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The Role of Eye Movements in the Relationship between Rapid Automatized Naming and Reading Ability

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THE ROLE OF EYE MOVEMENTS IN THE RELATIONSHIP BETWEEN RAPID AUTOMATIZED NAMING AND READING ABILITY

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 (Bowers and Wolf, 1993), however, the nature of this relationship remains unclear. The purpose of this study was to evaluate whether the visual scanning and sequential components of the continuous RAN format are similar to those same visual scanning processes required in reading, and whether these processes partially account for the relationship. The sample consisted of 57 undergraduate students (63.2% female). The majority of the sample was either Caucasian (33.3%) or African American (29.8%). The eye movement measures consisted of three short stories and the continuous versions of two RAN tasks (colors and letters). This study examined the percent of regressions and fixations during both types of tasks (reading text and RAN). The findings suggest that the continuous RAN measures important visual scanning and sequencing processes that are important in predicting reading ability.

INDEX WORDS: Reading, Rapid Automatized Naming, eye movements

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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.

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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 reading ability and that people who have poor performance on these tasks are expected to have difficulty reading fluently (Bowers and Wolf, 1993; Wolf, 1991). 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 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 (Blachman, 1984; Stanovich, 1981; Vellutino et al., 1996; and Wolf, Bally and Morris, 1986).

Since this early work, there has been a 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 motoric requirements, that make RAN such a strong predictor of reading ability (Bowers, 1989; Bowers, Steffy and Tate, 1988; Wolf, Bally and Morris, 1986; Wolf, 1997). More recent 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 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 (Bowers, 1989; Bowers, Steffy and Tate, 1988; Wolf, Bally and Morris, 1986), and such results have even been found among adults (Felton, Naylor and Wood, 1990).

There is 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 believe that RAN makes a distinct contribution (Blachman, 1984; Bowers, 1989; Bowers, Steffy and Tate, 1988; McBride-

Chang and Manis, 1996). However, others believe 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).

Although there are many hypotheses about why the continuous format of the RAN test is such a strong predictor of reading ability, there is no conclusive evidence leading to 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 argument that the visual scanning and sequential components of the continuous RAN format are similar to those same visual scanning processes required in reading, and that they account for some of the shared variance.

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).

A major conceptual and methodological issue concerns how best o summarize the eye movement record to understand the cognitive processing of reading. The two most frequently used measures are the gaze duration on a word and the first-fixation duration (Rayner, 1998).

Gaze duration represents the sum of all fixations made on a word prior to a saccade to another word. First fixation duration is the duration of the first fixation on a word regardless of whether it is the only fixation on a word or the first of multiple fixations on a word (Rayner, 1998). An alternative strategy that many researchers have adopted is to select target locations in text for careful analysis, and to examine many different measures such as first fixation duration, gaze duration, probability of fixating a target word, number of fixations on the target word, and saccade length to and from the target word (Rayner, Sereno, et al., 1989; Schmauder, 1992).

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.

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 purpose of the current study was to examine eye movement patterns during text reading and their relationship to eye movement patterns during continuous RAN tasks. In this study, I specifically examined the percent of fixations and regressions, and saccade and fixation lengths during both types of tasks (reading text and RAN). Based on previous literature, it was expected that the number of fixations made during text reading and the continuous RAN tasks would be similar. In addition, in this study I evaluated the contribution of phonological awareness abilities in conjunction with eye movements in explaining the variance accounted for by the RAN measures in reading. It was expected that the patterns of eye movements made during the continuous RAN naming tasks would be similar to the pattern of eye movements made during the text reading tasks. Additionally, it was expected that less productive eye movement patterns, such as a greater number of regressions and shorter saccades, would be indicative of poorer scores on both the RAN measures and other reading measures.

Chapter 2: Method

Participants

Sixty-one undergraduate students were recruited from an introductory Psychology class at Georgia State University to participate in this study. Of the 61 participants, 3 students did not show for their scheduled experiment time, 3 students were not native English speakers and did not meet the bilingual criteria, and 9 students' eye movement data were determined to be unusable due to equipment malfunction. Of the final sample of 46 participants, there was a mean age of 23 years (SD = 5.4), and 31 participants were female (67%). The sample was comprised of 16 (35%) Caucasian, 13 (28%) African American, 10 (22%) Asian, and 6 (13%) Other self-reported ethnic backgrounds. The mean self-reported grade point average for the sample was 3.14 (SD = .52).

Students were screened for both visual and auditory acuity at the time of testing. None of the students failed either of the screenings. No students were included with a history of serious neurological problems or diagnosed with attention-deficit/hyperactivity disorder (ADHD). One participant reported having one seizure as a child, two participants reported having mild head injuries without the loss of consciousness or any noticeable cognitive effects, and one student self-reported a history of non diagnosed ADHD. All of these participants were included in the final analyses, as the mild concussions were not deemed to be significant enough for exclusion, and the one participant did not endorsed items on the ADHD Behavior Checklist consistent with an ADHD profile.

Only native English speakers and simultaneous bilingual English speakers were included in the analyses. In this study, bilingual was defined as anyone who learned English simultaneously with another language either in the U.S. and in another country, or anyone who moved to the U.S. before entering or while in elementary school. Of the 46 participants, 13 participants met the simultaneous bilingual criteria. Between-groups ANOVAs were performed between those participants meeting the bilingual qualifications and the native English speakers across all of the primary measures in this study (GORT rate, accuracy, and fluency standard scores, CTOPP letter and color naming standard scores, and percent of regressions and fixations on both the text and naming tasks). Significant between group differences were found only for CTOPP color naming and percent of fixations on the average text. Because there were only these two differences between groups, the bilingual participants were included in the final sample in order to maintain a larger sample size and increase the statistical power of the analyses.

Apparatus

Eye movement and pupil dilation data were 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 a 15-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.

Procedure

Students received research credit for their Introductory Psychology class for participating in the study. Each participant was required to sign a consent form explaining the nature of the study and any risk involved. All students participated in one experimental session at Georgia State University. The session lasted approximately 1 hour. A brief informal interview was conducted by the experimenter to obtain a short background history for each student, including information about possible learning disabilities, traumatic brain injuries, ADHD, 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.

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

Eye Movement Variables

A decision was made to use the percent of fixations, regressions and saccades rather than using the total number of fixations, regressions and saccades on each task. This decision was made in order to make the measures equivalent across subtests, because the three experimental texts and two naming tasks did not contain the exact same amount of visual information.

Fixations

Fixations were defined as two or more consecutive pixel coordinate values differingalong the horizontal axis by no more than five pixels. In order further to differentiate fixations from saccades, it was specified that at least two of the consecutive data points must be the exact same horizontal value. The two fixation variables used in this study were percent of fixations and average fixation duration. Percent of fixations was calculated by taking each participant's total number of fixations and dividing it by the total number of words in each of the experimental texts or by the total number of letters or colors in the experimental naming tasks, and then multiplying that number by 100. Average fixation duration was calculated by taking the total number of data points classified as fixations and dividing that number by the total number of fixations. This value was then multiplied by 16.67 to convert the value from samples per second into milliseconds.

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 percent of saccades and average saccade duration. Percent of saccades was calculated by taking each participant's total number of saccades and dividing it by the total number of words in each of the experimental texts, or by the total number of letters or colors in the experimental naming tasks, and then multiplying that number by 100. Average saccade duration was calculated by taking the total number of data points classified as saccades and dividing that number by the total number of saccades. This value was then multiplied by 16.67 to convert the value from samples per second into milliseconds.

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 of information in the experimental stimulus delay 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 had 11 lines of material, and the hard text had 12 lines of material, so 10 and 11 were subtracted, respectively, from the total number of regressions in these conditions. Both of the experimental naming 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 percent of regressions. Percent of regressions was calculated by taking each participant's total number of regressions and dividing it by the total number of words in each of the experimental texts or by the total number of letters or colors in the experimental naming tasks, and then multiplying that number by 100.

Pupil Diameter

The measure of pupil diameter used in this study was average pupil diameter. This measure was calculated by summing all of the pupil diameter measurements for each subtest and dividing by the number of pupil diameter measurements recorded. Pupil diameter was not hypothesized to be related to reading and naming ability and was therefore not included in the statistical analyses of this study. It was instead used as a check of accurate data collection, as pupil diameter was a much more stable eye movement measure than POR. Additionally, it helped to distinguish between eye blinks and data error, as data error was recorded as horizontal and vertical values of 0 while pupil dilation was normal, whereas blinks were recorded as horizontal and vertical values of 0 while pupil dilation was 1.

Eye Blinks

As stated above, eye blinks were defined as anytime the horizontal and vertical readings were 0 while the pupil dilation value was 1. Following each eye blink, there was a period of useless 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.

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 movement during reading and RAN fluency in adult readers, only story 5, 10 and 13 from Form B were used s. These stories were chosen because they range in difficulty of readability from a 7th 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) are 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.

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 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 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).

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 participant was instructed to start at the top and name the letters from left to right as quickly as possible.

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 participant was instructed to start at the top and list the colors from left to right.

Rapid Automatized Naming.

Rapid naming was also 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.

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.

Standardized Reading Measures.

Reading ability was also 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) and the standardized version of the GORT-4 Form A: Comprehension and Fluency (Wiederholt, and Bryant, 2001).

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 required the students to pronounce single words correctly but did 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.

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.

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.

<u>Phonological Decoding and Awareness Measures.</u>

Phonological decoding and awareness was 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.

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.

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.

Word Retrieval Measure.

Non continuous word retrieval was also measured using a short version of the Boston Naming Test (Kaplan, Goodglass, and Weintraub, 2001). The Short Form of the Boston Naming Test is a confrontation naming test consisting of 15 pictures, ordered from easiest to most difficult. This task was presented on a computer screen so that a participant's latency of naming was also acquired for each item.

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 1. Demographic information about the participants was collected using a self-report questionnaire. There were three missing data points due to participants' neglect to fill in all of the information on this questionnaire, including one participant's date of birth, one participant's ethnicity and one participant's school classification. Of these missing data points, date of birth was the only influential missing data point, as age was used to calculate standard scores. In this particular situation, an age range score of 20-24 years was used to calculate standard scores, as this was the age range for the majority of the participants in this sample.

The data were checked for outliers using z-scores and box plots. Outliers were defined as z-scores greater than 3.00. The majority of the outliers were found in the eye movement data: duration of fixations on the hard text had one outlier, percent of color fixations had one outlier, percent of color regressions had one outlier, percent of color saccades had two outliers, duration of fixations on color naming had three outliers, duration of saccades on color naming had one outlier, and percent of letter regressions had one outlier. Additional variables containing outliers included: experimental letter naming time which had one, the experimental confrontation naming response time had one, and the standard score for color naming had two. Box plots of these variables did not demonstrate that the outliers were skewing the distributions of the variables, and so it was decided to leave the data points as they were.

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 (1996). 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. Four variables were found to be significantly skewed: the experimental confrontation naming response time was positively skewed, the standardized GORT-4 fluency score was positively skewed, and percent of regressions on both the experimental hard text and letter naming tasks were positively 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 four skewed variables were transformed using logarithms. 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.

Validation of Experimental Measures

The original plans for this study were to compare participants' time to read the standardized GORT-4 Form A stories 5, 10, and 13 to their time to read the experimental easy, average and difficult texts. The purpose of this proposed comparison was to establish the clear reading relationship between the standardized and the experimental story results. However, almost none of the participants read story 5 because the GORT-4 was given in the standardized manner and the majority of the participants did not require this low-level story. For this reason, story 5 was not included in the analyses of this study. Both stories 10 and 13 were included in the analyses, although five participants did not read each of these stories because they met the ceiling criteria prior to reading those stories.

In order first to document a valid relationship between the experimental versions of the tasks and the standardized versions, correlation analysis using Pearson's *r* was performed. 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) were used to establish a relationship between the standardized and experimental versions. As shown in Table 2, significant positive correlations were found between each of the three experimental text tasks and the standardized GORT stories irrespective of text difficulty. A second correlation analysis was performed between the GORT standard scores for rate, accuracy and fluency, and the time to read the three experimental texts. As shown in Table 2, all three of the experimental text tasks (easy, average and hard) were also significantly negatively correlated with each of the three GORT standardized measures (rate, accuracy and fluency), such that faster reading times were related to higher standard scores.

A similar analysis was performed between the two experimental naming tasks (letter and color naming) and standardized naming times on the CTOPP naming tasks (letter and color naming). The two-letter naming and two color-naming tasks were significantly positively correlated. A second correlation analysis was performed between the CTOPP standard scores for letter and color naming and the time needed to name letters and colors on the experimental tasks. As shown in Table 2, significant negative correlations, with faster times associated with higher standard scores, were found between both experimental naming tasks and the standard scores on the CTOPP naming tasks.

<u>Establishment of Relationship Between Reading and Naming</u>

Another correlation analysis was performed using Pearson's *r* to establish the relationship between text reading time and naming time on the computer tasks. As shown in Table 3, a statistically significant positive relationship was found between the time to read the average and easy text and the time to name colors, as well as between the time to read the easy text and the time to name letters. There were not any other statistically significant relationships between time to read text and time to name.

A correlation analysis was also performed using Pearson's *r* confirming the expected relationships between the GORT standard scores and the CTOPP RAN scores for letters and colors. As shown in Table 4, GORT rate was significantly positively correlated with both the color and letter standard scores, whereas GORT accuracy and fluency were only significantly positively correlated with color naming.

<u>Validation of Text Difficulty Manipulation</u>

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 (percent of regressions, saccades and fixations, and saccade and fixation duration) across the three text reading tasks (easy, average and hard). As shown in Table 5a and 5b, 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. For this reason, all three text tasks were included in further analyses.

<u>Evaluation of Redundancy in Eye Movement Variables</u>

In order to evaluate the covariance between the different eye movement measures, correlation analysis using Pearson's *r* was performed using the five eye movement variables (percent of regressions, saccades and fixations, and saccade and fixation length) across the experimental RAN and text tasks. As shown in Table 6, there were statistically significant correlations between percent of fixations and saccades, but not regressions, and average lengths of fixations and saccades for the three text tasks and the letter naming task. These strong correlations were not found for color naming. Because of the redundancy among measures, and to reduce possible type 2 error inflations, it was decided to use the percent of fixations variable for primary analyses as it generally had the highest correlation with all the other variables. The percent of regressions variable was also included in all further analyses because it did not have a consistent correlation with the other set of eye movement variables.

<u>Establishment of Relationship Between Eye Movement Variables and Reading</u>

A correlation analysis was next performed using Pearson's *r* to establish a relationship between the eye movements on the text tasks and time to read the text on the experimental tasks. Percent of fixations and regressions on each of the three text tasks were included in this analysis. As shown in Table 7, significant relationships were found between the time to read the text and eye movement variables for each of the three text difficulty levels (easy, average and hard), with the exception of percent of regressions on the easy text. Both percent of fixations and regressions were positively correlated with time to read, demonstrating that more fixations and regressions are associated with longer reading rates.

<u>Establishment of Relationship Between Eye Movement Variables and Naming</u>

A correlation analysis was performed using Pearson's *r* to establish a relationship between eye movements on the naming tasks and time to name on the computer tasks. Again, percent of fixations and regressions on both the color and letter naming tasks were included in the analyses. As shown in Table 8, significant positive relationships were found between time to name colors and letters and the corresponding eye movements, with the exception of percent of regressions on the color naming task. These findings demonstrate, as expected, that more fixations and regressions are also associated with longer naming task times. Such results help validate the eye movement methodology and operationalizations used.

Evaluation of Relationship Between Naming Eye Movements and Reading

Pearson's *r* correlation analysis was performed to evaluate whether the eye movement variables during the RAN tasks correlated with the eye movement variables during the reading tasks. As shown in Table 9, the percent of fixations in both the color and letter naming tasks were significantly positively correlated with the percent of fixations in the text reading tasks. A different pattern was found for percent of regressions, as the only significant positive correlations were between letter naming and easy and average texts.

A correlation analysis was performed using Pearson's *r* to establish a relationship between the eye movement variables on the naming tasks and time to read the three computer texts (easy, average and hard). As shown in Table 10, there was not a strong relationship between the eye movement variables from the RAN and the time to read text. The only significant positive relationships were between time to read the easy text and percent of letter and color fixations, and between time to read the average text and percent of color fixations.

An analysis was performed using Pearson's *r* correlations to establish a relationship between the eye movement variables on the naming tasks and time to read two paragraphs from the standardized GORT, which were comparable to the average and hard computer text tasks. As shown in Table 11, there were no significant relationships between naming eye movement fixations and time to read either paragraph. There were, however, significant negative relationships between percent of regressions on the letter naming task and time to read both stories. This finding is inconsistent with previous findings, and will be discussed further.

A correlation analysis was performed using Pearson's *r* to establish a relationship between the eye movements on the naming tasks and the standard scores on the GORT (rate, accuracy, and fluency). There were no significant relationships between any of the GORT standard scores and eye movement variables on the letter and color naming tasks.

Evaluation of Relationship Between Standardized RAN and Confrontation Naming and Reading Measures

Correlation analyses using Pearson's *r* were performed between the experimental confrontation naming task and all of the standardized reading measures (GORT-4; WJ-3 Word ID, Reading Fluency, Word Attack; CTOPP Elision, Blending Words, Color Naming, Letter naming; and GORT-4 Accuracy, Rate, Fluency, and Comprehension). There were no statistically significant correlations between the experimental naming task and any of the standardized reading measures. Since confrontation naming has sometimes been associated with reading ability, it is possible that the short experimental measure used was not an adequate measure of confrontation naming.

Evaluation of Relationship Between WJ-3 Subtests and Standardized RAN

Correlation analyses were performed between the three standardized WJ-3 measures of reading (Word ID, Reading Fluency and Word Attack). While these measures were all generally correlated with other measures of reading, such as the GORT-4, they were not significantly correlated with either of the standardized naming tasks (letters and colors). As shown in Table 12, the correlation between the WJ-3 Reading Fluency variable and the standardized color naming variable was the only statistically significant relationship between naming and the WJ-3 subtests. This finding is not surprising given that RAN is usually associated more the continuous reading, and both Word Attack and Word ID are administered in a discrete single-word format.

Predictors of RAN

Next a series of linear regressions were performed to evaluate the components of RAN. These analyses addressed a central hypothesis of the current study: the idea that visual processes, which were measured through eye-movement tracking, are an important predictor of continuous rapid naming. For these analyses, the dependent variables were the standard scores for color and letter naming of the standardized measures. The predictor variables were confrontation naming and speed of retrieval (BNT response time), phonological processing (Elision and Blending Words), and eye movements during naming tasks (percent of fixations and regressions on color and letter naming).

In the first regression model, the color naming standard score was the dependent variable. As shown in Table 13, this model of visual processing, phonological processing and speed of retrieval accounted for a significant proportion of the variance in color rapid naming. Additionally, the percent of fixations variable was the only predictive component of the model.

In the second regression model, the letter naming standard score was the dependent variable. As shown in Table 14, a similar model of visual processing, phonological processing and speed of retrieval again accounted for a significant proportion of the variance in letter naming. Again, the percent of fixations variable was the most predictive component of the model.

Predictors of Reading Ability

A series of linear regressions were performed to evaluate how much variance in reading can be accounted for by the eye movement variables on the naming tasks. In all of these analyses, different measures of reading were used as the dependent variables, and the naming eye movement variables and phonological processing variables (elision and blending words) were the predictors. Eight dependent variables, representing reading ability, were evaluated in separate models: time to read experimental easy, average and hard text, time to read GORT stories 10 and 13, and standard scores for GORT rate, accuracy and fluency. Four models of independent predictor variables were created to evaluate which independent variables accounted for the most variance with each of the 8 measures of reading ability. The four models were as follows: (a) phonological processing (Elision and Blending Words CTOPP standard scores), (b) naming eye movements (percent of fixations and regressions for color and letter naming), (c) phonological awareness and naming fixation eye movements (Elision, Blending Words, and percent of fixations for color and letter naming), and (d) phonological awareness and naming regression eye movements (Elision, Blending Words, and percent of regressions for color and letter naming). For each of the eight dependent measures of reading ability, the same four models of predictor variables were used. The purpose of these models was to distinguish whether phonological processing or eye movements during naming are better predictors of reading speed and ability, or whether a combination of the two is the best predictor. Several measure of reading ability were evaluated in order to determine whether certain models were more predictive for certain types of reading measures, such as rate versus accuracy.

The first series of linear regressions used time to read the easy, average and hard computer texts as the dependent variables, and evaluated those predictor variables which best predicted time to read. As shown in Table 15, different predictor variables best predicted text with different difficulty levels. For example, with time to read the easy text as the dependent variable, the best fitting model included both the phonological processing variables as well as percent of fixations for colors and letters as predictor variables. This model was statistically significant. For time to read the average text, the best fitting model included only the naming eye movement variables, but this model was only borderline to significant. For the hard text, none of the models were close to reaching statistical significance.

The next series of linear regressions used time to read two of the standardized GORT stories (story 10 and 13) as the dependent variables, and evaluated which predictor variables made the best fit for time to read. As shown in Table 16, the best fitting model for both of the GORT stories included both phonological processing and percent of regressions as predictor variables, although neither the model for GORT story 10 or 13 reached significance.

The final series of linear regressions used the standard scores from the GORT (rate, accuracy and fluency) as the dependent variables, and evaluated which were the best predictor variables for each of those standard scores. As shown in Table 17, when rate was used as the dependent variable, none of the models reached significance. When accuracy was the dependent variable, the phonological processing model was the best fit, although both of the models that included both phonological processing and naming eye movements approached significance. When fluency was the dependent variable, the phonological processing model was the best fit, although it did not reach significance.

Table 1

Descriptive Statistics of Standardized and Experimental Measures

Standardized Measures

Variables	Mean	Standard Deviation	Sample Size
Word ID SS	97.78	8.35	46
Fluency SS	100.39	11.57	46
Word Attack SS	98.00	10.78	46
Blending Words SS	8.37	3.26	46
Elision SS	7.43	2.93	46
Color Naming SS	9.93	2.15	46
Letter Naming SS	9.80	2.71	46
GORT Rate SS	10.87	2.00	46
GORT Accuracy SS	11.50	3.14	46
GORT Fluency SS	12.11	3.68	46
GORT Comprehension SS	8.46	2.71	46
GORT Story 10 Rate (Form A)	66.98	10.00	41
GORT Story 13 Rate (Form A)	71.94	13.02	41

Note. WORD ID SS = standard score on WJ-3 Word Identification; Fluency SS = standard score on WJ-3 Reading Fluency; Word Attack SS = standard score on WJ-3 Word Attack; Blending Words SS = standard score on CTOPP Blending Words; Elision SS = standard score on CTOPP Elision; Color Naming = standardized score on CTOPP Color Naming; Letter Naming = standardized score on CTOPP Letter Naming; GORT Rate = standardized rate score on GORT; GORT Accuracy = standardized accuracy score on GORT; GORT Fluency = standardized fluency score on GORT; GORT Comprehension = standard comprehension score on GORT; GORT Story 10 Rate = raw rate score on GORT story # 10 (seconds); GORT Story 13 Rate = raw rate score on GORT story # 13 (seconds).

Experimental Measures	Mean	Standard Deviation	Sample Size
% Easy Fixations	42.17	11.36	46
% Easy Regressions	10.84	5.64	46
% Easy Saccades	43.48	6.43	46
Easy Pupil Dilation	47.78	10.19	46
Easy Fixation Duration	166.30	18.18	46
Easy Saccade Duration	638.32	198.20	46
% Average Fixations	65.25	17.41	46
% Average Regressions	19.23	9.90	46
% Average Saccades	61.04	11.07	46
Average Pupil Dilation	50.72	7.11	46
Average Fixation Duration	181.74	23.46	46
Average Saccade Duration	565.69	147.40	46
% Hard Fixations	87.09	23.22	46
% Hard Regressions	28.33	10.21	46
% Hard Saccades	76.33	14.00	46
Hard Pupil Dilation	46.52	11.60	46
Hard Fixation Duration	186.50	21.50	46
Hard Saccade Duration	509.74	131.47	46
% Color Naming Fixations	123.49	22.36	46
% Color Naming Regressions	16.36	10.08	46
% Color Naming Saccades	85.45	10.36	46

Variables	Mean	Standard Deviation	Sample Size
Color Pupil Dilation	49.89	10.14	46
Color Fixation Duration	322.17	102.28	46
Color Saccade Duration	208.05	66.18	46
% Letter Naming Fixations	86.84	19.56	46
% Letter Naming Regressions	10.02	8.04	46
% Letter Naming Saccades	71.32	11.43	46
Letter Pupil Dilation	49.09	8.40	46
Letter Fixation Duration	212.07	39.27	46
Letter Saccade Duration	254.07	110.38	46
Easy Text Rate	18.02	2.51	37
Average Text Rate	24.73	4.39	37
Hard Text Rate	31.45	6.49	37
Color Naming Rate	20.46	3.62	34
Letter Naming Rate	13.36	2.73	37
BNT response time(ms)	1184.08	412.11	46

Note. % Easy Fixations = percentage of eye movements classified as fixations during easy text reading tasks; % Easy Regressions = percentage of eye movements classified as regressions during easy text reading tasks; % Easy Saccades = percentage of eye movements classified as saccades during easy text reading tasks; Easy Pupil Dilation = average pupil dilation during easy text reading tasks; Easy Fixation Duration = average fixation duration in ms during easy text reading task; Easy Saccade Duration = average saccade duration in ms during easy text reading task; . % Average Fixations = percentage of eye movements classified as fixations during average text reading tasks; % Average Regressions = percentage of eye movements classified as regressions during average text reading tasks; % Average Saccades = percentage of eye movements classified as saccades during average text reading tasks;

Average Pupil Dilation = average pupil dilation during average text reading tasks; Average Fixation Duration = average fixation duration in ms during average text reading task; Average Saccade Duration = average saccade duration in ms during average text reading task; . % Hard Fixations = percentage of eye movements classified as fixations during hard text reading tasks; % Hard Regressions = percentage of eye movements classified as regressions during hard text reading tasks; % Hard Saccades = percentage of eye movements classified as saccades during hard text reading tasks; Hard Pupil Dilation = average pupil dilation during hard text reading tasks; Hard Fixation Duration = average fixation duration in ms during hard text reading task; Hard Saccade Duration = average saccade duration in ms during hard text reading task; % Color Naming Fixations = percentage of eye movements classified as fixations during color naming tasks; % Color Naming Regressions = percentage of eye movements classified as regressions during color naming tasks; % Color Naming Saccades = percentage of eye movements classified as saccades during Color Naming tasks; Color Naming Pupil Dilation = average pupil dilation during color naming tasks; Color Naming Fixation Duration = average fixation duration in ms during color naming task; Color Naming Saccade Duration = average saccade duration in ms during color naming task; % Letter Naming Fixations = percentage of eye movements classified as fixations during letter naming tasks; % Letter Naming Regressions = percentage of eye movements classified as regressions during letter naming tasks; % Letter Naming Saccades = percentage of eye movements classified as saccades during letter naming tasks; Letter Naming Pupil Dilation = average pupil dilation during letter naming tasks; Letter Naming Fixation Duration = average fixation duration in ms during letter naming task; Letter Naming Saccade Duration = average saccade duration in ms during letter naming task; Easy Text Rate = raw rate score during experimental easy text reading task (seconds); Average Text Rate = raw rate score during experimental average text reading task (seconds); Hard Text Rate = raw rate score during experimental hard text reading task (seconds); Color Naming Rate = raw rate score during experimental color naming task (seconds); Letter Naming Rate = raw rate score during experimental letter naming task (seconds); BNT response time(ms)= average time to respond in ms on the experimental confrontation naming task.

Table 2

Pearson's r Correlations Between Standardized and Experimental Versions of GORT Text Tasks and RAN Naming Tasks (n = 46)

	GORT 10	GORT 13	GORT rate	GORT accuracy	GORT fluency
Experimental					
Easy	.36*	.41*	-.69**	-.58**	-.66**
Average	.36*	.47**	-.67**	-.59**	-.67**
Hard	.47**	.58**	-.84**	-.73**	-.83**

	CTOPP Letter	CTOPP Color	CTOPP Letter SS	CTOPP Color SS
Experimental				
Letter	.67**	.35*	-.66**	-.38*
Color	.54**	.54**	-.46**	-.57**

Note. GORT 10 = raw rate score on GORT story # 10 (seconds); GORT 13 = raw rate score on GORT story # 13 (seconds); GORT Rate = standardized rate score on GORT; GORT Accuracy = standardized accuracy score on GORT; GORT Fluency = standardized fluency score on GORT; Easy = raw rate score on experimental easy text task (seconds); Average = raw rate score on experimental average text task (seconds); Hard = raw rate score on experimental hard text task (seconds); CTOPP Letter = raw rate score on CTOPP Letter Naming (seconds); CTOPP Color = raw rate score on CTOPP Color Naming (seconds); CTOPP Letter SS = standardized rate score on CTOPP Letter Naming; CTOPP Color SS = standardized rate score on CTOPP color naming; Letter = raw rate score during experimental letter naming task (seconds); Color = raw rate score during experimental color naming task (seconds).
$^*p < .05$. $^{**}p < .01$.

Table 3

Correlations Between Time to Read Text and Time to Name

	Easy Text	Average Text	Hard Text
Color Naming	.47**	.36*	.27
Letter Naming	.40*	.30	.26

Note. Easy Text= raw rate score on experimental easy text task (seconds); Average Text = raw rate score on experimental average text task (seconds); Hard Text = raw rate score on experimental hard text task (seconds); Color Naming = raw rate score during experimental color naming task (seconds); Letter Naming = raw rate score during experimental letter naming task (seconds).
*p < .05. **p < .01.

Table 4

Correlations between Standardized GORT and RAN

	GORT Rate	GORT Accuracy	GORT Fluency
CTOPP Color Naming	.52**	.37*	.44**
CTOPP Letter Naming	.36*	.23	.29

Note. GORT Rate = standardized rate score on GORT; GORT Accuracy = standardized accuracy score on GORT; GORT Fluency = standardized fluency score on GORT; CTOPP Color = raw rate score on CTOPP Color Naming; CTOPP Letter = raw rate score on CTOPP Letter Naming.
*p < .05. **p < .01.

Table 5a

Repeated Measure ANOVAs of Text Difficulty Manipulation

	MS	F	Sig
% of Fixations	152.96	171.64	.001
% of Regressions	43.87	80.25	.001
% of Saccades	61.75	237.43	.001
Fixation Duration	190.75	26.86	.001
Saccade Duration	8178.56	23.38	.001

Note. % of Fixations = percentage of eye movements classified as fixations during text reading tasks; % of Regressions = percentage of eye movements classified as regressions during text reading tasks; % of Saccades = percentage of eye movements classified as saccades during text reading tasks; Fixation Duration = average fixation duration in ms during text reading tasks; Saccade Duration = average saccade duration in ms during text reading tasks.

Table 5b

Post Hoc Tests for Text Difficulty Manipulation

	Difficulty Level	Mean Difference	Sig
% of Fixations			
	Easy - Average	23.08	.05
	Easy - Difficult	44.92	.05
	Average - Difficult	21.84	.05
% of Regressions			
	Easy - Average	8.39	.05
	Easy - Difficult	17.49	.05
	Average - Difficult	9.10	.05
% of Saccades			
	Easy - Average	17.56	.05
	Easy - Difficult	32.85	.05
	Average - Difficult	15.29	.05
Fixation Duration			
	Easy - Average	15.44	.05
	Easy - Difficult	20.19	.05
	Average - Difficult	4.75	
Saccade Duration			
	Easy - Average	72.63	.05
	Easy - Difficult	128.58	.05
	Average - Difficult	55.95	.05

Note. See Table 5a. Easy = easy experimental text; Average = average experimental text; Difficult = difficult experimental text

Table 6

Correlations Between Eye Movement Variables (n = 46)

Eye Movement	% of fixations	% of regressions	% of saccades	Fixation duration	Saccade duration
		Average Text			
% of fixations	--	.21	.77**	.46**	-.36**
% of regressions		--	.57**	-.07	.06
% of saccades			--	.31*	-.36*
Fixation duration				--	-.38**
Saccade duration					--
		Easy Text			
% of fixations	--	-.03	.66**	.45**	-.41**
% of regressions		--	.50**	.04	-.13
% of saccades			--	.41**	-.60**
Fixation duration				--	-.22
Saccade duration					--
		Hard Text			
% of fixations	--	.22	.76**	.61**	-.43**
% of regressions		--	.55**	.01	.06
% of saccades			--	.41**	-.44**
Fixation duration				--	-.31*
Saccade duration					--

	% of fixations	% of regressions	% of saccades	Fixation duration	Saccade duration
Letter Naming					
% of fixations	--	-.02	.76**	.56**	-.43**
% of regressions		--	.26	-.06	.03
% of saccades			--	.37*	-.43**
Fixation duration				--	-.11
Saccade duration					--

Color Naming					
% of fixations	--	-.17	.32*	.05	.01
% of regressions		--	.05	-.18	.42**
% of saccades			--	.24	-.02
Fixation duration				--	-.19
Saccade duration					--

Note. % of Fixations = percentage of eye movements classified as fixations during text reading tasks; % of Regressions = percentage of eye movements classified as regressions during text reading tasks; % of Saccades = percentage of eye movements classified as saccades during text reading tasks; Fixation Duration = average fixation duration in ms during text reading tasks; Saccade Duration = average saccade duration in ms during text reading tasks.

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

Table 7

Correlations Between Eye Movements During Text Tasks and Time to Read Text Tasks (n = 46)

	% of Fixations	% of Regressions
	Easy Text	
Easy Text Time	.70**	.32
	Average Text	
Average Text Time	.72**	.51**
	Hard Text	
Hard Text Time	.82**	.49**

Note. % of Fixations = percentage of eye movements classified as fixations during text reading tasks; % of Regressions = percentage of eye movements classified as regressions during text reading tasks; Easy Text Time = raw rate score on experimental easy text task; Average Text Time = raw rate score on experimental average text task; Hard Text Time = raw rate score on experimental hard text task.

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

Table 8

Correlations Between Time to Name and Eye Movements on Computer Naming Tasks (n = 46)

	% of Fixations	% of Regressions
	Letter Naming	
Letter Time	.84**	.33*
	Color Naming	
Color Time	.86**	.02

Note. % of Fixations = percentage of eye movements classified as fixations during text reading tasks; % of Regressions = percentage of eye movements classified as regressions during text reading tasks; Letter Time = raw rate score during experimental letter naming task; Color Time = raw rate score during experimental color naming task.

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

Table 9

Correlations Between Eye Movements on Text Reading Tasks and Naming Tasks (n = 46)

	Easy Text	Average Text	Hard Text
	Percent of Fixations		
Color Naming	.55*	.58**	.50**
Letter Naming	.35*	.45**	.33*
	Percent of Regressions		
Color Naming	.17	.17	-.10
Letter Naming	.50**	.33*	.19

Note. Easy Text = experimental easy text task; Average Text = experimental average text task; Hard Text = experimental hard text task; Color Naming = experimental color naming task; Letter Naming = experimental letter naming task.

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

Table 10

Correlations Between Eye Movements on Naming Tasks and Time to Read Computer Texts

	% Letter Fixation	% Letter Regression	% Color Fixation	% Color Regression
Easy Text	.39*	.02	.54**	.11
Average Text	.18	.11	.41*	.30
Hard Text	.16	.10	.30	.09

Note. % Letter Fixations = percentage of eye movements classified as fixations during letter naming tasks; % Letter Regressions = percentage of eye movements classified as regressions during letter naming tasks; % Color Fixations = percentage of eye movements classified as fixations during color naming tasks; % Color Regressions = percentage of eye movements classified as regressions during color naming tasks; Easy Text= raw rate score on experimental easy text task (seconds); Average Text = raw rate score on experimental average text task (seconds); Hard Text = raw rate score on experimental hard text task (seconds).
**p* < .05. ***p* < .01.

Table 11

Correlations Between Naming Eye Movements and Time to Read Average and Hard Standardized GORT Stories

	% Letter Fixations	% Letter Regressions	% Color Fixations	% Color Regressions
Story 10	.13	-.39*	.23	-.26
Story 13	.04	-.33*	.15	-.14

Note. % Letter Fixations = percentage of eye movements classified as fixations during letter naming tasks; % Letter Regressions = percentage of eye movements classified as regressions during letter naming tasks; % Color Fixations = percentage of eye movements classified as fixations during color naming tasks; % Color Regressions = percentage of eye movements classified as regressions during color naming tasks; Story 10 = raw rate score on GORT story # 10 (seconds); Story 13 = raw rate score on GORT story # 13 (seconds).
*$p < .05$. **$p < .01$.

Table 12

Correlations Between WJ-3 and Standardized Measures of Reading and Naming

	Word ID	Word Attack	Reading Fluency
Elision	.28	.27	-.04
Blending Words	.45**	.42**	.22
Color Naming	.16	.25	.61**
Letter Naming	.01	.16	.26
GORT Accuracy	.61**	.65**	.40**
GORT Fluency	.58**	.60**	.45**
GORT Rate	.51**	.46**	.46**
GORT Comprehension	.21	.01	.35*

Note. WORD ID = standard score on WJ-3 Word Identification; Word Attack = standard score on WJ-3 Word Attack; Fluency = standard score on WJ-3 Reading Fluency; Elision = standard score on CTOPP Elision; Blending Words = standard score on CTOPP Blending Words; Color Naming = standardized score on CTOPP Color Naming; Letter Naming = standardized score on CTOPP Letter Naming; GORT Accuracy = standardized accuracy score on GORT; GORT Fluency = standardized fluency score on GORT; GORT Rate = standardized rate score on GORT;GORT Comprehension = standard comprehension score on GORT.

Table 13

Linear Regression Model for Predictors of Color RAN SS

	B	SE B	ß	R^2
Model				.32**
BNT Response Time	1.07^{-3}	.00	.21	
Elisions SS	-9.90^{-3}	.12	-.01	
Blending Words SS	8.21^{-2}	.10	.12	
% Color Fixations	-5.38^{-2}	.01	-.56**	
% Color Regressions	-3.64^{-2}	.03	-.17	

Note. BNT Response Time = average raw rate score in ms on experimental confrontation naming task; Elision SS = standard score on CTOPP Elision; Blending Words SS = standard score on CTOPP Blending Words; % Color Fixations = percentage of eye movements classified as fixations during color naming tasks; % Color Regressions = percentage of eye movements classified as regressions during color naming tasks.
*p < .05. **p < .01.

Table 14

Linear Regression Model for Predictors of Letter RAN SS

	B	SE B	ß	R^2
Model				.47**
BNT Response Time	1.21 E-03	.00	.18	
Elisions SS	-6.64 E-02	.13	-.07	
Blending Words SS	4.78 E-02	.12	.06	
% Letter Fixations	-9.24 E-02	.02	-.67**	
% Letter Regressions	3.42 E-02	.04	.10	

Note. BNT Response Time = average raw rate score in ms on experimental confrontation naming task; Elision SS = standard score on CTOPP Elision; Blending Words SS = standard score on CTOPP Blending Words; % Letter Fixations = percentage of eye movements classified as fixations during letter naming tasks; % Letter Regressions = percentage of eye movements classified as regressions during letter naming tasks.
*p < .05. **p < .01.

Table 15

Linear Regressions for Best Predictors of Time to Read Computer Tasks (n = 46)

	B	SE B	ß	R^2
		Easy Text		
Model 1				.08
Elision	-.11	.17	-.14	
Blending Words	-.13	.16	-.17	
Model 2				.32*
% Color Fixations	4.9^{-2}	.02	.42*	
% Color Regressions	3.8^{-2}	.05	.13	
% Letter Fixations	2.8^{-2}	.03	.21	
% Letter Regressions	-1.4^{-2}	.06	-.04	
Model 3				.08
Elision	-.11	.18	.54	
Blending Words	-.13	.17	.46	
% Color Regressions	-1.9^{-2}	.05	.73	
% Letter Regressions	-8.3^{-3}	.07	.90	
Model 4				.41**
Elision	-.20	.14	-.24	
Blending Words	-8.9^{-2}	.13	-.11	
% Color Fixations	5.3^{-2}	.02	.45**	
% Letter Fixations	2.7^{-2}	.02	.21	

	B	SE B	ß	R^2
		Average Text		
Model 1				.01
Elision	2.28^{-2}	.31	.54	
Blending Words	-.17	.29	.02	
Model 2				.24[a]
% Color Fixations	7.78^{-2}	.04	.38	
% Color Regressions	.13	.09	.25	
% Letter Fixations	5.14^{-3}	.05	.02	
% Letter Regressions	3.69^{-2}	.12	.06	
Model 3				.09
Elision	1.91^{-2}	.31	.01	
Blending Words	-7.53^{-2}	.29	-.06	
% Color Regressions	.15	.09	.28	
% Letter Regressions	1.22^{-2}	.12	.02	
Model 4				.18
Elision	-5.91^{-2}	.30	-.04	
Blending Words	-.10	.27	-.07	
% Letter Fixations	-6.63^{-3}	.04	-.03	
% Color Fixations	8.76^{-2}	.04	.43*	

	B	SE B	ß	R^2
		Hard Text		
Model 1				.04
Elision	.11	.45	.05	
Blending Words	-.47	.42	-.23	
Model 2				.11
% Color Fixations	.10	.07	.33	
% Color Regressions	5.13^{-3}	.15	.01	
% Letter Fixations	-1.44^{-2}	.08	-.04	
% Letter Regressions	.13	.19	.13	
Model 3				.05
Elision	9.26^{-2}	.47	.04	
Blending Words	-.43	.44	-.21	
% Color Regressions	2.19^{-2}	.14	.03	
% Letter Regressions	5.64^{-2}	.17	.06	
Model 4				.13
Elision	1.26^{-2}	.45	.01	
Blending	-.40	.41	-.20	
% Color Fixations	8.57^{-2}	.06	.28	
% Letter Fixations	9.88^{-3}	.07	.03	

Note. Elision = standard score on CTOPP Elision; Blending = standard score on CTOPP Blending Words; % Color Fixations = percentage of eye movements classified as fixations during color naming tasks; % Color Regressions = percentage of eye movements classified as regressions during color naming tasks; % Letter Fixations = percentage of eye movements classified as fixations during letter naming tasks; % Letter Regressions = percentage of eye movements classified as regressions during letter naming tasks.
*p < .05. **p < .01, a: p = .061.

Table 16

Linear Regressions for Best Predictors of Time to Read GORT Stories (n = 46)

	B	SE B	ß	R^2
		GORT Story 10		
Model 1				.05
Elision	.58	.63	.17	
Blending Words	-.81	.59	-.25	
Model 2				.17
% Color Fixations	7.81^{-2}	.11	.14	
% Color Regressions	-.16	.18	-.16	
% Letter Fixations	2.36^{-2}	.11	.04	
% Letter Regressions	-8.32	5.46	-.27	
Model 3				.21[a]
Elision	.60	.59	.18	
Blending Words	-.82	.55	-.26	
% Color Regressions	-.12	.16	-.12	
% Letter Regressions	-.41	.21	-.34	
Model 4				.01
Elision	.51	.64	.15	
Blending Words	-.66	.61	-.21	
% Color Fixations	.10	.11	.18	
% Letter Fixations	1.20^{-2}	.10	.02	

	B	SE B	ß	R^2
		GORT Story 13		
Model 1				.02
Elision	.20	.83	.05	
Blending Words	-.66	.78	-.16	
Model 2				.11
% Color Fixations	2.95^{-2}	.15	.04	
% Color Regressions	6.68^{-3}	.25	.01	
% Letter Fixations	5.83^{-3}	.15	.01	
% Letter Regressions	-.51	.32	-.32	
Model 3				.13
Elision	.24	.81	.05	
Blending Words	-.65	.76	-.16	
% Color Regressions	-5.21^{-3}	.23	-.01	
% Letter Regressions	-.53	.28	-.33[b]	
Model 4				.04
Elision	.14	.85	.03	
Blending Words	-.53	.81	-.13	
% Color Fixations	.11	.14	.15	
% Letter Fixations	-3.42^{-2}	.14	-.05	

Note. Elision = standard score on CTOPP Elision; Blending = standard score on CTOPP Blending Words; % Color Fixations = percentage of eye movements classified as fixations during color naming tasks; % Color Regressions = percentage of eye movements classified as regressions during color naming tasks; % Letter Fixations = percentage of eye movements classified as fixations during letter naming tasks; % Letter Regressions = percentage of eye movements classified as regressions during letter naming tasks.
*$p < .05$. **$p < .01$, a: $p = .07$, b: $p = .07$.

Table 17

Linear Regressions for Best Predictors of GORT Standard Scores (n = 46)

	B	SE B	ß	R^2
		GORT Rate		
Model 1				.07
Elision	-5.48^{-2}	.12	-.08	
Blending Words	0.18	.12	.30	
Model 2				.01
% Color Fixations	-7.58^{-3}	.02	-.09	
% Color Regressions	-1.10^{-2}	.04	-.06	
% Letter Fixations	-5.27^{-4}	.02	-.01	
% Letter Regressions	-1.33^{-2}	.05	-.05	
Model 3				.07
Elision	-5.33^{-2}	.12	-.08	
Blending Words	0.18	.11	.29	
% Color Regressions	-1.55^{-3}	.03	-.01	
% Letter Regressions	-1.06^{-2}	.04	-.04	
Model 4				.07
Elision	-4.86^{-2}	.12	-.07	
Blending Words	0.18	.11	.30	
% Color Fixations	-3.62^{-3}	.02	-.04	
% Letter Fixations	-3.35^{-3}	.02	-.03	

	B	SE B	ß	R^2
		GORT Accuracy		
Model 1				.17*
Elision	9.30^{-2}	.18	.09	
Blending	0.35	.16	.36*	
Model 2				.01
% Letter Fixations	-2.93^{-3}	.03	-.02	
% Letter Regressions	3.46^{-2}	.08	.09	
% Color Fixations	-3.78^{-2}	.06	-.12	
% Color Regressions	7.58^{3}	.03	.05	
Model 3				.17[a]
Elision	8.98^{-2}	.18	.08	
Blending Words	0.34	.16	.36*	
% Color Regressions	-1.19^{-2}	.05	-.04	
% Letter Regressions	1.33^{-2}	.06	.03	
Model 4				.17[b]
Elision	9.03^{-2}	.18	.08	
Blending Words	0.35	.16	.36*	
% Letter Fixations	-2.76^{-3}	.03	-.02	
% Color Fixations	4.27^{-3}	.02	.03	

	B	SE B	ß	R^2
		GORT Fluency (n = 46)		
Model 1				.13[c]
Elision	2.09^{2}	.21	.02	
Blending Words	0.39	.19	.35*	
Model 2				.01
% Letter Fixation	-1.90^{-3}	.04	-.01	
% Letter Regression	1.07^{-2}	.09	.02	
% Color Fixation	-4.14^{-2}	.07	-.11	
% Color Regression	1.02^{-3}	.03	.01	
Model 3				.13
Elision	2.00^{-2}	.22	.02	
Blending	0.39	.20	.34[d]	
% Letter Regressions	-3.36^{-3}	.08	-.01	
% Color Regressions	-1.61^{-2}	.06	-.04	
Model 4				.13
Elision	2.07^{-2}	.22	.08	
Blending Words	0.40	.20	.35*	
% Color Fixations	2.36^{-3}	.03	.01	
% Letter Fixations	-3.31^{-3}	.03	-.02	

Note. Elision = standard score on CTOPP Elision; Blending = standard score on CTOPP Blending Words; % Color Fixations = percentage of eye movements classified as fixations during color naming tasks; % Color Regressions = percentage of eye movements classified as regressions during color naming tasks; % Letter Fixations = percentage of eye movements classified as fixations during letter naming tasks; % Letter Regressions = percentage of eye movements classified as regressions during letter naming tasks.
*$p < .05$. **$p < .01$, a: $p = .094$, b: $p = .095$, c: $p = .053$, d: $p = .056$.

Chapter 4: Discussion

Although the primary purpose of this study was to investigate the role of eye movements in rapid naming and reading tasks, it was initially important to evaluate the methodology used in this study. First, the significant relationships found between both time to read text on the computer tasks and the standardized GORT stories, as well as time to name between the computer naming tasks and the standardized CTOPP color and letter naming, suggest that the experimental computer tasks were comparable adaptations of the standardized, commonly used text versions. This relationship supports the notion that data collected from the computer text reading tasks are similar to the data collected from the standardized GORT and CTOPP naming tasks.

Second, the text-difficulty manipulation using the easy, average and hard computer texts showed differentiated results as predicted. This is evident in both the average length of time it took for participants to read the text (taking longer with the more difficult text) as well as on eye movement measures. The differences found in the eye movement data between difficulty levels was consistent with previous research findings (Rayner, 1998), which showed that as the difficulty level of text increases, people make more regressions, more fixations, more saccades, fixation duration increases, and saccade duration decreases.

Several decades of research have consistently found strong relationships between reading and serial naming tasks such as color and letter rapid naming (e.g., Bowers, Golden, Kennedy, & Young, 1994). In the current study, a strong relationship was found using the computer tasks, between color naming time and both the easy and average text reading times, as well as between letter naming time and time to read the easy text. It is interesting that there was not a significant relationship between the difficult text and either of the naming tasks. This may be due to the role of color and letter naming automaticity in adults. There appears to be a different relationship in adults between automatic processes and their relationship with reading more difficult text. This idea is further supported by the finding that rapid letter naming had a strong association only with the easy text, as letter naming is likely more automated than color naming.

Similar analyses were performed using the standardized measures of rapid naming and reading (CTOPP color and letter naming and the GORT rate, accuracy and fluency). A strong relationship was found between both color and letter naming and the GORT rate measures; however, only color naming was strongly associated with GORT accuracy and fluency. These findings suggest that naming tasks may be most predictive of overall reading rate, and less predictive of accurate word reading in average college readers.

Altogether, the relationship between naming time and reading ability in the current study was inconsistent. This variable relationship is likely due to the fact that the sample consisted of only college students. It is likely that there was not enough variability in reading ability among this sample. This lack of a stronger relationship between naming speed and reading ability is not surprising given previous research findings that the RAN losing its predictive ability in normal readers after elementary school (Meyer, Wood, Hart, and Felton, 1998).

It was hypothesized that there would be a strong relationship between eye movements on the naming tasks and reading ability. This relationship was evaluated using several different measures of reading ability, such as time to read the computer texts, time to read two of the GORT stories, and the GORT standard scores (rate, accuracy and fluency). Overall, the relationship between eye movements during letter and color naming and reading ability was inconsistent, and dependent on the reading metric used. Whereas no significant relationships were found between the GORT standard scores and naming eye movements, there were significant relationships between time to read easy text and color- and letter-naming eye movements, time to read the average text and percent of fixations, and time to read both of the GORT stories and percent of regressions on the letter-naming task. Altogether, these findings suggest that eye movements during naming tasks are more strongly correlated with the time to read connected text than with standardized scores or accuracy measures.

The inconsistency in the relationship between eye movements on the naming tasks and reading ability is not surprising given the previously reported weak relationship between naming speed and reading ability in the present study. This again may be due to the lack of variability in reading ability in the current sample of normal readers. Given these findings, there would not be an expected relationship between eye movements on a naming task and reading ability among a population of normal readers who do not demonstrate the relationship between naming speed and reading ability. There may, however, be a relationship between eye movements on a naming task and reading ability among a population of reading disabled participants or poor readers. The current study does not address this possibility.

A series of linear regressions were performed to evaluate the best predictors of reading ability. Several different models were evaluated, including phonological awareness alone, eye movements alone, and the combination of the two. The analyses revealed that the best predictors changed as a function of what dependent variable was used. When the dependent variable was time to read easy text, a combination of phonological awareness measures and eye movements was most predictive of reading ability. The models for the average and hard text did not reach statistical significance, although the best fitting model for the average text was eye movements alone, and the best fitting model for the hard text was a combination of eye movements and phonological processes. The fact that naming and phonological processes were not statistically significant predictors for the more difficult texts suggests that those text-reading tasks may require more complex cognitive skills that are not well measured by simple RAN and phonology tasks. A similar conclusion can be drawn for the two GORT texts of average and hard difficulty. Although models with a combination of eye movements and phonological processes were the best fit for both stories, neither model was statistically significant. A different pattern emerged from the GORT standard score data. A model containing only the phonological processing measures was most predictive for both the accuracy score and the fluency score. None of the models approached significance for the rate scores. This pattern of data also supports the idea that eye movements on the naming tasks are better predictors for raw time scores, and not as good predictors for accuracy of text reading. The findings that eye movements on the naming tasks were not statistically significant predictors for the majority of the measures of reading ability are again not surprising, given the variable, weak relationship between naming speed and reading ability.

A central hypothesis of the current study was that there should be a strong relationship between eye movements made while reading and eye movements made while rapidly naming colors and letters. This hypothesis was supported in the current study, as strong relationships were found between percent of fixations on all of the computer text tasks and the two naming tasks. The same pattern was not found for percent of regressions, as percent of regressions for color naming was not significantly correlated with percent of regressions for any of the text tasks, and letter naming was only associated with the easy and average texts. The weaker association between percent of regressions across these tasks may be due to the ease and automaticity of the naming tasks. This explanation is supported by the finding that participants did not make as many regressions on the naming tasks as they did on the average and difficult text reading tasks, as regressions are indicative of errors and these tasks are fairly automated for most adults. Additionally, research has found that naming speed is much more predictive of reading ability than naming errors, which would be represented by the regressions (Denkla and Rudel, 1972). These findings support the idea that the visual scanning and sequential components of the continuous RAN are similar to the visual scanning processes required in reading.

A series of linear regressions were also performed to evaluate the best predictors of RAN. The purpose of these analyses was to evaluate the underlying components of the RAN task to help further understand its relationship with reading ability. Two models were evaluated. In the first model, rapid color naming standard scores were the dependent variable and the predictors were phonological processes, confrontation naming speed, and fixations and regressions on the experimental color naming tasks. The second model was similar, except that the rapid color naming variables were replaced with the rapid letter naming variables. Both of these models were found to explain significant portions of variance in RAN. Additionally, the percent of fixations variable was the most significant predictor in both models. These findings are in congruence with several advocates of the continuous RAN version, who argue that it is the very nature of the continuous format, including the visual scanning, sequencing, and motoric requirements, that make RAN such a strong predictor of reading ability (Bowers, 1989; Bowers, Steffy and Tate, 1988; Wolf, Bally and Morris, 1986; Wolf, 1997).

These findings also provide insight into the debate over whether or not 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. That percent of fixations was the strongest predictor of RAN standard scores suggests that the variance related to eye movements is separate from phonological processing and working memory. This conclusion is further supported by prior research showing 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).

Collectively, the findings from this study support the argument that the visual scanning and sequential components of the continuous RAN format are similar to those same visual scanning processes required in reading. Additionally, the findings suggest that the continuous RAN is measuring processes that are independent of phonological processing.

There are several limitations of the current study. One possible limitation is that a convenience sample of undergraduate students was used in this study. 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 predict individual variation in word identification skill among normal readers past the elementary grades (Meyer, Wood, Hart, and Felton, 1998). Because a sample of normal readers was used in this study, it is possible that the strong level of relationship between RAN and reading was limited in this sample. It is also possible that there was limited variability in the sample as most of the readers were average to above average with very few weak readers. It is possible that the adults used in this study were too automatic at letter and color naming, and therefore did not produce the kind of variability that would yield more significant relationships.

A second limitation of the current study was related to the analysis of the eye movements. Analyzing raw eye movement data is very difficult, and there is inevitably some error in the measurement. Great effort was made to create an accurate and consistent analysis program, by scoring several trials by hand and comparing the hand scores to the computerized scoring program. The computerized scoring program underwent several revisions in order to make it as consistent as possible with the hand scoring; however, it is possible that some limitations remain in the scoring program. Although there likely is some error in the scoring program, those errors should be consistent across all eye movements and subjects across all text reading and the naming tasks. Additionally, any scoring errors should make it more difficult to find significant relationships, making the analyses in this study somewhat conservative. It is possible that with more precise scoring, stronger relationships may have been found between eye movements and reading ability.

In summary, the findings of this study suggest that there is a relationship between eye movements on naming tasks and reading ability. The research suggests that this relationship stronger for time to read, rather than accuracy. However, the findings from this study are somewhat inconsistent, and more research is needed to understand further the impact of eye movements on naming tasks and the relationship between RAN and reading ability. Future research should use samples of both adults and children with reading disabilities, as well as normal child readers. The findings further suggest that the scanning, sequencing, and motoric requirements of the continuous RAN format distinguish the RAN from measures of phonological awareness and working memory. These findings suggest that the RAN makes important contributions to the evaluation of reading ability above that which is accounted for by measures of phonological processes and working memory. The continuous RAN seems to measure important visual scanning and sequencing processes that are important in predicting reading ability, and which are not measured by most tasks of phonological processing and working memory.

References

Blachman, B.A. (1984). Relationship of rapid naming ability and language analysis skills to kindergarten and first-grade reading achievement. *Journal of Educational Psychology*, *76*, 610-622.

Boersma, T., Zwagam H.J., and Adams, A.S. (1989). Conspicuity in realistic scenes: An eye movement measure. *Applied Ergonomics, 20*, 267-273.

Bowers, P.G. (1989). Naming speed and phonological awareness: Independent contributors to reading disabilities. In S. McCormick and J. Zutell (Eds.) *Cognitive and Social Perspectives for Literacy Research and Instruction: 38th Yearbook of the National Reading Conference,* Chicago: National Reading Conference, Inc.

Bowers, P.G., Steffi, R.A., and Tate, E. (1988). Comparison of the effects of IQ control methods on memory and naming speed predictors of reading disability. *Reading Research Quarterly, 23*, 304-319.

Bowers, P.G., and Swanson, L.B. (1991). Naming speed deficits in reading disability: Multiple measures of a singular process. *Journal of Experimental Child Psychology, 51*, 195-219.

Bowers, P.G., and Wolf, M. (1993). Theoretical links between naming speed, precise timing mechanisms and orthographic skill in dyslexia. *Reading and Writing: An Interdisciplinary Journal, 5*, 69-85.

Cardomy, D.P., Nodine, C.F., and Kundel, H.L. (1980). AN analysis of perceptual and cognitive factors in radiographic interpretation. *Perception, 9*, 339-344.

Carpenter, P.A., and Just, M.A. (1983). What your eyes do while your mind is reading. In K. Rayner (Ed.), *Eye Movements in Reading: Perceptual and Language Processes.* New York: Academic Press, 275-307.

Denckla, M.B., and Cutting, L.E. (1999). History and significance of Rapid Automatized Naming. *Annals of Dyslexia, 49*, 29-42.

Denckla, M.B., and Rudel, R.G. (1972). Color-naming in dyslexic boys. *Cortex, 8*, 164-176.

Denckla, M.B., and Rudel, R.G. (1974). Rapid "Automatized" Naming of pictured objects, colors, letters, and numbers by normal children. *Cortex, 10*, 186-202.

Denckla, M.B., and Rudel, R.G. (1976). Naming of objects by dyslexic and other learning disabled children. *Brain and Language, 3*, 1-15.

Eden, G.F., Stein, J.F., Wood, H.M., and Wood, F.B. (1994). Differences in eye movements and reading problems in dyslexic and normal children. *Vision Research, 34*, 1345-1358.

Felton, R.H., Naylor, C.E., and Wood, F.B. (1990). Neuropsychological profile of adult dyslexics. *Brain and Language, 39*, 485-497.

Geschwind, N., and Fusillo, M. (1966). Color-naming deficits in association with Alexia. *Archives of Neurology, 15*, 137-146.

Gray, W.B. (1975). *How to measure readability*. Philadelphia: Dorrance & Co., 11-12.

Lefton, L.A., Nagle, R.J., Johnson, G., and Fisher, D.F. (1979). Eye movement dynamics of good and poor readers: Then and now. *Journal of Reading Behavior, 11*, 319-328.

Martos, F.J., and Vila, J. (1990). Differences in eye movement control among dyslexic, retarded and normal readers in the Spanish population. *Reading and Writing, 2*, 175-188.

Matin, E. (1974). Saccadic suppression: A review. *Psychological Bulletin, 81*, 899-917.

McBride-Chang, C., and Manis, F. (1996). Structural invariance in the associations of naming speed, phonological awareness, and verbal reasoning in good and poor readers: A test of the double-deficit hypothesis. *Reading and Writing: An Interdisciplinary Journal, 8,* 323-339.

Morrison, R.E. (1983). Retinal image size and the perceptual span in reading. In K. Rayner (Ed.), *Eye movements in Reading: Perceptual and Language Processes.* New York: Academic Press, 31-40.

Murray, W.S., and Kennedy, A. (1988). Spatial coding in the processing of anaphor by good and poor readers: Evidence form eye movement analyses. *Quarterly Journal of Experimental Psychology, 40*, 693-718.

Noyes, L. (1980). The position of type on maps: The effect of surrounding material on word recognition times. *Human Factors, 22*, 353-360.

Perfetti, C.A., Finger, E., and Hogabaum, T. (1978). Sources of vocalization latency differences between skilled and less skilled young readers. *Journal of Educational Psychology, 70*, 730-739.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124(3),* 372-422.

Rayner, K. and Betrea, J.H. (1979). Reading without a fovea. *Science, 206*, 468-469.

Rayner, K., and Duffy, S.A. (1988). On-line comprehension processes and eye movements in reading. In M. Daneman, G.E. MacKinnon, and T.G. Waller (Eds.), *Reading Research: Advances in Theory and Practice*. New York: Academic Press, 13-66.

Rayner, K., and Fisher, D.L. (1987). Letter processing during eye fixations in visual search. *Perception and Psychophysics, 42*, 87-100.

Rayner, K. and McConkie, G.W. (1976). What guides a reader's eye movements. *Vision Research, 16,* 829-837.

Rayner, K. and Pollatsek, A. (1989). *The Psychology of Reading.* Englewood Cliffs, NJ: Prentice Hall.

Rayner, K., Sereno, S.C., Morris, R.K., Schmauder, A.R., and Clifton, C. (1989). Eye movements and on-line language comprehension processes. *Language and Cognition Processes, 4,* 21-49.

Reichle, E.D., Pollatsek, A., Fisher, D.L., and Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review, 105,* 125-157.

Reichle, E.D., Pollatsek, A., Fisher, D.L., and Rayner, K. (2000). Eye movement control in reading: accounting for initial fixation locations and refixations within the E-Z Reader model. *Visual Research, 39,* 4403-4411.

Schmauder, A.R. (1992). Eye movements and reading processes. In K. Rayner (Ed.), *Eye Movements and Visual Cognition: Scene Perception and Reading.* New York: Springer-Verlag, 369-378.

Stanovich, K.E. (1981). Relationships between word decoding speed, general name-retrieval ability, and reading progress in first-grade children. *Journal of Educational Psychology, 73,* 809-815.

Starr, M.S., and Rayner, K. (2001). Eye movements during reading: some current controversies. *Trends in Cognitive Sciences, 5(4),* 156-163.

Tabachnick, B.G. and Fidell, L.S. (1996). *Using Multivariate Statistics* (3rd Ed.) New York: Harper Collins College Publishers.

Uttal, W.R., and Smith, P. (1968). Recognition of alphabetic characters during voluntary eye movements. *Perception and Psychophysics, 3*, 257-264.

Vellutino, F.R., Scanlon, D.M., Sipay, E.R., Small, S.G., Pratt, A., Chen, R., and Denckla, M.B. (1996). Cognitive profiles of difficult-to-remediate and readily remediated poor readers: Early intervention as a vehicle for distinguishing between cognitive and experiential deficits as basic causes of specific reading disability. *Journal of Educational Psychology, 88,* 601-638.

Wagner, R.K., Torgesen, J.K., Laughon, P., Simmons, K., and Rashotte, C.A. (1993). Development of young reader’s phonological processing abilities. *Journal of Educational Psychology, 85,* 83-103.

Wolf, M. (1997). A provisional, integrative account of phonological and naming-speed deficits in dyslexia: Implications for diagnosis and intervention. In B. Blachman (Ed.) *Foundations of Reading Acquisition and Dyslexia,* NJ: Lawrence Erlbaum Associates.

Wolf, M. (1991). Naming speed and reading: The contribution of the cognitive neurosciences. *Reading Research Quarterly, 26*, 123-141.

Wolf, M., Bally, H., and Morris, R. (1986). Automaticity, retrieval processes, and reading: A longitudinal study in average and impaired readers. *Child Development, 57*, 988-1005.

Zelinsky, G.J. (1996). Using eye saccades to assess the selectivity of search movements. *Vision Research, 36*, 2177-2187.

Zelinsky, G.J., and Sheinberg, D.L. (1997). Eye movements during parallel-serial visual search. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 244-262.