)		.26**
RAN SS	-.35	.07	-.46**	
Color Word Interference SS	-.71	.51	-.13	
		GORT-4 Time (n = 95)		.57**
RAN SS	-.23	.06	-.29**	
Hard Text Fixations	.57	.07	.60**	

Note. GORT-4 Time = Median latency in ms for GORT-4 story 10; Discrete Color Naming = Median latency in ms on discrete color naming task; Digit Span SS = Standard score on Digit Span; Color Word Interference SS = Standard score on Color Word Interference test condition 4; Hard Text Fixations = Number of fixations on hard text; RAN SS = Rapid naming composite standard score on CTOPP.
$*p < .05$. $**p < .01$

Chapter 4: Discussion

The primary purpose of this study was to identify the underlying components of rapid naming and to use that information to examine the relationship between rapid naming and reading ability. These objectives were accomplished using an undergraduate sample of readers with a wide range of reading abilities. Approximately 20% of the undergraduates included in the final sample met criteria for low reading achievement based on reading ability one standard deviation or more below the normative mean. Still, this undergraduate sample limited the number of subjects from the lowest end of the reading distribution.

Out of 145 participants who initially registered for the experiment, only 100 were included in the final analyses. Of the 45 participants who were not included, approximately half of them did not show for the experiment. It is possible that there was something systematically different about the group who did not show for the experiment, allowing for the possibility that the sample used for this study is not completely representative of the undergraduate population. Additionally, the other half of the participants who were not included in the final analyses were excluded either because of the poor quality of eye movement data or because of exclusionary criteria, such as significant neurological conditions, drug abuse or being color blind. This again leaves the possibility open that there was something different about this sample which would make the current sample less predictive of the general population. At the same time, the actual distributions of reading and reading related measures were generally normally distributed, suggesting that a relatively representative sample was obtained for an undergraduate sample. The exception to this is that there were very few participants at either of the extreme tails of the distribution.

To further increase the generalizability of the findings from this study, a decision was made to include participants with clinically significant symptoms of depression, anxiety and ADHD. In the final sample, 11 participants endorsed clinically elevated anxiety, 6 endorsed clinically elevated depression and 6 endorsed clinically elevated symptoms of ADHD on a self-report checklist. These variables were entered into the first step of the final regression models but were not found to significantly impact any of the final models.

Several of the measures used in this study proved to have limitations in this sample. Specifically, the standardized GORT-4 variables for rate, accuracy and fluency showed ceiling effects. In order to compensate for this and obtain the variability and sensitivity needed to run the analyses, it was decided to use time in seconds to complete GORT-4 story 10 as the outcome measure for connected text reading fluency. Story 10 was chosen because it was the hardest story completed by the majority of the participants (97% of the sample). Additionally, the GORT-4 Comprehension measure proved to be very difficult for this sample ($M = 7.78$, $SD = 2.25$). It is unclear why the participants in this sample scored so poorly on comprehension, when overall reading ability across measures was at least average. One possible explanation is that participants were so focused on reading the stories quickly, that they did not pay close enough attention to the content of the stories and thus had difficulty answering comprehension questions about the stories. Fortunately, the comprehension variable was not hypothesized to be a critical variable for this study, as previous research had documented that there is not a strong relationship between reading comprehension and rapid naming (Katzir et al., 2006).

Another measure which proved to have limitations in this sample was the confrontation naming task. This was intended to be a measure of speed of word retrieval and naming, with the expectation that most participants would correctly name the majority of the items. Unfortunately, this task proved to be more difficult than expected, as on average participants only correctly named 62% of the items. For this reason, both percent correct and median response time on correctly named items were evaluated in the analyses. Neither of these variables ultimately accounted for a significant portion of the variance in the model for components of RAN. On the other hand, the finding that discrete RAN was a significant predictor of continuous RAN, suggested that retrieval speed of more highly rehearsed information may be a more important component of continuous RAN, compared to confrontation naming, which has higher demands on vocabulary knowledge. This is supported in the literature by findings that when vocabulary knowledge is controlled for, RAN continues to account for independent variance in reading scores (Manis, Seidenberg and Doi, 1999).

A final set of measures that proved to have limitations in this sample were the experimental visual scanning tasks. On these tasks, participants were explicitly instructed to search from left to right across the stimuli. This was important because scanning from right to left would not mimic text reading and would be counted as a regression in eye movement data. Despite explicit instruction, 5 participants appeared to scan both from left to right and from right to left on one or both of the scanning measures. The scanning eye movement data from these subjects was not included in the analyses.

With these considerations in mind, it was first important to examine the relationship between rapid naming and reading ability in this sample. Was there a significant relationship between reading and rapid naming within this sample? It was shown that within this sample, the longer it took to name sets of colors and letters, the poorer the reading performance across both connected and unconnected text, as well as across both timed and untimed reading measures. The strongest correlations were found between rapid naming and timed reading measures, such as the

TOWRE and the time to read GORT-4 story 10. Although still statistically significant, weaker correlations were found between rapid naming and measures of reading accuracy, such as the GORT-4 accuracy and WJ-III Word Attack. Statistically significant correlations were not found between rapid naming and the limited available measures of reading comprehension, such as GORT-4 comprehension. These findings suggest that within this sample of adult readers, rapid naming was most useful in evaluating reading speed or reading efficiency, and was less useful in evaluating accuracy of reading decoding and reading comprehension, although measurement limitations may have impacted the later relationship. This finding is supported by previous research indicating that phonological awareness adds significantly to the variance in word attack and comprehension, and naming speed adds significantly to the variance in word recognition, prose passage speed and prose passage accuracy (Cornwall, 1992).

These relationships are further supported by findings in the current study that the predictive value of rapid naming and phonological processing varies depending on the format of the reading outcome measure. Specifically, when predicting performance on timed reading measures, such as the TOWRE and GORT-4 time to read story 10, rapid naming accounted for more of the variance, when compared to phonological processing. In contrast, with untimed single word and nonword reading, phonological processing measures accounted for significantly more of the variance, when compared to rapid naming. These findings highlight the differential role rapid naming and phonological processing play in predicting different reading skills and again emphasize the fact the rapid naming is more useful in predicting reading speed and reading efficiency among adult readers.

These results also support previous findings that rapid naming and phonological processing are distinct constructs. Wolf and Bowers (1999) make a convincing argument in support of this idea through a review of available research. Researchers have highlighted the fact that only weak correlations have been found between naming speed and phonological awareness. Additionally, they report that there have been independent, differential contributions of both phonemic awareness and naming speed to the variance in word identification, orthographic skill, fluent text reading and comprehension. Additionally, Denckla and Cutting (1999) highlight the fact that poor readers can be subtyped into those with RAN deficits only, phonological deficits only, or those with both phonological and RAN deficits. RAN impaired readers tend to be accurate, slow decoders, while phonologically impaired readers tend to be poor decoders, and double-deficit readers tend to be the poorest readers overall. The counter argument has been that RAN belongs within the phonological processing domain along with phonological synthesis, analysis, memory span, and working memory (Wagner and Torgesen, 1998). Denckla and Cutting (1999) explain that researchers who take this stance define RAN as the efficiency of phonological code retrieval. Findings from the current study do not support this stance in that RAN accounted for independent variance from phonological awareness and made a unique contribution in predicting reading fluency in these adult readers.

The second important step in evaluating the relationship between reading and rapid naming in this study was to determine the underlying components of rapid naming. In this study, the potential underlying components which were evaluated included measures of visual search and scanning, phonological processing, cognitive flexibility and inhibition, discrete naming speed, confrontation naming speed, and sequential processing. Confrontation naming speed and phonological processing were not found to be significant predictors of rapid naming. The top portion of Figure 2 provides a visual illustration of the significant predictors of rapid naming. As shown in this figure, visual scanning, sequential processing, cognitive flexibility and inhibition and discrete naming were all significant predictors of continuous rapid naming.

In this model, visual text scanning (measured as number of fixations on hard text) represents the ability to efficiently move from one data point to the next in a horizontal, left to right fashion. This variable likely incorporates both the eyes ability to focus on relevant text and scan, as well as some of the underlying cognitive processes taking place (attention, processing speed, word retrieval). Visual scanning and search was included in the model because of previous research indicating that the continuous format of RAN consistently predicts reading fluency above and beyond the variance accounted for by discrete RAN (Bowers and Swanson, 1991). In the model proposed in Figure 2, visual scanning and search appears to be a significant component of RAN ($\beta = -.24$) and partially mediates the relationship between RAN and reading fluency.

Auditory sequential processing represented the ability to attend to, remember and sequence orally presented numbers of increasing length. In the literature, Digit Span has been considered a measure of attention, short-term and working memory (Lezak, 1995; Spreen and Strauss, 1998). This variable was included in the model because of previous research that groups RAN, digit span and phonological awareness together as measures of phonological processing (Wagner and Torgesen, 1998). In the model proposed in Figure 2, digit span represents auditory sequential processing, working memory and attention. This variable also appears to be a significant component of RAN ($\beta = .18$), and mediates the relationship between RAN and reading fluency.

Cognitive flexibility and inhibition represented the ability to mentally switch from one task to another and inhibit an automatic response. In the literature, the Color Word Interference test has been defined as a measure of executive functioning which assesses attention, mental flexibility and verbal inhibition (Delis, Kaplan and Kramer, 2001). It was included in the model as a measure of executive functioning because of previous research and theoretical models suggesting that the RAN had executive demands (Denckla and Cutting, 1999). In the model proposed in Figure 2, cognitive flexibility and inhibition appears to be a significant component of RAN ($\beta = .26$), although it did not mediate the relationship between RAN and reading fluency.

Discrete naming speed represented the ability to rapidly retrieve automatic verbal and symbolic information (letters and colors) one at a time, eliminating the visual search, scanning, and sequential processing aspects of the continuous RAN format. This variable was included in the model because of the debate in the research regarding the relative contributions of discrete and continuous RAN in predicting reading ability (Denckla and Cutting, 1999). Additionally, by including discrete naming, it was possible to control for the actual naming component in RAN in order to assess the other cognitive contributors (attention, executive functioning, visual scanning, and sequential processing) outside of language functioning. As expected, discrete naming speed did emerge as a significant component of RAN ($\beta = -.35$), however, it did not mediate the relationship between RAN and reading fluency. This is consistent with previous research indicating that the continuous RAN makes additional contributions in predicting reading ability above that accounted for by the discrete RAN format (Bowers and Swanson, 1991).

Together, visual scanning, cognitive flexibility and inhibition, discrete naming speed, and auditory sequential processing accounted for 41% of the variance in rapid naming. Within this multicomponent model, discrete naming speed emerged as the most significant predictor of rapid naming, followed by visual scanning and sequential processing. This finding highlights the impact and importance of visual scanning and sequential processing in continuous rapid naming performance above that of naming language speed. Similar to these findings, Cutting, Carlisle and Denckla (1998) evaluated the contributions of processing speed and articulation (measured by speed of repetition of letters and numbers) in a group of normal first, second and third grade readers and found that processing speed accounted for a significant portion of the variance in RAN, but not articulation.

Wolf and Bowers (1999) proposed a conceptual cognitive process model of RAN that included attentional, perceptual, conceptual, memory, lexical and articulatory processes. Their model begins with the activation of attentional processes that activate visual processes at many levels, such as the shape of the stimulus and finer visual details. This allows for the identification or recognition processes that integrate information about the stimulus with known mental representations. Lexical processes, such as semantic, phonological access and retrieval processes, are integrated with the already processed information. Motor commands translate this information into an articulated name. Finally, Parrila and Kirby (2006) examined how the components of RAN (pause time and articulation) impact the relationship between RAN and reading between Kindergarten and first grade. They found that pause time on RAN was highly correlated with reading accuracy and reading fluency. In contrast, articulation time on RAN was only weakly correlated with reading measures.

These 3 models for the RAN proposed in the literature highlight the role of processing speed, attention, visual processes and lexical retrieval. These processes were evaluated and supported as significant predictors of the RAN in the current study. Although pause time was not measured in the current study, it is likely that these cognitive processes are what was taking place in the pauses during the RAN. Thus, the current study lends empirical support to previously theorized models.

Although the current results and model of RAN successfully accounted for an impressive 41% of the variance in RAN, that leaves an additional 59% unaccounted for. This begs the question, what accounts for the additional variance? This is a difficult question to answer, as the current model appears to be relatively comprehensive based on the literature. Possible other constructs to be considered include processing speed, attention, articulation and pause time on the RAN, and overall intelligence (IQ). Of these possibilities, it appears that both attention and processing speed have been well accounted for in the current model and measures used to evaluate it. These cognitive processes (attention and processing speed) are required by many of the tasks included in the model, such as Digit Span, Color Word Interference and VSAT. Articulation time and pause time really are not cognitive constructs, but are a way to break down the RAN task into smaller, measurable units. It appears that these are overt measures impacted by the underlying cognitive processes proposed in the model in Figure 2. That leaves overall IQ. This was not assessed in the current model and has not been directly explored in the literature, although vocabulary knowledge, a potential verbal proxy, has been fluency (Manis, Seidenberg and Doi, 1999). This research demonstrated that vocabulary knowledge did not account for RAN's ability to predict reading, which would be partly consistent with the BNT findings in the current study. It would be important to include IQ in future investigations into the underlying components of RAN as an additional check on its role.

The final step in evaluating the relationship between rapid naming and reading ability was to determine whether the established underlying predictors of rapid naming (visual scanning, cognitive flexibility and inhibition, discrete naming speed, and auditory sequential processing) would mediate the relationship between rapid naming and reading ability. Findings indicated that for both connected and unconnected timed reading, auditory sequential processing and visual scanning partially mediated the relationship between rapid naming and reading ability. In contrast, cognitive flexibility and inhibition and discrete naming speed were not found to significantly mediate the relationship between rapid naming and reading ability. These findings suggest that part of what makes rapid naming a significant predictor of timed reading in adult readers is the fact that it is measuring the ability to visually scan information and process auditory information sequentially, thus supporting the central hypothesis of the current study.

Figure 2 provides a visual illustration of the relationship between continuous rapid naming and reading fluency. As shown in this figure, visual scanning, auditory sequential processing, cognitive flexibility and inhibition and discrete naming speed are all important components of continuous rapid naming. Additionally, visual scanning and auditory sequential processing partially mediated the relationship between continuous rapid naming and reading ability.

In summary, the current study suggests that among adult readers, continuous rapid naming is most predictive of reading speed and efficiency, and is less predictive of untimed reading decoding accuracy and reading comprehension. These findings highlight the importance of assessing multiple aspects of reading when evaluating for potential reading deficits. Specifically, these findings highlight the importance of evaluating reading rate, accuracy and comprehension in both timed and untimed formats. Additionally, these findings highlight the need to measure and understand the underlying predictors of reading, such as phonological processing and RAN.

Finally, the findings from the current study suggest a more comprehensive model for understanding the relationship between continuous rapid naming and timed reading, in which visual scanning and auditory sequential processing partially mediate the relationship between RAN and reading fluency. This suggests that it is not enough to just understand what aspects of reading are difficult for an individual, such as the underlying RAN and/or phonological processing deficit; but, it is also important to assess why that deficit might exist for that individual. For example, an individual with impairments in reading fluency and underlying rapid naming deficits, along with deficits in auditory sequential processing, may not benefit as much from an intervention that focuses on reading fluency. In addition to intervention, this individual may also always require accommodations, such as additional time to read and re-read text and a quiet working environment, even after intervention.

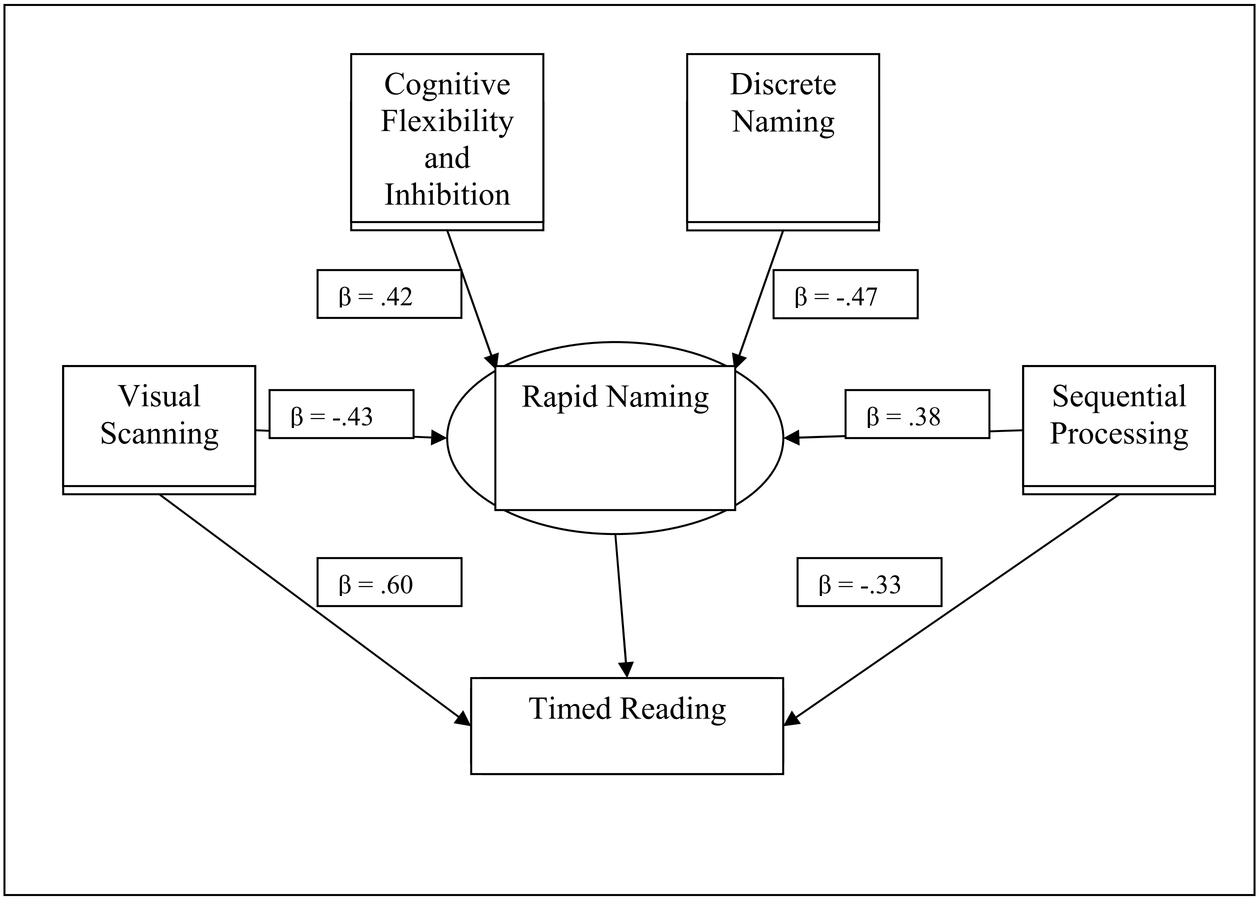

Figure 2. A visual model of the relationship between continuous rapid naming and speeded reading.

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Appendix

Table 1

Variables with Outliers

Variable	Number of Outliers
BNT Response Time	1
Digit Span SS	2
Spatial Span Backwards Actual Span	1
Spatial Span SS	1
CTOPP Rapid Naming Composite SS	1
TOWRE Reading Composite SS	1
WJ-3 Fluency SS	1
GORT Rate SS	2
GORT Story 10 Rate	2
GORT Reading Composite SS	1
D-KEFS Trail Making Test 1 SS	1
D-KEFS Color Word Interference 3 SS	1
D-KEFS Color Word Interference 4 SS	2
Color Naming Fixations	1
Color Naming Regressions	2
Color Naming Saccades	2
Color Naming Fixation Duration	4
Letter Naming Fixations	1
Letter Naming Regressions	4
Letter Naming Fixation Duration	1
Easy Regressions	1
Average Fixations	1
Average Regressions	2
Symbol Scanning Fixations	1
Symbol Scanning Regressions	1
Symbol Scanning Fixation Duration	4
Letter Scanning Fixations	1
Letter Scanning Regressions	1
Letter Scanning Saccades	2
Letter Scanning Fixation Duration	1

Note. WJ-3 Fluency SS = standard score on WJ-3 Reading Fluency; CTOPP Rapid Naming Composite SS = composite Rapid Naming standard score on CTOPP; GORT Rate SS = standardized rate score on GORT; GORT Reading Composite SS= reading composite standard score on the GORT; GORT Story 10 Rate = raw rate score on GORT story # 10 (seconds); TOWRE Reading Composite SS = overall composite standard score on TOWRE test; Digit Span SS = standard score on WMS-3 Digit Span; Spatial Span Backward Actual Span = longest backward span on WMS-3 Spatial Span; Spatial Span SS = standard score on WMS-3 Spatial Span; D-KEFS Trail Making Test 1 SS = standard score on D-KEFS Trail Making Test subtest 1 D-KEFS Color Word Interference 3 SS = standard score on D-KEFS Color Word Interference subtest 3; D-KEFS Color Word Interference 4 SS = standard score on D-KEFS Color Word Interference subtest 4; Easy Regressions = number of eye movements classified as regressions during easy text reading tasks; Average Fixations = number of eye movements classified as fixations during average text reading tasks; Average Regressions = number of eye movements classified as regressions during average text reading tasks; Color Naming Fixations = number of eye movements classified as fixations during color naming tasks; Color Naming Regressions = number of eye movements classified as regressions during color naming tasks; Color Naming Saccades = number of eye movements classified as saccades during Color Naming tasks; Color Naming Fixation Duration = average fixation duration in ms during color naming task; Letter Naming Fixations = number of eye movements classified as fixations during letter naming tasks; Letter Naming Regressions = number of eye movements classified as regressions during letter naming tasks; Letter Naming Fixation Duration = average fixation duration in ms during letter naming task; Letter Scanning Fixations = number of eye movements classified as fixations during letter scanning task; Letter Scanning Regressions = number of eye movements classified as regressions during letter scanning task; Letter Scanning Saccades = number of eye movements classified as saccades during letter scanning task; Letter Scanning Fixation Duration = average fixation duration in ms during letter scanning task; Symbol Scanning Fixations = number of eye movements classified as fixations during symbol scanning tasks; Symbol Scanning Regressions = number of eye movements classified as regressions during symbol scanning task; Symbol Scanning Fixation Duration = average fixation duration in ms during symbol scanning task; BNT response time(ms)= median time to respond in ms on the experimental confrontation naming task.

Table 2

Correlations Between Number of Eye Movement Fixations during Experimental Reading, Naming and Scanning Tasks

	Color Naming	Letter Naming	Symbol Scanning	Letter Scanning
Easy Text	$.43_b$**	$.53_a$**	$.37_d$**	$.28_d$**
Average Text	$.29_b$**	$.41_b$**	$.39_e$**	$.42_e$**
Hard Text	$.27_b$**	$.44_a$**	$.35_d$**	$.31_d$**
Color Naming	1.00_b**	$.63_c$**	$.27_e$**	$-.01_e$
Letter Naming	$.63_c$**	1.00_a**	$.35_e$**	$.19_e$

Note. Easy Text = number of eye movements classified as fixations during experimental easy text reading task Average Text = number of eye movements classified as fixations during experimental average text reading task; Hard Text = number of eye movements classified as fixations during experimental hard text reading task; Letter Naming = number of eye movements classified as fixations during experimental letter naming task Color Naming = number of eye movements classified as fixations during experimental color naming task; Letter Scanning = number of eye movements classified as fixations during experimental letter scanning task; Symbol Scanning = number of eye movements classified as fixations during experimental symbol scanning task.

[a]n = 99. [b]n = 98. [c]n = 97. [d]n =95. [e]n =94.

*p < .05. **p < .01.

Table 3

Correlations Between Variables Included in Regression Analyses

	DS	VSAT	TOWRE	CW 4	TMT	HTF	GORT	PHON	RAN	BNT
DCN (ms)	-.23*	-.09	-.22*	-.19	-.29**	.12	.26**	-.14	-.47**	.44**
DS	1	.16	.40**	.09	.22*	-.35**	-.48**	.37**	.38**	-.24*
VSAT		1	.22*	.36**	.36**	-.34**	-.25*	.10	.30**	-.06
TOWRE			1	.39**	.25	-.65**	-.71**	.51**	.60**	-.14
CW 4				1	.41**	-.31**	-.31**	.27**	.42**	-.14
TMT					1	-.21*	-.30**	.25*	.33**	-.16
HTF						1	.71**	-.28**	-.43**	.11
GORT (sec)							1	-.34**	-.53**	.11
PHON								1	.18	-.27**
RAN									1	-.12
BNT (ms)										1

Note. DCN = median time in milliseconds to perform discrete color naming task; DS = standard score on Digit Span; VSAT = standard score on VSAT; TOWRE = composite standard score on TOWRE; CW 4 = standard score on D-KEFS Color Word Interference Test condition 4; TMT= standard score on D-KEFS Trail Making Test condition 4; HTF = number of fixations on hard text; GORT = time in seconds to read GORT-4 story 10; PHON = composite phonological awareness standard score on CTOPP; RAN = composite rapid naming standard score on CTOPP; BNT = median time in milliseconds to perform confrontation naming task.
**p* < .05. ***p* < .01.

Table 4

Hierarchical Linear Regressions for Predictors of RAN Controlling for Group Differences (n = 93)

	B	SE B	ß	Adjusted R^2
Model 1				.09**
Group	-11.49	3.58	-.32**	
Model 2				.27**
Group	-9.70	3.23	-.27**	
Discrete Color Naming (ms)	-.08	.02	-.44**	
Model 3				.31**
Group	-8.14	3.19	-.22**	
Discrete Color Naming (ms)	-.07	.02	-.39**	
Digit Span SS	1.51	.58	.23**	
Model 4				.38**
Group	-4.47	3.21	-.12	
Discrete Color Naming (ms)	-.06	.02	-.34**	
Digit Span SS	1.52	.56	.23**	
Trail Making Test SS	.19	.79	.02	
Color Word 4 SS	2.04	.67	.29**	
Model 5				.41**
Group	-2.17	3.30	-.06	
Discrete Color Naming (ms)	-.07	.02	-.35**	
Digit Span SS	1.12	.57	.17*	
Trail Making Test SS	.10	.79	.01	

Color Word 4 SS	1.68	.69	.24*
Hard Text Fixations	-.26	.11	-.22*
VSAT SS	.04	.09	.04

Note. Group = indication of whether participant meets criteria for below average reading ability; Discrete Color Naming = median latency in seconds on discrete color naming task; Digit Span SS = Standard score on Digit Span; Trail Making Test SS = Standard score on Trail Making test condition 4; Color Word 4 SS = Standard score on color word interference test condition 4; VSAT SS = Standard score on VSAT; Hard Text Fixations = Number of fixations on hard text.
*$p < .05$. **$p < .01$