4-19-2013

Advanced Statistical Analysis of the Pupil Project Program

Erin Marie Brooks
University of Missouri-St. Louis, embwt9@mail.umsl.edu

Advanced Statistical Analysis of the Pupil Project Program

Erin Marie Brooks
O.D., Doctorate of Optometry, University of Missouri – St. Louis, 2011
B.S., Chemistry with Emphasis in Biochemistry, University of Missouri – St. Louis, 2007

A Thesis Submitted to The Graduate School at the University of Missouri – St. Louis in partial fulfillment of the requirements for the degree
Master of Science in Vision Science

April 2013

<u>Advisory Committee</u>

Carl J. Bassi, Ph.D.
Chairperson

Aaron S. Franzel, O.D.
Co-chair

Ralph P. Garzia, O.D.

Abstract

Objective: Early visual processing integrity is correlated with word reading. In previous reports, duration of fixation when reading sight-words has been established as an early sensory correlate of single word decoding ability. In attempts to model the direct and indirect predictive value between duration of fixation, number of fixations, orthographic processing, phonological processing, and rapid automatized naming (RAN) to word decoding ability, we compared Visagraph duration of fixation and number of fixations data to results of the Processing and Learning Test-Reading and Writing (PAL-RW) and dyslexia screening test (DST) in a structural equation modeling (SEM) analysis.

Methods: Seventy-four students with reading difficulties (age range 8-13) referred to the Pupil Project were used in the analyses. A theoretical model outlining the proposed relationship between factors was established, then direct and indirect effects between factors were calculated in multiple regression analysis. Model fit was evaluated with SEM analyses in Amos.

Results: Of the five factors explored (duration of fixation, number of fixations, RAN, orthographic and phonological processing), only number of fixations and phonological processing failed to hold a significant ($p<0.05$) direct effect on word reading. RAN and duration of fixation held significant indirect effects mediated through orthographic processes. The model was strongest when all five factors were incorporated. In all models, RAN, duration of fixation, and orthographic processing held the strongest relationship to word reading.

Conclusions: These results suggest that, at least for our clinical population with visually related reading difficulties, RAN, duration of fixation, and orthographic processing held higher path coefficients than phonological processing or number of fixations in predicting single word reading ability. Further, RAN was a good predictor for orthographic processing. Duration of fixation held the second strongest predictive value of any single factor to word reading. It may serve optometrist well in analyzing risk factors for dyslexia. Results suggest modification to the double deficit hypothesis for dyslexia to incorporate visual/orthographic processing.

Background

Dyslexia can generally be defined as a deficit or delay in reading ability despite normal intelligence; however a unitary definition of dyslexia is elusive (Shaywitz, 1998; Eisenberg, 1978; Rutter, 1978). Many define dyslexia based on specific deficits in reading skills (Rutter, 1978). Reading ability in dyslexia is often evaluated using reading comprehension scores, single word, or **pseudoword** (groups of letters that are decoded phonetically but are not real words) reading ability (appendix a, figure 1) (Rathvon, 2004). Tests of decoding ability usually determine reading skill by the number of words or pseudowords read in a given time period. The main detriment to finding a universally acceptable definition for dyslexia lies in the controversy over the exact cause of dyslexia.

Most dyslexia research in the past 7 decades have centered on **minimal brain dysfunction** or delays in either **higher order visual perception** (visual cognitive skills), **phonological processing** (ability to sound out words based on the letter sounds), **rapid automatized naming** (ability to rapidly identify objects, letters, or numbers), and **orthographic processing** (ability to identify words by sight, especially words that don't follow normal phonics rules) ability (Badian, 1997). Phonologic skills (appendix a, figure 2) in dyslexia can be evaluated with a variety of methodologies, but most include removing a letter, phoneme, or syllable in a spoken word and either saying the new word or sound or determining what sound is missing in a word from which a letter, phoneme, or syllable has been omitted. Rapid automatized naming skills (appendix a, figure 3) are usually assessed by having the child identify a group of pictures, numbers or letters as quickly and accurately as he or she can. Orthographic skills (appendix a, figure 4) are usually tested in situation where phonics skills are not helpful in determining the correct answer; a sight word is presented in a group of phonetically correct non-words.

Introduction

Early Theories of Dyslexia

Early theories centered on reading instruction and social factors as the main areas associate with the presence or absence of a reading disability. Gates (1936) believed that anyone who had an IQ above 70 could learn to read, and reading abilities were only impaired in those who had learned to read using inappropriate techniques. Monroe (1932) attributed reading disabilities to a variety of factors during early years including learning environment and instruction strategies. Robinson (1946) agreed with Monroe’s conclusion, but his research expanded on Monroe's research by finding that a greater number of negative factors led to more serious reading impairment.

Orton's Influence: Laterality and Reversals

Orton (Orton 1932, 1937) theorized that each hemisphere receives visual input when viewing letters and numbers; however these images are perceived as reversed in the non-dominant brain hemisphere. In children with poor brain laterality or no specific dominant hemisphere, letters and words are seen as backwards in a phenomenon he termed strephosymbolia (meaning "twisted signs") (Corballis & Beale 1993). While Orton's theory has been largely disproven, some evidence remains that eye-hand dominance is opposite or more ambiguous in reading disabled children.

Higher Order Visual Perceptual (Developmental) Theory

Getman (1965, 1985) believed the cause of dyslexia was due to poor visual tracking resulting from developmental ocular motor deficiencies. Barsch (1965) attributed dyslexia to poor visual spatial development. Kephart (1964) proposed an alternate theory stating that deficient visual perceptual motor skills are the cause of reading dysfunction in dyslexia. All of these theories relied on previously established hierarchal models of child development. The presumption was that a lag of development in an early phase would affect all subsequent levels of development thought to depend on it. Underdevelopment of perceptual motor match or eye movement control would lead to consequences in reading development. Although these higher order visual perceptual models may describe elements of a dyslexic profile, any attempt to provide evidence of causation has not been successful when verbal coding effects were limited (Fletcher, Foorman, Shaywitz, & Shaywitz, 1999).

Progression from Phonetic to Triple Deficit Theory Beyond

Originally dyslexia was believed to be purely due to poor or delayed phonetic skills (Bruck, 1992: Wagner & Torgesen, 1987). Pioneers in dyslexia researchers believed that while other related factors such as rapid automatized naming and visual processing skills are often impaired in dyslexics and may contribute to reading disabilities, phonetic dysfunction is the true root of dyslexia (Vellutino, Steger, Kaman, & Setto, 1975). More recent evidence disputes these ideas (Pennington, 2000). The double deficit hypothesis of dyslexia (Badian, 1997; Wolf & Bowers 1999) was introduced in the early 1990's. The double deficit hypothesis states that there are two major components which contribute to reading deficits in dyslexia - phonetic skills and rapid automatized naming - while both of these areas are related, each contributes independently to reading skills and the presence of impairments in both areas leads to a more severe reading disability (Manis, Doi, & Bhadha, 2000). Researchers who support the double deficit hypothesis have found that rapid automatized naming alone can be used to separate dyslexic and normal readers (Arnell, 2000; Lovett 1987). Further research has shown that RAPID rapid automatized naming can even separate poor readers with low IQs from dyslexics with similar reading levels and normal IQs (Denckla & Rudel, 1976). Children with low intellectual abilities and poor reading skills will perform better than expected (based on reading level) on rapid automatized naming tasks while dyslexic children require significantly longer time than expected to complete the same rapid automatized naming task (Denckla & Rudel, 1976). These relationships between rapid automatized naming and reading abilities hold across various linguistic populations (Wolf & Bowers, 1999). In the triple deficit hypothesis, orthographic skills – in addition to rapid automatized naming and phonetic skills – have been shown to be associated with more severe impairment in the reading skills of dyslexic readers (Wolf & Bowers, 1999). Other areas which may impact reading skills in dyslexic readers include early visual and auditory processing, visual perception, ocular motor skills, and semantic skills (Facoetti et al., 2003).

Dyslexia: The Phonetic Theory

Subsequent dyslexia research noted a defect in phonetic skills in dyslexic readers who have poor word reading skills. Vellutino, Steger, Kaman, and De Sotto (1975) were strong proponents of the phonetic theory of dyslexia. They conducted several studies seeking to prove that phonetic skills are paramount in reading disabilities and other extraphonetic factors (i.e. visual perception) do not contribute to reading disabilities. Vellutino et al. conducted a study to disprove the importance of visual perceptual processing in reading disability in both early and more advanced readers. They selected three groups of 11 students in both the second and sixth grades. One group in each grade consisted of normal readers who attended a bilingual Hebrew and English school. The other two groups consisted of poor readers (sixth grades who read at or below a fourth grade level and second grades who read at or below a first grade reading level) and normal English-speaking readers who read at their respective grade levels. Vellutino et al. briefly presented strings of Hebrew letters consisting of three, four, and five letters and asked members of each of the six groups to write what they saw after the letters disappeared. The children were instructed to study the string of letters from presentation until disappearance. The number of orientation, sequence, omission, and substitution errors was recorded and averaged for each group. Vellutino et al. found that members of the bilingual Hebrew group were much more likely to omit letters at the left of the string of letters while members of the non-Hebrew groups were more likely to omit letters in the right side of each letter string. This finding was used to dispute the directionality-centered theories of reading disability, especially those of Orton (Corballis & Beale, 1993). Vellutino et al. also found no significant difference in the number of errors made by the poor readers and normal non-Hebrew readers.

Fletcher and Satz (1979a,1979b) found several shortcoming's in Vellutino's studies. For some tasks, members of both reading groups achieved correct responses 90 or 100 percent of the time. Fletcher and Satz (1979a) argued that group difference would be masked by the lack of difficulty. For other tasks, members in both groups answered correctly less than 50 percent of the time. The ceiling effect caused by these tasks would also mask group differences (Fletcher & Satz, 1979b). Bruck (1992) attempted to determine whether or not the phonetic skills in dyslexics were appropriate for their reading level or if phonetic skills were deficient not just delayed. Her study included two main groups of adult and child (ages 8-16) dyslexics with age and reading level matched controls. Adult dyslexic readers in this study were selected based on their reading skills as a child while the child dyslexics in this study had poor word recognition skills despite normal intelligence, regular schooling, and good general health. Both the adult and child dyslexics and their respective controls were evaluated based on their abilities to count syllables, count phonemes, and delete phonemes.

The first question Bruck (1992) attempted to answer was whether or not dyslexic readers are able to acquire age appropriate phonetic skills. Dyslexic children and adults had significantly more errors on all tasks compared to age matched controls. Interestingly, in the phoneme counting task, dyslexic readers were much less likely to make errors consistent with using orthographic information compared to controls. Both groups were significantly different in their performance of the various phonetic tasks with dyslexics performing significantly more poorly. This suggests that dyslexic readers utilize orthographic information less often or differently than normal readers. The second question Bruck attempted to answer was whether or not dyslexic readers have reading level appropriate phonics skills. When the dyslexic children were compared to reading level matched younger normal readers, they performed significantly worse on all phonetic tasks compared to the younger normal readers. The adult dyslexic readers who read at or above a seventh grade reading level were compared to normal children who read at a third grade reading level. The third grade level and adult dyslexic readers performed similarly on one of the phoneme deletion tasks and the syllable counting task; however, the adult dyslexics performed significantly worse than the third grade readers on the other phoneme deletion task and the phoneme counting tasks despite the fact the dyslexics read at a higher reading level compared to the controls. Again, the control readers in made more orthographic-based phoneme counting errors compared to the child and adult dyslexics. Finally, Bruck compared the phonics skills for both the dyslexic and normal child readers in grades one, two, and three to determine if phonics skills improve with reading level and age changes. The controls children improved in both phoneme deletion and counting skills while the dyslexic children did not have significant changes in phonetic tasks with increased grades and reading levels.

Recent fMRI evidence lends support to unimodal phonological theory. Shaywitz & Shaywtiz (2005) proposed that dyslexia is due to a deficit in lower order linguistic functioning, specifically phonologic coding, which blocks order processing of language. In fMRI studies, Shaywitz and Shaywitz observed underaction of the occipital temporal and superior temporal brain areas in dyslexic subjects compared to normal subjects during pseudoword reading. Using fMRI, Richards and Berninger (2008) observed abnormal connection in the brains of dyslexic children that disappeared after phonics remediation. Willis (2007) argues that the sampling of subjects from Shaywitz and Shaywitz (2005) was not sufficient to represent the heterogeneous cause of reading disabilities. Additionally, there was no evidence to support the theory that improved brain connectivity reflected an increase in phonemic awareness and could predict other facets of reading ability (reading comprehension and reading fluency).

Dyslexia: The Double Deficit Hypotheses

While reading disabilities had traditionally been attributed solely to defects in phonics, research has shown that other extra-phonological factors may be independently related to reading. One such factor is rapid automatized naming. Lovett (1967) attempted to classify 8-13 year old disabled readers based on accuracy with word reading (accuracy disabled) and rate of word reading (rate disabled). All readers in her disabled groups had IQ scores above 85, demonstrated underachievement in reading, and performed at least 1.5 levels below grade level in word recognition accuracy and rate tasks respectively. Normal reading controls were selected from surrounding school and age matched to the disabled readers as much as possible. The study included 32 children per group, 96 children total. All children in this study underwent extensive testing in achievement, intelligence, phonics, orthographic skills, and random automatized naming. Most testing included both an accuracy and rate of response component.

Lovett (1987) was able to successfully separate the disabled readers into the accuracy and rate impaired groups as evidenced by the fact that rate disabled readers performed significantly slower on the reading achievement tests used for this study compared to normal and accuracy disabled readers. Similarly, the accuracy disabled group had greater difficulty in accurately decoding single words compared to their rate disabled and normal reading counterparts. The various groups were analyzed using a three way analysis of variance analysis (ANOVA) comparing all three groups along with single ANOVAs in which the three groups were compared individually to each other. The performance of the disabled readers was significantly different for rate disabled readers compared to accuracy disabled readers on four out of the five tests of phonics skills with accuracy disabled readers having more difficulty in these skills. On three of these five phonics skills, the performance of normal and rate disabled readers did not differ significantly while the performance of the accuracy disabled readers was significantly worse than normal readers on four out the five phonics skills. Random automatized naming tasks were able to distinguish between normal and disabled readers, but only the rapid automatized naming task using letters was able to distinguish between rate disabled and accuracy disabled readers with accuracy disabled readers performing significantly worse than rate disabled readers. Performance on orthographic skills was significantly different for the two groups of disabled readers, and rate disabled readers were not significantly different from normal readers on two of the four orthographic skills. Accuracy disabled readers performed significantly worse than fluent normal readers on all task of orthographic skill. The accuracy disabled group performed worse overall on all skills compared to the rate disabled group.

Lovett's (1987) study cast doubt on the previous theory that phonics underlie all reading disabilities and helped opened the way to the double and triple deficit hypotheses. (Some phonetic skills were not significantly different in rate disabled readers compared to fluent normal readers.)

In two separate studies, Manis and colleagues attempted to determine experimentally whether two fundamental points in the double deficit hypothesis were true: symbol naming speed and phonics are independent contributors to the variance in reading skills in the population and naming speed is related to reading via orthographic processing. In the first study, Manis, Seidenberg, and Doi (1999) tested 67 second grade students with the full range of reading abilities on three measures of word reading - word identification (word ID - reading real words), word attack (nonsense word decoding), and reading comprehension. Manis et al. (1999) also tested phonics skills using the auditory analysis test (AAT - a test in which the child must delete a letter or syllable from a spoken word and repeat changed word back to experimenter); orthographic skills using an orthographic choice test, word likeness test, and exception word reading. After accounting for vocabulary skills, he determined the unique variance each phonics and rapid automatized naming skill contributed to all three word reading and orthographic skills tests. Using hierarchical regression analyses, he found that rapid automatized naming-letters and numbers correlated significantly with all orthographic and word reading tasks; exception word reading correlated most strongly with both rapid automatized naming- digits and rapid automatized naming - letters tasks. When RAN-digits was used in the analysis, sound deletion still contributed significantly to the variance in all three orthographic tasks; when he included RAN-letters in the task, sound deletion only contributed significantly to the variance in exception words.

Because the groups were small analysis of whether or not deficits in both phonics and rapid automatized naming led to more impaired reading skills compared to having a single deficit could not be determined, Manis, Doi, and Bhadha (2000) conducted a second study with seventeen additional second graders. In the second study, Manis et al. (2000) conducted similar analyses of rapid automatized naming, phoneme, and orthographic skills. In this study, rapid automatized naming-Letters contributed to the largest amount of variance in two of the three orthographic tasks; however, phoneme deletion contributed the greatest amount of variance to exception word reading and contributed a significant amount of unique variance to all three orthographic tasks.

Subjects for this study were also classified in four distinct reading groups based on a 25th percentile cut-off: phonemic awareness deficit (PD), naming speed deficit (NSD), double deficit (DD), and no deficit (ND). Members of the NSD group were classified based on their rapid automatized naming-Digits scores, but members did poorly on rapid automatized naming-Letter and rapid automatized naming-Picture tasks as well. Members of the NSD group did not perform worse than the other groups on orthographic tasks. The DD group performed significantly worse than the other groups in most tasks.

While the research of Manis et al. (1999, 2000) did not prove that children with deficits in rapid automatized naming also had deficits in orthographic skills; their work did show a difference between double deficit and single deficit readers.

Dyslexia: The Triple Deficit Hypothesis and Beyond

Badian (1997) attempted to determine whether or not the number of deficits in phonetic, orthographic and rapid automatized naming skills impacted the level of reading disability in dyslexics. Her study involved 90 children ages 6 to 10 separated into four different groups: poor readers (children with low verbal IQ and poor reading skills), good readers with low verbal IQs, younger readers with the good readings skills matched to the level of the poor readers and dyslexics, and dyslexics (readers with normal to high verbal and readings skills at least 1.5 standard deviations below expected based on verbal IQ.) Reading level for all of the children in this study was determined by single word reading on the word identification subtest of the Woodcock Reading Mastery Test-Revised. Phonetic skills for each study participant were evaluated using two different tests: the word attack subtest from Woodcock Johnson which involved the reading of non-words and the Test of Auditory Analysis Skills (TAAS) in which the child must say a word with an omitted phoneme. Orthographic skills were tested using the Jordan Left-Right Reversal Test (Jordan L-RRT) in which a child must determine which letters and numbers are written backwards. [This test was chosen because it correlated significantly with another well accepted test of orthographic skills, the homophonic orthographic choice test, in which the child must choose the correctly spelled word in a group of phonetically correctly spelled words (i.e. girl, gerl, or gurl).] Rapid automatized naming skills were assessed using times it took to name five items (numbers, letters, objects, and colors) randomly distributed in a set of 50. Verbal intelligence was assessed using the Wechsler Intelligence Scale for Children-Revised or Third Edition.

A multivariate analysis of the various tests determined that one test for each skill was most significant. For phonological skills, non-word reading skills were significantly better for the low IQ good readers, similar for the poor and younger readers while dyslexics were significantly worse than the other three groups of readers. For orthographic skills, the Jordan L-RRT showed significant differences in the groups; garden variety and low IQ good readers had similar scores while younger and dyslexic readers were significantly worse than these two groups. Finally, rapid automatized naming skills for the groups were most significantly differentiated using a combination of the alphabetical and numeric subsets; low IQ good readers were significantly better at this skill than both dyslexic and younger readers. Poor readers were also significantly better at this task than dyslexic readers.

From these results, several statements can be made. In the phonetic task, dyslexics were worse than poor readers and low IQ good readers despite having a higher IQ and were worse than younger readers despite being older; this suggests that IQ isn't enough when determining expected phonetic skills and phonetic skills may not be purely developmental in nature. In both the rapid automatized naming and orthographic tasks, younger children and dyslexic children displayed similar scores; this may indicate a developmental delay in these skills for dyslexic children. Orthographic skills are highly associated with print exposure which explains why younger readers have worse skills compared to poor and low IQ good readers; this does not explain why dyslexics perform poorly on these tasks compared to age matched readers with lower IQs. In terms of number of deficits, all groups had members with at least a single deficit. For the 24 younger readers, 36.6 percent had at least one deficit; seven (29.1%) readers had a single deficit (2 in rapid automatized naming and 5 in orthographic skills) while only two (8.3%) readers had a double deficit in the areas of rapid automatized naming and orthographic skills. The 15 low IQ good readers had the fewest members (26.7%) with any deficit; one (6.7%) member had a double deficit in the areas of rapid automatized naming and orthographic skills while three (20%) other members had single deficits (2 in rapid automatized naming and 1 in orthographic skills). Of the 22 poor readers, 72.7% had at least a single deficit; one member (4.5%) had deficits in all three areas (triple deficit) while eight members had a double deficit (5 in the areas of phonetics and rapid automatized naming, 2 in the areas of phonetics and orthographic skills, and one in the areas of rapid automatized naming and orthographic skills). Seven members (31.8%) of the poor readers group had a single deficit: two (9.1%) members in phonetics, four (18.2%) members in naming, and one member (4.5%) in orthographic skills. Finally, all members of the dyslexic group had a least one deficit; 14 (50%) of the dyslexic readers had a triple deficit. Ten (35.8%) dyslexic readers had double deficits (5 rapid automatized naming with orthographic skills and 5 rapid automatized naming with phonetic skills); the remaining four (14.2%) dyslexics had single deficits in the areas of orthographic (2 dyslexics) and phonetic (2 dyslexics) skills.

Finally, Badian (1997) assessed the discrepancy between reading skills and verbal IQ compared to the number of deficits present in all readers. She divided all readers into four groups of standard scores: poor readers were divided into below 80 and 80-85 while good readers were divided into 90-105 and 106 or higher standardized reading achievement scores (SRAS). Her results indicated that more impaired readers (reading standard score less than 80) were eight times more likely to have triple deficit (57% <80 SRAS compared to 7% 80-85 SRAS). The percentage of children with at least one deficit changed at each level. All children in the more impaired reading group (<80 SRAS) had at least one deficit while 88% of children in the less impaired (80-85 SRAS) reading group had at least one deficit. In the good readers group, 45% in the 90-105 SRAS group had at least one deficit compared to only 21% of >106 SRAS group.

Additionally, dyslexia is often associated with letter reversals in writing. There two main types of letter reversals - static and kinetic. **Static reversals** include true reversals (flipping letter on vertical meridian, for example confusing b and d), inversions (flipping letter on horizontal meridian, for example confusing b with p), and rotations (rotating letter, for example confusing b with q); while these distinctions exist, the term letter reversal is often used to signify any type of static reversal. **Kinetic reversals** involve the switching of letters within a word; a common example of this is confusing "was" with "saw." Letter reversals are common in younger children, but decrease with age. Children over the age of six are not expected to reverse letters: the presence of letter reversals in the writing of such children is often considered a warning sign for dyslexia. (Cairns & Steward 1970) Research (Willows & Terepocki, 1993) has supported this by finding that children with dyslexia require longer times to determine correct letter orientation in both **linguistic** (consisting of familiar letters and numbers) and non-linguistic object tasks. Some research has shown the ability to distinguish between **poor readers** (children who read below grade level and have low IQ) and **disabled readers** (children who read below grade level and have normal IQ) using letter reversal tasks (Fischer, Liberman, & Shankweiler, 1978).

Dyslexia: Early Processing

While it has been established to varying degrees that phonetic, orthographic, and random automatized naming skills are delayed in dyslexic readers, there are other, earlier primary sensory and motor deficits common to dyslexic readers. These include: eye movement anomalies, auditory frequency threshold insensitivity, and impaired random dot motion sensitivity.

Eye Movements in Reading

Most eye movement studies involve case reports in the mid to late 1900's when devices such as the ophthalmograph, a predecessor of the modern day Visagraph, gained popularity for studying eye movements during reading. Pavlidis (1978) recorded the reading eye movements for five different subjects of various reading levels and ages while they read age appropriate reading material. There were two adult readers in the study; one of these readers had dyslexia while the other reader had normal reading skills. The dyslexic adult made several more regression eye movements (reading from right to left) and fixations (period of eye stability when initial visual processing can take place); he also had a shorter average duration of fixation (time spent during each fixation) compared to the normal adult. There were three adolescent subjects in the study – two dyslexic children and one poor reader. Despite being older than one of the dyslexic readers, the poor reader spent less time fixating words, had fewer fixations, and had fewer regression eye movements. Several others have noted increased duration of fixation,

The presence of ocular motor irregularities in children with dyslexia has led some observers to theorize that ocular motor control is causative in dyslexia. Pavlidis (1981) studied the eye movements of normal and dyslexic readers who view lights which moved sequentially across computer monitor to the left or right. He observed that dyslexics were significantly more likely to make right to left movements when the lights were moving from left to right. This work could not be replicated by future studies (Stanley, Smith, & Howell, 1983). Rayner (1985) attributed this discrepancy to a high number of visual dyslexics in Pavlidis' (1981) sample. Rayner (1985) concluded that regression eye movements are caused by an underlying defect and are only a peripheral component of the reading process.

Duration of Fixation and Rapid Automatized Naming

Duration of fixation has also been linked to reading ability by rapid automatized naming. If early visual processing skills are impaired or slowed, then later processes such as rapid automatized naming may be impaired as well. Jones, Obregon, Kelly, and Branigan (2008) conducted a study which investigated the relationship between rapid automatized naming and duration of fixation. Twenty subjects with dyslexia and age matched control adult readers read different groups of letters that were designed to be phonetically or visual confusing; they also read similar sets of letters that included similar letter in a non-confusable arrangement. The times it took to read the whole set, read each individual letter with and without regressions, and the time it took to vocalize the letter compared to when the eye first stopped on the letter were compared in the dyslexic and non-dyslexic readers. The phonetic tasks included two sets - rime (b vs. v) and onset (k vs q) - which were adjacent in the "confusable" condition and separated in the "non-confusable" condition. The visual task included lowercase reversible letters (p, q, b, d) in the "confusable" condition and uppercase letters in the "non-confusable" condition. In the non-confusable condition, dyslexic readers were statistically slower than the non-dyslexic readers for all tasks. Additionally, the dyslexic readers were even slower compared to the non-dyslexic readers than expected in the confusable condition: visual whole trial naming time, onset time to vocalization, and visual time to vocalization. Dyslexic readers did not take statistically longer than expected in the confusable condition to read individual letters even when regressions were included in that time.

Reading and the M-Pathway

In addition to specific sensory and perceptual developmental deficits and brain laterality theories, the magnocellular theory of dyslexia is a well-known theory (Stein, 2001). The visual pathway consists of two main divisions – the magnocellular and parvocellular pathways. The magnocellular pathway (**M-pathway**) quickly encodes large visual details – fast motion, low spatial frequency objects, and general object information – and synapses in the ventral two layers of the lateral geniculate nucleus (LGN) of the thalamus. Conversely the parvocellular pathway (**P-pathway**), more slowly encodes small visual details including color, high spatial frequency objects, and detailed object information and synapses in the dorsal four layers of the LGN. The magnocellular theory of dyslexia holds that deficits in the M-pathway lead to poor reading skills.

In reading, the general shape of sight words would be encoded by the M-pathway; while identifying individual letters in words would be the domain of the P-pathway. Efficient readers are able to identify words by their general shape and quickly scan over basic sight words such as *and*, *but*, *the*, etc. It has also been suggested that letter position (not identity) is determined by the M-pathway (Cornelissen et al., 1998a).

Deficits in the M-pathway can also lead to slower reading by disrupting the reducing saccadic suppression, disrupting the normal timing differential between the M and P-pathways, and altering visual attention. **Saccadic suppression**, thought to the mediated by the M-pathway, allows information from each fixation to be processed separately by suppressing information between fixations. The M-pathway is faster than the P-pathway, and this timing differential allows the overall shape of the word to be processed first followed by individual letter details. If this timing is disrupted, reading is slowed; colored filters have been used to restore this timing difference and have been shown to be effective in increasing reading rate (O'Connor, Sofo, Kendall, & Olsen, 1990; Solan & Richman, 1990). Finally, **visual attention**, the ability to visually attend to one primary location and ignore competing information, is also mediated by the M-pathway (Stein & Walsh, 1997). Poor visual attention can lead to longer than expected durations of fixations when reading (Steinman, Steinman, & Garzia, 1996).

Physiologic testing of the M-pathway reveals deficits in children with reading disabilities (Steinman et al., 1996). Lehmkuhle, Garzia, Turner, Hash, and Baro (1991) found that the reading disabled children process low contrast objects significantly more slowly than normal readers. **Coherent motion** (appendix a, figure 5), an M-pathway task, evaluates an individual's ability to detect motion when varying percentages of dots are moving in a given direction while the remaining dots move in random directions (Talcott, Hansen, Elikem, Assoku, & Stein, 2002). Cornelissen et al. (1998b) found that coherent motion thresholds correlated significantly with letter errors during word reading even when no reading disabled children were included in the results.

In addition to functional studies, anatomy also supports the magnocellular theory. Livingstone, Rosen, Drislane, and Galaburda (1991) discovered that dyslexic readers have fewer and smaller cells in the ventral two layers of the LGN compared to the LGN of normal brains.

Dyslexia: Early Auditory and Visual Processing

Numerous studies have investigated the relationship between reading skills and early auditory and visual processing skills. Witton, Stein, Stoodley, Rosner, and Talcott (2002) evaluated the word reading, spelling skills, orthographic, and phonetic skills of 32 ten year old normal readers and compared these skills to their coherent motion thresholds and sensitivity to two distinct frequencies - 2 Hz and 240 Hz. When these early processing measures were compared to reading and spelling ability in a hierarchical regression analysis, sensitivity to the 2 Hz frequency explained the most variance in both reading and spelling ability. Coherent motion thresholds explained an additional 8% of the variance in spelling while sensitivity to the 240 Hz frequency contributed an additional 5% of the variance in word reading; both of these results were statistically significant. A multiple regression analysis of variance in phonetic processing found that sensitivity to the 2 Hz frequency explained 24% of the total variance; this was the only significant result. A similar analysis found that coherent motion alone explained a significant portion (20%) of the variance.

Cornelissen, Richardson, Mason, Fowler, and Stein (1995) compared the coherent motion thresholds of dyslexic and control readers and found significantly higher thresholds in the dyslexic group despite both groups being matched on age, intelligence, and functional vision skills.

Path Analysis and Structural Equation Modeling Reading Studies

Path analysis is traditionally defined as a statistical means of evaluating causal relationships in a model using a series of multiple regressions (Hair, Black, Babin, & Anderson, 2010). Path analysis allows for analysis of the relationships between variables in a model and evaluates the significance of these relationships. Additionally, various factors can be used to create one specific variable; this analysis is a more complex path analysis called structural equation modeling. Hierarchical regression which is often used in causality research evaluates the relative importance of each variable in a step-wise fashion removing the proportion of variance explained by each variable and determining how much variance the remaining variable(s) explain. Unlike hierarchical regression, path analysis allows relative weights of several different factors to be evaluated and the most important "path" or relationship can be determined in the presence of all other variables in the model; the "order" in which the variables are evaluated is irrelevant. Path analysis has been used for analysis for various experiments concerning vision research. Boets, Vandermosten, Cornelissen, Wouters, and Ghesquiere (2011) used path analysis to evaluate the relationship between coherent motion sensitivity and letter knowledge in a longitudinal study involving young readers in kindergarten and first grade. Bavelier, Toman, Hutton, Corina, Liu, and Neville (2000) used structural equation modeling (a more complex path analysis) to evaluate visual attention in normally hearing and deaf young adults.

Holland, McIntosh, and Huffman (2004) conducted a structural equation modeling analysis on normal readers using components of the Process Assessment of the Learner - Reading and Writing (PAL-RW) and Weschler Individual Achievement Test, Second Edition (WIAT-II) as variables in his model. The main outcome variable for Holland et al.'s study was single word decoding as measured by two factors - pseudoword decoding and word reading. The pseudoword decoding factor is a subtest on the PAL-RW in which the student phonetically reads non-words. Pseudoword decoding is often used alone in analysis of word readings skills in normal and dyslexic readers. The word reading factor is a subtest in the WIAT-II in which the student reads a list of real words and is graded on the accuracy pronunciation for each word. The definition of dyslexia often includes a deficit in both phonologic and single word decoding skills. Factors that were included in the phonological skills variable of Holland et al.'s model include the phonemes, syllable, and rimes subtest of the PAL-RW. Holland et al. also assessed the rapid automatized naming skills of his readers using both letters and numbers. Both skills are part of the PAL-RW and are evaluated by timing students while they read a group of random numbers or letters; while accuracy is recorded, the overall score is based on time to completion only. Finally, Holland et al. evaluated the visual processing skills of his normal readers using both the word choice and receptive coding subtests of the PAL-RW.

Each subtest loaded well on its respective factor with the lowest factor loading being 0.58 which is "good" according to the criteria specified by Comrey and Lee (1973).

In light of the prevailing double deficit hypothesis, Holland et al. sought to determine which two of the three factors - phonological, rapid automatized naming, and orthographic processing- best predicted word readings. Contrary to the popular theory that phonologic processing was the major factor in dyslexia with orthographic processing as a minor factor, Holland et al.'s best model showed orthographic reading as the best predictor of word reading skills with phonological processing serving as the second best predictor. Holland et al. also wanted to determine the best model for incorporating the link between rapid automatized naming and both phonological and orthographic processing. They constructed six different models. Only two of the six models demonstrated excellent fit. Model number six included rapid automatized naming contributing both directly and indirectly to word reading via orthographic and phonologic processing; however, the direct effect wasn't statistically significant with a meager coefficient of 0.03. The model which best described the data was model number four, in which rapid automatized naming only contributed to word reading indirectly mediated by both phonologic and orthographic processing. Interestingly, in Holland et al.'s model, orthographic processing contributed the most variance to word reading while rapid automatized naming (indirectly) contributed the second most variance to word reading; despite the popularity of phonologic processing as the major component to reading skills in dyslexics, it contributed the least variance to word reading in Holland et al.'s analysis.

In 1975, dyslexia was considered to be due to poor phonetic skills (Vellutino et al., 1975). Lovett (1987) challenged this hypothesis by purposing a separate rapid naming component was present in dyslexia in addition to poor phonetic skills. Wolf and Bowers (1999) established a double deficit hypothesis which had two main components – phonetic dysfunction and poor rapid automatized naming skills – and the presence of both deficits led to more impaired reading ability. Badian (1997) expanded on the double deficit adding orthographic dysfunction to the list of possible independent contributors to reading impairment in dyslexia. Finally, several additional causes of reading dysfunction have been seen in subjects with dyslexia including eye movement abnormalities and impaired coherent motion thresholds (Pavlidis, 1978; Cornellissen et al., 1995; Talcott et al., 2000).

The Pupil Project

The Pupil Project, corroboration between the Colleges of Optometry and Education and the University of Missouri-St. Louis, has conducted several studies regarding dyslexia research (Franzel et al., 2005, 2006, 2007; O'Brien et al., 2011). The program aims to aid in the identification and remediation of children with reading disabilities – especially those with significant visual processing deficits – by providing both achievement and intelligence testing in conjunction with visual perceptual, eye movement, and phonics testing. The population is unique in that it contains a high proportion of children with visual dyslexia. Often Pupil Project patients may have already received remediation services through special education in phonemic awareness. In spite of this intervention these children are still struggling with reading.

Hypotheses

Based on the previously mentioned studies, particularly those of Lovett (1987), Badian (1997), Holland et al. (2004), and past Pupil Project correlation studies (Franzel et al., 2005, 2006, 2007; O'Brien et al., 2011): we propose a three step hypothesis when studying the reading ability of Pupil Project participants:

1. When sight word vocabulary is used fixation characteristics including duration of fixation, number of fixations, and number of regressions should predict single word decoding skills.

2. In addition to phonetic processing and rapid automatized naming, the two main components of the double deficit hypothesis, orthographic processing should predict significant independent variance in single word decoding ability.

3. Orthographic processing in addition to phonologic processing and rapid automatized naming skills in Pupil Project patients will predict single word reading for subjects with dyslexia in a triple deficit pattern as first described by Badian (1997).

4. Duration of fixation will significantly contribute to variance in orthographic processing either directly or indirectly via rapid automatized naming.

Methods

Approximately 307 students completed the Pupil Project testing during the years of interest (2009-2013) while the Process Assessment of the Learner – Reading and Writing versions one and two PAL-I and PAL-II) were administered. The PAL, a battery of tests designed to test the reading and writing skills of school-aged children, includes phonologic, rapid naming, orthographic, and fine motor subtests which were normalized using the same population as the WIAT II&III (Berninger, 2007; Lyres, 2008). Of these 307 students, only children who were older than seven and a half and younger than thirteen and a half were included in the analysis. Children were required to display normal intelligence with an intelligence quotient (IQ) within one standard deviation of average (90-115) on the Stanford-Binet, 5th edition, Wechler Intelligence Scale for Children 3rd or 4th edition (WISC III or IV), or Kaufman Assessment Battery for Children, 2nd edition (KABC-2); brief versions of these intelligence tests were also included. Only children with a diagnosis of visual dyslexia or reading fluency were included in the study: children with dysgraphia or attention deficits were only included if they had concurrent visual dyslexia or reading fluency deficits. Children with cognitive deficits were not included in the analysis. All Pupil Project testing was conducted in the University Eye Center by highly trained pediatrics resident following a standardized protocol. They were supervised by the Chief of Pediatric Services during testing and subsequent analysis of testing results. Only children who had completed all of the tasks in the analysis were included. Individual patients were given a three digit code and de-identified prior to analysis by the investigator. Institutional Review Board approval was sought and received through the University of Missouri-St. Louis committee before the investigation began.

Orthographic Testing (PAL RW 1&2)

Receptive Coding (PAL RW I&2)

While receptive coding is considered and indeed is an orthographic task, children can still use other cues to determine the correct answer (Rathvon, 2004). In the receptive coding task, children are briefly shown a word, briefly shown a letter or group of letters, and asked if the letter or letters appeared in the word. The word is not spoken aloud, however, each word is a real word and good phonics skills can be used in the place of orthographic skills in answering whether or not the letter(s) were present. (Sample items for this task include good/f, well/e, well/a, them/n.) In the second receptive coding task, children are shown a word and asked if the following word is the same. (Sample items for this task include then/them, careful/cairful, quarter/quieter, from/from, well/wall.)

Sentence Sense (PAL- RW I&2)

The sentence sense test (appendix a, figure 6) is the broadest measure of orthographic skills on the PAL-RW (Lyres, 2008). Children are shown three sentences and asked which sentence makes the most logical sense. Incorrect sentences may contain letter reversals (kinetic and/or static) or homophones (words that sound the same but don't have the same spelling and/or meaning). While sentence sense tests orthographic skills, semantics (word meanings), contextual analysis, and phonics skills are also involved in determining which sentences make sense.

Word Choice (PAL RW I&2)

Given the nature of the task, word choice can be seen as the purest measure of orthographic skills among the three variables (Rathvon, 2004). Children are presented with three different alternative spelling of the same word and asked to choose the correct spelling. The alternate spellings of the word are phonetically correct, and only the visual appearance of the word and the child's ability discern the correct spelling (appendix a, figure 4).

Phonologic Testing

Phonemes (PAL RW I&2)

The phonemes task is the more difficult of the two chosen phonologic tests on the PAL-RW (Franzel, 2013). The examiner says a word which the child must repeat. The examiner then repeats the same word with a missing phoneme. The child repeats the modified word and then is asked which sound was removed from the word (appendix a, bottom half of figure 2).

Syllables (PAL RW I&2)

In syllables, the child is responsible for removing a sound from the real or fabricated word. The examiner says a word, and the child is asked to say the word with a given syllable omitted. The omitted syllable is often the beginning or ending of the word (appendix a, top half of figure 2).

Rapid Naming Testing – Pictures, Numbers, and Letters

Rapid Naming – Pictures (Dyslexia Early Screening Test)

The rapid naming subtest of the dyslexia screening test evaluates a child's ability to quickly naming pictures. The test consists of twenty different common animals or objects arranged in eight rows of five. Each animal and/or object appears twice (appendix a, top left figure 3).

Rapid Naming – Numbers (Developmental Eye Movement Test)

The developmental eye movement test was designed to assess a child's ability to rapidly name both vertically and horizontally arranged numbers. While not traditionally considered a rapid naming test, the first part of the test requires the child to rapidly name four randomly arranged columns of 20 single digits. The times are recorded and times are standardized by age (appendix a, top right figure 3).

Rapid Automatized Naming – Letters (PAL-RW 1&2)

The rapid automatized naming – letters subtest assesses the child's ability to rapidly name letters arranged randomly in three separate rows. The letters used in this task include the following: h, n, a, o, t, f, u, w, b, d, . Errors in naming are noted, but are not used to influence the score for this subtest. Errors for the subtest are recorded as a separate score (appendix a, bottom half of figure 3).

Fixation Data (Visagraph)

The Visagraph (appendix a, figures 7 and 8) is an infrared eye tracker similar to the ophthalmograph used by Pavlidis (1978). The device tracks eye movements during reading and records various reading parameters including average duration of fixation, number of fixations per 100 words, number of regressions per 100 words, time spent reading from right to left, average words read per fixation, and reading rate while factoring comprehension. The child reads a passage knowing he or she will be asked to answer ten true or false questions after reading. The goal is to read quickly but still retain the information read.

Statistical Methods

Correlation Analysis

One of the most basic statistical analyses used to establish a relationship between two variables is the correlation analysis. The Pearson's R correlation coefficient is used to determine if two variables vary together; however, correlation analysis cannot be used to imply a causal relationship exist between the two variables. In other words, a strong correlation (large Pearson's R value) does not mean that one variable causes the other variable to change. While useful for establishing relationships between variables, simple correlation analyses have limited value in analyzing the types and/or dynamics of the relationships that exists between variables.

Multiple Regression Analysis

Regression analysis evaluates the degree to which one variable or variables influence another variable. In a multiple regression analysis, several independent variables influence one dependent variable. Multiple regression generates a correlation coefficient similar to the one calculated in correlation analysis; however, this correlation is for several variables. The square of the Pearson's R (R squared) indicates the amount of the variation in the dependent variable that is explained by the group of independent variables. Each independent variable contributes to this R squared value; the degree to which one variable contributes to this value can be evaluated using either semi-partial or partial correlations. The semi-partial correlation represents the unique variance contributed by one independent variable compared to all of the variance in the dependent variable, while the partial correlations is a measure of the unique variance from one independent variable compared to the part of the dependent variable that is not explained by any of the other independent variables. The squared partial correlation for an independent variable reflects the decrease in the overall R squared if that variable had not been included in the analysis. Additionally, multiple regression analysis calculates a beta coefficient for each independent variable which can be used in conjunction with a constant term (also included in the analysis) to generate an equation which will predict the value for a dependent variable given values for all the independent variables. (For a simple regression analysis with only one independent variable, the beta coefficient is the Pearson's R correlation coefficient for the independent and dependent variable.) Multiple regression analysis requires at least thirty observations and five times as many observations as independent variables (Hair et al., 2010).

Sequential Regression Methods

In addition to simple and multiple regression analysis, sequential methods can also be used to determine which factors are most important in the regression analysis or model. In forward addition regression analyses, variables are added one by one to the multiple regression model according to strict statistical criteria. The first variable added to model is the statistically significant independent variable with the high partial correlations (this variable would be expected to generate the largest initial R squared). With each step, a new independent variable with the highest partial regression is added to the analysis until there are no statistically significant variables remaining. Once a variable is added to the model, it cannot be removed even if it is no longer statically significant after the addition of other variables. Backward elimination analysis similarly uses partial correlations to determine which variable to delete from a model. The initial model contains all of the independent variables of interest; the statistically non-significant variable with the smallest partial regression coefficient is removed at each step until all of the remaining variables contribute significantly to the model. Once a variable is removed from the equation, it cannot be reinserted even if it would have contributed significantly to the model. Stepwise multiple regression is very similar to forward regression; however, the whole model is evaluated at each step, and any variable in the model that loses statistical significance during the analysis is removed unless it becomes significant again. The final model includes only those variables which contributed significantly to the dependent variable in the presence of the preceding variables in the model. Stepwise procedures can be used to generate a very parsimonious (explained with the fewest variables) models. Stepwise regression analyses require at least fifty cases, and one hundred or more cases are preferred (Hair et al., 2010).

Exploratory Factor Analysis

Exploratory factor analysis (EFA) is a statistical technique that utilizes simple correlations in order to group several different variables into a more compact list of factors. These correlations are used to group variables into common factors; the correlation between a variable and individual factor is called a factor loading. EFA can be used to determine the structural relationships between variables before conducting a confirmatory analysis such as confirmatory factor analysis (CFA) or a more detailed structural equation model (Gerbing & Hamilton, 1996). According to Hair et al. (2010), factor analysis should not be considered when there are fewer than fifty cases, and an analysis containing one hundred or more cases is ideal. A large number of cases can lead to excess type one error (finding significance when it is not truly present). An initial EFA typically yields confusing results; however, and either an orthogonal (the individual variables are not correlated) or oblique (the individual variables within each factor are correlated) rotation must be employed to clean up the analysis (Spicer 2005). The number of factors extracted or determined by the analysis can vary by method; however, it is generally acceptable that a solution with more factors is better than a solution with fewer factors as long as the solution makes sense and does not lead to cross loading (variables loading significantly onto the multiple factors) (Comrey & Lee, 1973, Hair et al., 2010).

Structural Equation Modeling

Path analysis (figure 1 left side) uses regression analyses to determine the relation between variables in a path diagram in which several variables are inter-related. Variables within a path diagram can serve as both independent and dependent variables in the same model. Path diagrams can be used to model relationships where one variable is related to another through a different third variable; these are called indirect effects. Indirect effects can be evaluated by regression analysis; however, path analysis is a much simpler method and provides better analysis of statistical significance. Additionally, unlike regression analyses, path analysis contains an error term which helps account for measurement and/or procedural errors in each of the model's observed variables.

While some consider path analysis to be the most basic form of structural equation modeling (SEM), path analysis does not utilize latent variables, a key feature in most forms of SEM (Raykov & Marcoulides, 2006, Hair et al., 2010). Latent variables (figure 1 right side) are not directly observed; rather, they are factors which are made of observable variables. Often SEM is used in behavioral research to define a concept that cannot be directly measured such as happiness or job satisfaction. Questionnaires or multiple different tests are used to define each factor. Like path analysis, SEM also allows for easy analysis of variables that act as both independent and dependent variables in the same model and accounts for error in observed variables. In dyslexia research, the latent variables in SEM can used to determine overall skills in the several key areas: orthographic processing, phonologic processing, rapid automatized naming, and early visual processing including fixation duration and patterns. SEM with latent variables can be useful for incorporating several tests into one factor rather than conducting a simple path analysis in which each variable is considered individually. The initial SEM model and latent variables should be determined using theory and past research including technique such as exploratory factor analysis.

Using the most common model estimation technique, maximum likelihood estimation, SEM can generate valid results with only fifty cases. (Hair et al., 2010) More cases are recommended especially when there are several cases with missing data. SEM is very sensitive to missing data and any cases with missing information must be eliminated, or the missing variables must be replaced with mean values or imputed (calculated). The absolute value for the loadings of each variable onto a latent variable should be at least 0.6 but not larger than one. Factor loadings above 0.70 are preferred; loadings greater than one indicate possible multicollinearity problems (too much inter-relationship between variables) and should be removed from the analysis. (Hair et al 2010. An overall SEM analysis can be analyzed using several goodness of fit variables – chi-square (CS, should be non-significant), root means squared error of approximation (RMSEA, should be less than 0.08), standardized root mean residual (SRMR, greater than 0.1 indicates a poor fit), and the comparative fit index (CFI, greater 0.95 usually indicates a good fit) (Raykov & Marcoulides, 2006; Hair et al., 2010). Models with several variables and large sample sizes (>250 observations) are subject to less rigid standards while smaller models must show good fit using several goodness of fit indices before being considered a viable model. (Hair et al., 2010)

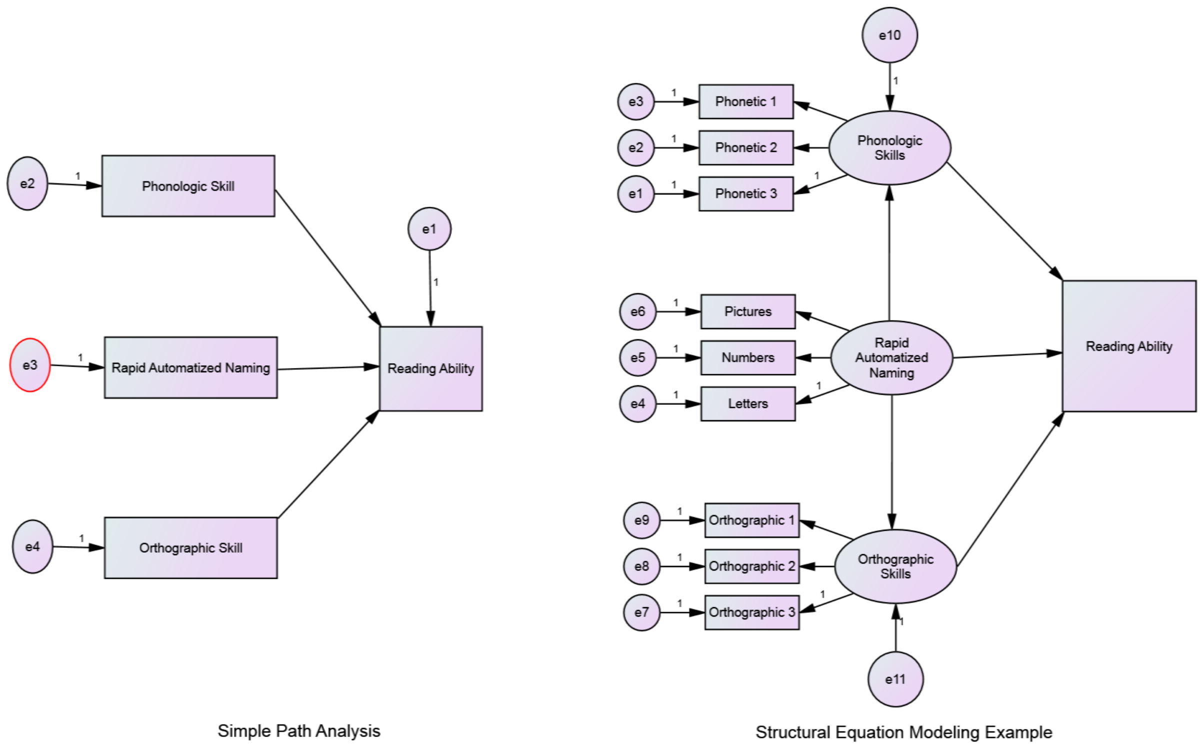


Figure 1 – Structural equation modeling. Simple path diagram (*left*) and more complex structural equation model (*right*).

Assumptions and Outliers

Before performing any multivariate analyses, the following four assumptions must be tested:

1. The data is linearly distributed.
2. There is equal error variance in the data.

3. The error terms are independent.
4. The data is normally distributed.

The first three assumptions were tested by examining the partial regression plots for each variable for linear distribution, spread in the data (heteroscedasticity), and consistent patterns; no violations to the first three assumptions were detected. The final assumption was evaluated using the SAS cqplot macro which evaluates multivariate normality; multivariate outliers were removed until the data conformed to multivariate normality. Following the removal of multivariate outliers, seventy-four cases remained in the data set.

Results

Using theory and past research (Holland 2004, Brooks, Franzel, Garzia, 2012), a structural equation model (figure 2) was designed. Holland's (1996) best fit model showed that rapid automatized naming skills influence both phonetic and orthographic processing while previous research with the Pupil Project (Brooks et al, 2012 Franzel et al., 2005, 2006, 2007; O'Brien et al., 2011) has established a relationship between duration of fixation and rapid automatized naming skills as illustrated by the model.

In order to test the first hypothesis - duration of fixation, number of fixation, and number of regressions will predict word decoding skills – a fixations factor was constructed with a path to one minute reading. The fixation factor included duration of fixation, number of fixations, and number of regressions from Visagraph testing. The second hypothesis, that orthographic processing will predict word decoding skills, was tested by constructing an orthographic factor with a path to one minute reading. The orthographic factor was created using receptive coding, sentence sense, and word choice subtests of the PAL-RW I&II. The third hypothesis, which stated that orthographic processing, phonetic processing and rapid automatized naming will predict single word reading in a triple deficit pattern, was tested by drawing additional paths between a phonologic skills factor and a rapid automatized naming factor. The phonologic skills factor included phonemes and syllables from the PAL-RW I&II; while the rapid naming factor was created using rapid naming (from the DEST - pictures), vertical time on the DEM (numbers), and the rapid automatized naming- letters (RANL – letters) subtest from the PAL-RW I&II. The final hypothesis that duration of fixation will indirectly contribute significant variance to word reading was tested by drawing a path between duration of fixation and the rapid automatized naming factor.

Unfortunately, the initial model contained several problems including poor factor loadings (loadings less than 0.6), multi-collinearity problems (loadings greater than one), and non-significant paths; the model needed to be changed (respecified). Respecifying the model by eliminating variables with non-significant or problematic loadings could lead to a better but less generalizable model (Hair et al., 2010). Instead, the data was analyzed using correlation analysis, stepwise multiple regression analyses, and exploratory factor analysis. The different analyses were used to determine which variables could best be used to best define each factor in the respecified path diagram.

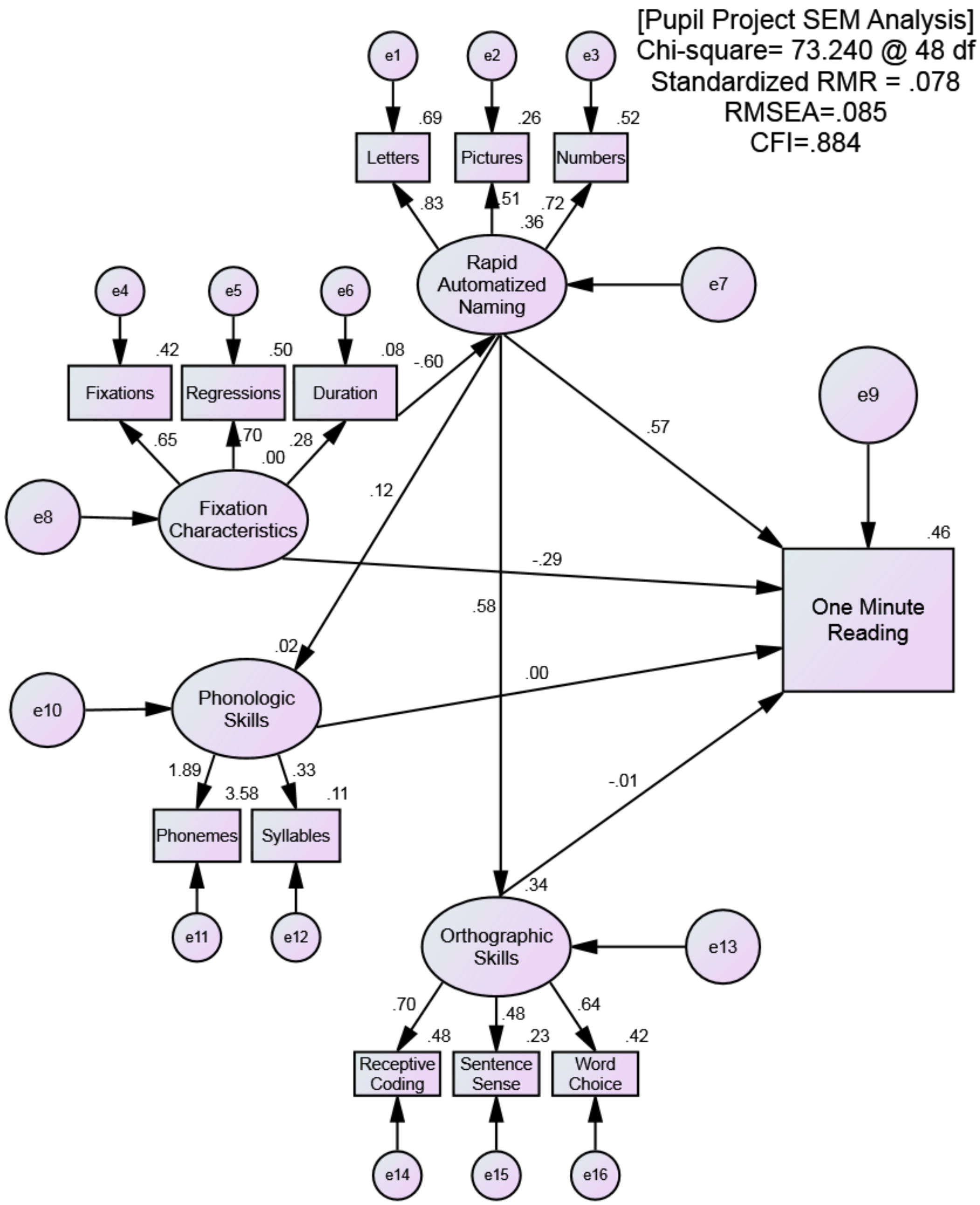


Figure 2 – Initial All-Inclusive model. SEM with four latent variables.

Correlation Analysis

A simple bivariate correlation analysis (figure 3) was used to determine which variables were significantly correlated with one minute reading ability and which variables were significantly correlated with other related skills. Age and IQ were included in the analysis in order to determine if there was any significant relationship between them and any other variable. Standardized scores and percentiles were used for each variable; however, both phonetic skills – phonemes ($r=-0.425$, $p<0.001$) and syllables ($r=-0.433$, $p<0.001$), sentence sense ($r=-0.337$, $p<0.001$), and, to a lesser degree, vertical DEM scores ($r=-0.245$, $p=0.036$) were significantly correlated with age. The orthographic skills – receptive coding, sentence sense, and word choice – correlated significantly with each other; similarly syllables and phonemes ($r=0.625$, $p<0.001$) were significantly correlated. The rapid naming skills – RANL, vertical DEM time, and rapid naming – correlated significantly with each other, duration of fixation, and two of the orthographic skills – word choice and receptive coding. Two of the three rapid naming skills – DEM vertical time ($r=0.462$, $p<0.001$) and RANL ($r=0.497$, $p<0.0001$), – all of the fixation skills (duration $r=-0.558$, $p<0.001$; fixations $r=-0.286$, $p=0.014$; regressions $r=-0.285$, $p=0.014$), and word choice ($r=0.464$, $p<0.0001$) correlated significantly with one minute reading; full scale IQ also correlated significantly with one minute reading ($r=0.265$, $p=0.023$).

	Age	IQ	DFD	Fix2	Reg.	RC	SS	WC	Pho	Syll.	RANL	RN	VT	OMR
Age	1													
FSIQ	-.062	1												
DFD	.006	-.281*	1											
Fix2	.088	-.051	.147	1										
Reg.	-.144	-.167	.166	.470**	1									
RC	-.133	.131	-.166	-.173	-.085	1								
Sent.	-.337**	.210	-.239*	-.088	-.019	.360**	1							
Word	.007	.290*	-.365**	-.171	-.154	.442**	.290*	1						
Phon.	-.425**	.134	-.179	-.132	.062	.213	.201	.050	1					
Syll.	-.433**	.154	-.109	-.195	.098	-.083	.140	-.045	.625**	1				
RANL	-.198	.100	-.445**	-.258*	-.108	.368**	.188	.345**	.165	.039	1			
RN	-.105	.019	-.316**	-.093	-.162	.239*	.094	.143	.100	.064	.468**	1		
VT	-.245*	.186	-.398**	-.160	-.251*	.263*	.187	.121	.210	.049	.621**	.379**	1	
OMR	.019	.265*	-.558**	-.286*	-.285*	.104	.132	.464**	.080	-.086	.497**	.222	.462**	1

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

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

Figure 3 – Correlation Analysis. Correlation analysis of pupil project variables.

Stepwise Regression Analysis

Stepwise multiple regression analyses were conducted using the individual variables that loaded on each latent variable in the previous SEM analysis to determine if the unique contribution from each variable significantly correlated with one minute reading. To determine if the significant results in the initial step down analysis could be explained by a combination of age and full scale IQ, a second stepwise analysis that controlled for age and IQ was completed for each set of variables. Simple regression analyses were also included for model comparison purposes.

Neither of the phonics tasks (figure 4, model #4) contributed significantly to variation in one minute reading in a stepwise analysis. In a simple multiple regression analysis (figure 4, model #3), both phonemes (partial squared = 0.029) and syllables (partial squared = 0.031) contributed a nearly equal portion of individual variance to the model.

Model	Model Variable(s)	R squared	Adjusted R^2	R^2 Change	Standard Beta	t statistic	significance
1	Phonemes	0.006	-0.007		0.080	0.680	0.499
2	Syllables	0.007	-0.006		-0.086	-0.736	0.464
3	Syllables, Phonemes	0.037	0.010				
	Phonemes			0.029	0.220	1.472	0.146
	Syllables			0.031	-0.223	-1.498	0.138
4	Syllables, Phonemes	No variables					

Figure 4 – Phonetic regression analysis. – Phonetic single and stepdown regression analyses. *Note R^2 change, partial regression coefficient squared, indicates the change in overall R^2 if that variable is removed from the analysis.

In a stepwise regression of the rapid naming skills (figure 5 model# 8), only RANL (partial squared=0.071, p=0.010) significantly predicted the variance in reading. DEM vertical time approached significance (partial squared=0.038, p=0.054). In a second step-down analysis controlling for age and full scale IQ, RANL still significantly regressed onto one minute reading (partial squared=0.078, p=0.005) and DEM vertical time still approached significance (partial squared= 0.035, p=0.060).

Model	Model Variable(s)	R squared	Adjusted R^2	R^2 Change*	Standard Beta	t statistic	significance
5	Rapid Naming	0.049	0.036		0.222	1.923	0.057
6	Vertical Time	0.214	0.203		0.462	4.424	<0.001
7	RAN-Letters	0.247	0.236		0.497	4.854	<0.001
8	RANL, VT	0.285	0.265				
	RAN-Letters			0.071	0.341	2.664	0.010
	Vertical Time			0.038	0.251	1.958	0.054
9	Age,IQ,RANL, VT	0.345	0.307				
	Age			0.025	0.162	1.609	0.112
	Full Scale IQ			0.036	0.194	1.954	0.055
	RAN-Letters			0.078	0.358	2.876	0.005
	Vertical Time			0.035	0.243	1.911	0.060

Figure 5 – Rapid Naming Regression Analysis. Rapid naming single and step-down regression analyses. *Note R^2 change, partial regression coefficient squared indicates the change in overall R^2 if that variable is removed from the analysis.

Only word choice (r squared=0.215, p<0.001) was significant in the step-down analysis of one minute reading with orthographic skills (figure 6, model #13). Additionally, in a step-down analysis controlling for age and full scale IQ (figure 6, model #14), word choice remained significant (partial squared=0.163). Receptive coding (partial squared= -0.016, p=0.292) and sentence sense (partial squared=0.0002, p=0.896) failed to approach significance at a level of p<0.10.

Model	Model Variable(s)	R squared	Adjusted R^2	R^2 Change	Standard Beta	t statistic	significance
10	Receptive Coding	0.011	-0.003		0.104	0.887	0.378
11	Sentence Sense	0.017	0.004		0.132	1.13	0.262
12	Word Choice	0.215	0.204		0.464	4.443	<0.001
13	Word Choice	0.215	0.204		0.464	4.443	<0.001
14	Age,IQ, Word Choice	0.234	0.202				
	Age			0.001	0.025	0.242	0.810
	Full Scale IQ			0.019	0.144	1.319	0.192
	Word Choice			0.163	0.422	3.86	<0.0004

Figure 6 Orthographic Regression Analysis – Orthographic single and step-down regression analyses. *Note R^2 change, partial regression coefficient squared indicates the change in overall R^2 if that variable is removed from the analysis.

For the step down analysis of fixation variables (figure 7, model #18), duration of fixation (partial squared=0.271, p<.0001) and number of fixations (partial squared=0.042) significantly predicted variance in one minute reading. These results were also found when the analysis was controlled for age and full scale IQ (duration: partial squared=0.220, p<0.001 and number of fixations: partial squared=0.043, p=0.033). While regressions were significant in the single regression analysis, they failed to approach significance in the step down analysis (partial squared=0.013, p=0.344)

Model	Model Variable(s)	R squared	Adjusted R^2	R^2 Change	Standard Beta	t statistic	significance
15	Duration of Fixation	0.311	0.302		-0.558	-5.704	<0.001
16	Number of Fixations	0.082	0.069		-0.286	-2.531	0.014
17	Regressions	0.081	0.069		-0.285	-2.525	0.014
18	DFDev2, Fix2	0.354	0.335				
	Duration of Fixation			0.271	-0.527	-5.465	<0.001
	Number of Fixations			0.042	-0.208	-2.158	0.034
19	Age, IQ, DFDev2, Fix2	0.368	0.332				
	Age			0.023	0.048	0.502	0.618
	Full Scale IQ			0.013	0.119	1.187	0.239
	Duration of Fixation			0.220	-0.494	-4.902	<0.001
	Number of Fixations			0.043	-0.211	-2.176	0.033

Figure 7 – Visagraph Regression Analysis – Visagraph parameters single and step-down regression analyses. *Note R^2 change, partial regression coefficient squared indicates the change in overall R^2 if that variable is removed from the analysis.

Finally, the variables from each set of analyses were entered into a stepwise equation which controlled for age and IQ. All of the non-phonetic variables were significant predictors at some point during the analysis, but RANL (partial=0.013, p=0.360) was not included in the final model (figure 8, model #21). RANL was added in the second step of the seven step model; however, it was no longer significant (partial=0.020, p=0.252) when DEM vertical time entered at the fifth step of the model. Number of fixations (partial squared=0.022, p=0.092) only approached significance in the seventh step of the model (figure 8, model #21). Duration of fixation (partial squared=0.065, p=0.004) was the largest contributor in the age and IQ controlled analysis, followed by word choice (partial squared=0.063, p=0.005), DEM vertical time (partial squared=0.071, p=0.003), and finally fixations. Syllables (partial squared=0.033 , p=0.138) did not approach significance, however, it would have been the next variable added to the model. RANL and phonemes (partial squared=0.0025, p=0.687) did not significantly contribute to the final model.

Model	Model Variable(s)	R squared	Adjusted R^2	R^2 Change	Standard Beta	t statistic	significance
20	Age, IQ, DFDev2, WC, VT	0.472	0.434				
	Age			0.009	0.100	1.090	0.280
	Full Scale IQ			0.001	0.037	0.396	0.694
	Duration of Fixation			0.069	-0.311	-2.990	0.004
	Word Choice			0.075	0.300	3.099	0.003
	Vertical Time			0.080	0.320	3.201	0.002
21	Age, IQ, DFD, WC, VT, Fix2	0.494	0.449				
	Age			0.011	0.109	1.211	0.230
	Full Scale IQ			0.002	0.042	0.455	0.651
	Duration of Fixation			0.065	-0.302	-2.940	0.004
	Word Choice			0.063	0.278	2.881	0.005
	Vertical Time			0.071	0.303	3.061	0.003
	Number of Fixations			0.022	-0.153	-1.708	0.092

Figure 8 – Final Regression Analysis. Overall step-down regression analyses. *Note R^2 change, partial regression coefficient squared indicates the change in overall R^2 if that variable is removed from the analysis.

Exploratory Factor Analysis

An initial exploratory factor analysis using principle component analysis and an oblique rotation was conducted on the variables that were significant in a step down analysis, the variables that approached significance in step down analysis, and the phonetic variables – duration of fixation, word choice, RANL, DEM vertical time, number of fixations, phonemes, and syllables. A four factor solution was specified since four different categories were expected – phonologic, rapid naming, orthographic, and fixation variables. In the resulting solution (figure 9), fixations and duration and fixation failed to load on the same factor, and duration of fixation loaded with the same factors as word choice and the rapid naming skills. The rapid automatized naming variables, DEM vertical time and RANL, loaded on the same factor; the phonetic skills also loaded together. A second analysis was conducted specifying a five factor solution (figure 10). There was no cross loading in the second analysis. DEM vertical time (0.917) and RANL (0.873) loaded on the first factor while syllables (0.905) and phonemes (0.898) loaded together on the second factor. Word choice (-0.986), duration of fixation (0.994), and number of fixations (0.997) loaded on the third, fourth, and fifth factors respectively.

Structure Matrix

	Component			
	1	2	3	4
DEM Vertical Time	**.913**	.158	-.141	-.085
RAN-Letters	**.846**	.110	-.432	-.244
Syllables	.031	**.900**	.013	-.193
Phonemes	.227	**.897**	-.091	-.063
Word Choice	.185	-.008	**-.926**	-.179
Duration of Fixation	***-.596***	-.222	***.666***	.001
Number of Fixations	-.193	-.177	.168	**.982**

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Figure 9 – Four factor EFA. Numbers in **bold** indicate appropriate factor loadings. Numbers in ***bold italics*** indicate cross-loading of variables.

Structure Matrix

	Component				
	1	2	3	4	5
VT	**.917**	.142	-.057	-.120	-.394
RANL	**.873**	.102	-.402	-.262	-.415
Phonemes	.228	**.905**	-.063	-.087	-.153
Syllables	-.001	**.898**	.081	-.231	-.140
WordChoice	.217	-.001	**-.986**	-.166	-.348
Fix2	-.196	-.170	.160	**.994**	.149
DFDev2	-.431	-.150	.335	.139	**.997**

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

Figure 10 – Five factor EFA. Numbers in **bold** indicate appropriate factor loadings.

SEM Analyses

Modification of the Original

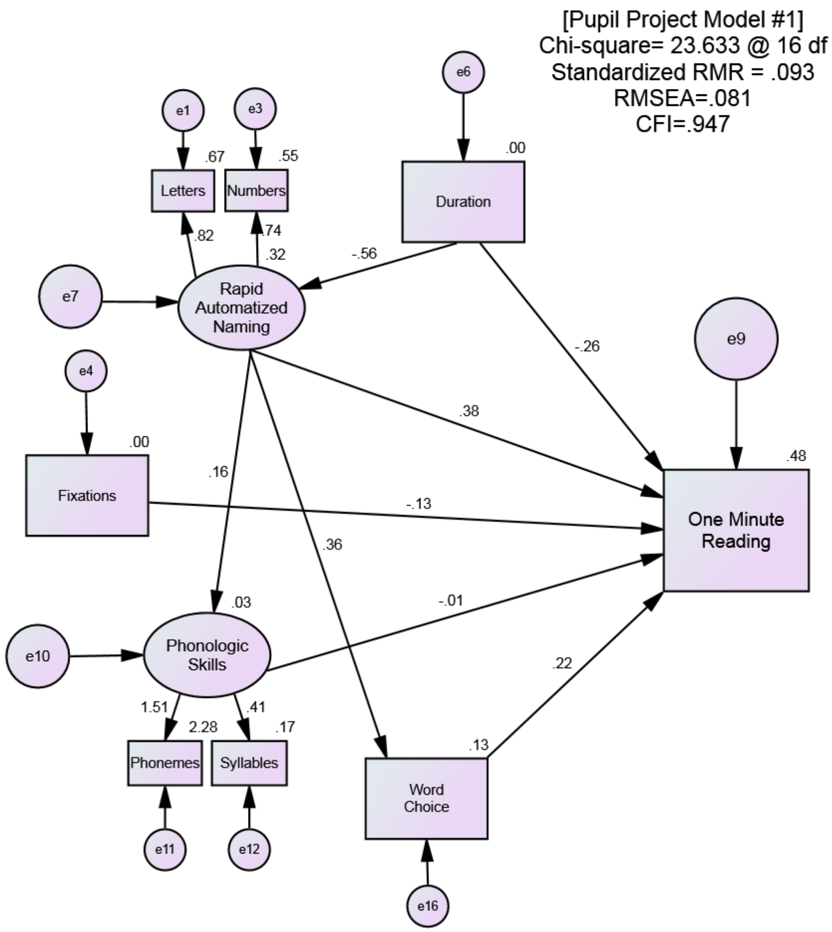
Given the results of the multiple regression and exploratory factor analyses, a five factor model (figure 11) was constructed with only two latent variables – rapid automatized naming (DEM vertical time - numbers and rapid automatized namingL-letters) and phonologic skills (phonemes and syllables). Phonologic skills were included in the analysis despite their lack of significance in the earlier analysis because the phonetic component in reading disabilities is well established in the literature (Vellutino et al., 1975; Bruck 1992). Duration of fixation, number of fixations, and word choice were included as observed variables.

To test the first hypothesis that fixation characteristics will predict variance in word reading, two separate paths were constructed. Given the results of correlation and regression analysis, duration and fixation were considered individual factors with individual paths to one minute reading. The second hypothesis – orthographic skills will explain variance in single word decoding – was tested using only word choice as the orthographic variable. (Receptive coding and sentence sense were not found to be significant predictors or word decoding). The third hypothesis which predicted a triple deficit pattern in which phonologic, rapid naming, and orthographic skills will significantly predict word decoding skills in the presence of each other was tested by constructing additional paths between the rapid automatized naming factor and syllables. (Phonemes was not included in the analysis because earlier factor loadings onto the phonologic skills factor were poor and/or erroneous). Finally, the second part of the fourth hypothesis that duration of fixation will indirectly predict orthographic skills through rapid naming was tested by drawing a path between duration of fixation and rapid automatized naming and a path between rapid automatized naming and word choice. The path between rapid automatized naming skills was included in support of Holland et al.'s previous research.

The resultant model explained 48 percent of the variance in word reading and had a non-significant chi-square (CS=23.633 @ 16 degrees of freedom, $p<0.05$). The other overall fit variables standardized RMR (SRMR=0.0927), RMSEA (0.081), and CFI (0.947) also indicate the model shows adequate fit given the data; however, the model contained several non-significant paths and a factor loading which was larger than one.

A new model (figure 12), constructed to eliminate the erroneous loading, included only one latent variable, rapid automatized naming. The phonologic skills latent variable was replaced with the observed variable, syllables, and the non-significant path between rapid automatized naming and phonologic skills was removed. (Syllables was chosen as the phonologic variable of choice because it did not contain an erroneous loading and would have been the next factor included in the step wise final analysis conducted previously.) All of the paths in the model were significant or approached significance ($p<0.1$), and the model explained 50 percent of the variance in one minute reading. The new model had a non-significant chi-square (CS=19.623 @ 12 degrees of freedom, $p<0.05$). Only the SRMR (0.0992) indicated that the model fit was acceptable. The CFI (0.932) and RMSEA (0.093) suggested that the model poorly fit the data.

Given the previous model's poor fit, a final model (figure 13) was constructed after eliminating the variables (fixations and syllables) with paths that approached significance. This final model explained 48 percent of the variance in word reading, contained only significant paths ($p<0.05$), but had a significant chi-square (CS=9.241 @ 3 degrees of freedom, $p>0.05$). The fit variables RMSEA (0.169) and CFI (0.941) also indicated a poorly fitting model. The SRMR did not indicate a poor fit.

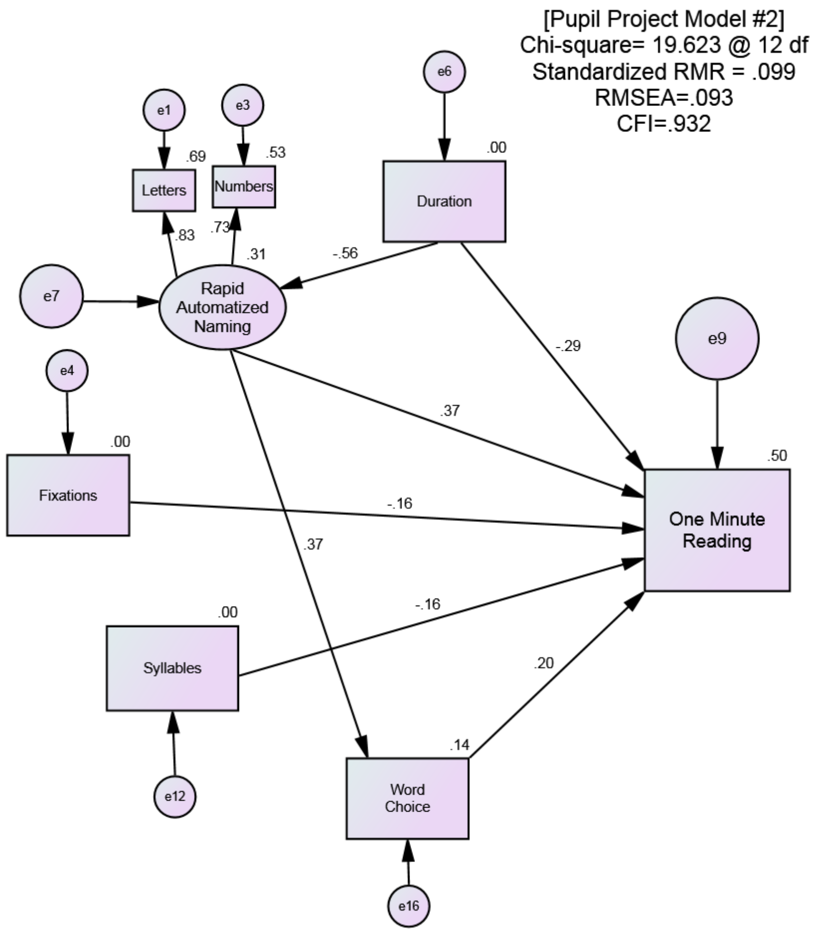


Path	Correlation Coefficient	Probability
RAN --> Duration of Fixation	-0.563**	**<0.001**
Word Choice --> RAN	0.365**	**0.006**
Phonetic --> RAN	0.159*	*0.068*
One Mintute Reading --> Phonetic	-0.013	0.821
One Minute Reading --> RAN	0.385**	**0.010**
One Minute Reading --> Fixations	-0.132	0.129
One Minute Reading --> Word Choice	0.221**	**0.023**
One Minute Reading --> Duration	-0.260**	**0.025**

Figure 11 – Modified SEM: Model #1

****.Path is significant at the 0.05 level.**

**.Path is significant at the 0.1 level.*

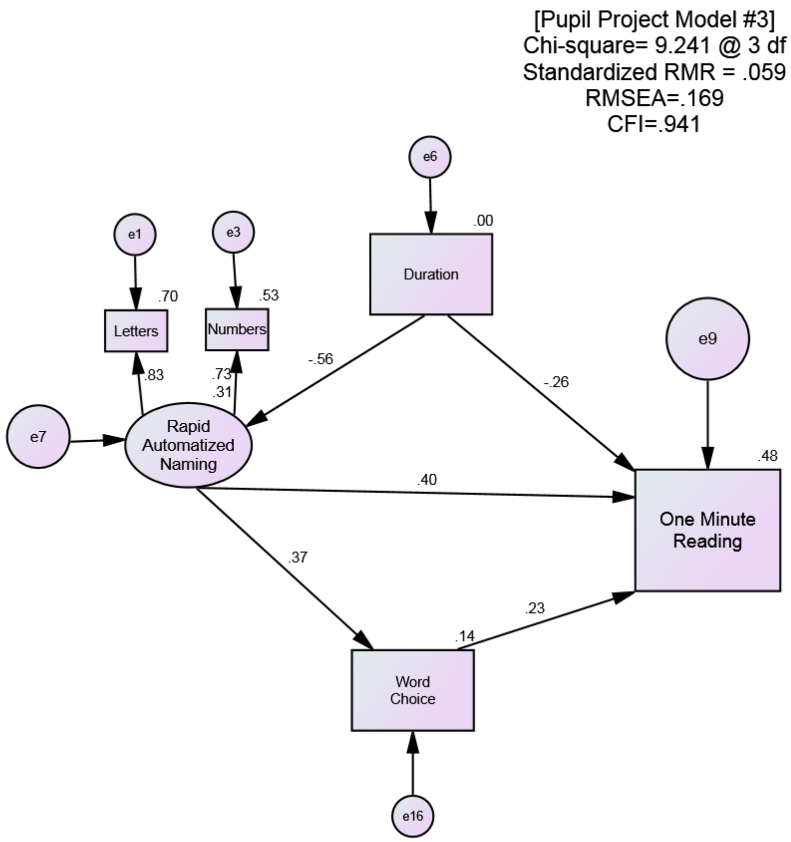


Path	Correlation Coefficient	Probability
RAN --> Duration of Fixation	-0.558**	**<0.001**
Word Choice --> RAN	0.369**	**0.005**
One Mintute Reading --> Syllables	-0.161*	***0.057***
One Minute Reading --> RAN	0.365**	**0.011**
One Minute Reading --> Fixations	-0.164*	***0.053***
One Minute Reading --> Word Choice	0.200**	**0.035**
One Minute Reading --> Duration	-0.288**	**.0.010**

Figure 12 – Modified SEM without erroneous loading: Model #2

****.Path is significant at the 0.05 level.**

**.Path is significant at the 0.1 level.*



Path	Correlation Coefficient	Probability
RAN --> Duration of Fixation	-0.557**	**<0.001**
Word Choice --> RAN	0.369**	**0.005**
One Minute Reading --> RAN	0.401**	**0.007**
One Minute Reading --> Word Choice	0.226**	**0.020**
One Minute Reading --> Duration	-0.257**	**0.025**

Figure 13 – Modified SEM with only significant paths: Model #3

****.Path is significant at the 0.05 level.**

**.Path is significant at the 0.1 level.*

New Hypothesis Testing Models

Given the previously established link between duration of fixation and rapid automatized naming, it was hypothesized that the link between rapid automatized naming and word choice could be completely explained by directly by duration of fixation (hypothesis 4) since both variables are related to visual processing. A new hypothesis model (figure 14) was constructed with only one change: the link between rapid automatized naming and word choice was eliminated and a new pathway was drawn between duration of fixation and word choice. The initial new hypothesis model contained the same erroneous loadings and non-significant paths as the previously modified model (figure 11); however this model explained slightly more variance in word reading (49 percent). The chi-square was non-significant (CS=20.590 @ 16 degrees of freedom, $p<0.1$) and all of the other fit indices – SRMR (0.0909), RMSEA (0.063), and CFI (0.968) – suggested the model fit the data well.

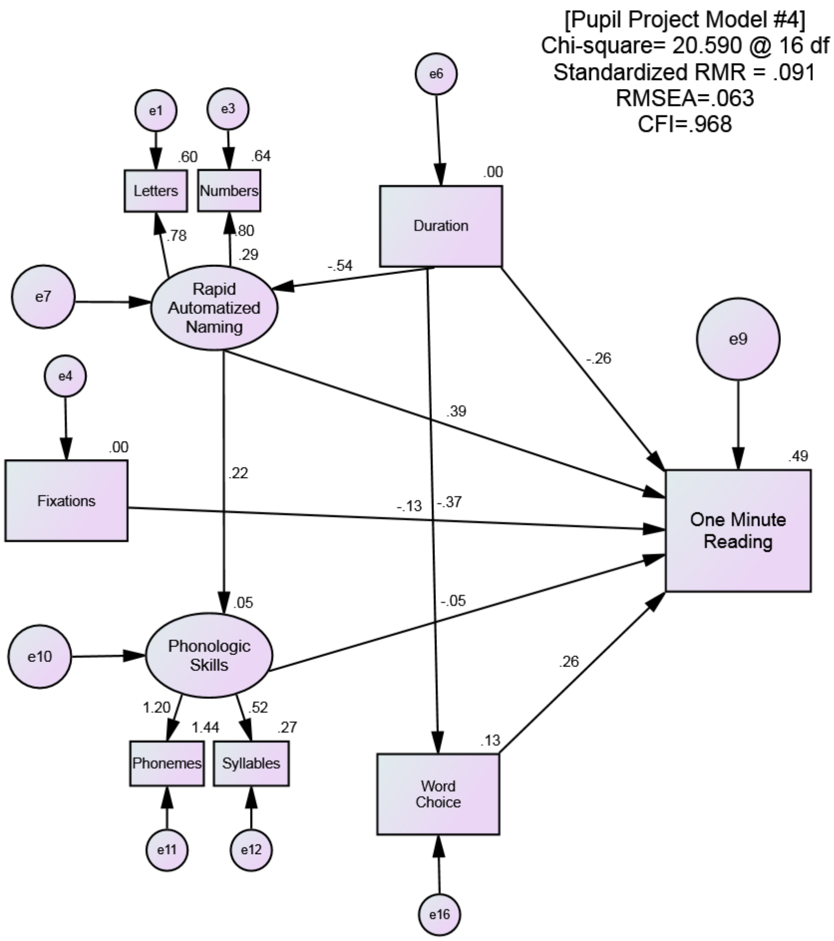
While the new model fit the data well, erroneous loadings are not acceptable in a model regardless of the fit estimations. A second model (figure 15) was constructed which eliminated the erroneous loadings replacing phonologic skills with syllables which was done in the modified model analyses. (rapid automatized naming to phonetic was significant in the first model, so this path remained). The new model contained only one non-significant path (rapid automatized naming to syllables) and explained 51 percent of the variance in word reading. The chi-square was non-significant (CS=16.573 @ 11 degrees of freedom, $p<0.1$), and SRMR (.0949) and CFI (0.950) showed an acceptable fit. The RMSEA (0.083) showed a borderline acceptable fit.

The path between syllables and rapid automatized naming was eliminated in second modification of the new hypothesis model. The resultant model (figure 16) explained 51 percent of the variance in word reading, contained only paths that were significant or approaching significance ($p<0.1$), and had a non-significant chi-square

(CS=16.873 @ 12 degrees of freedom, $p<0.1$). All of the fit indices alluded to a perfect fit. (SRMR=0.0972, RMSEA=0.075, and CFI=0.956)

In order to make the model more parsimonious (or explained with the fewest paths and variables), a third modification to the new hypothesis model (figure 17) was designed by removing the path that approached significance (syllables to one minute reading). This model contained a non-significant path (fixations to one minute reading), explained 49 percent of the variance word reading, yet had a non-significant chi-square (CS=12.405 @ 7 degrees of freedom, $p<0.05$). The SRMR (0.1000) and RMSEA (0.103) pointed to a poorly fitting model while the CFI (0.951) indicated an acceptable fit.

The final variant of the new hypothesis model (figure 18) eliminated the non-significant path between fixations and one minute reading. The final model explained 49 percent of the variance in the word reading, contained only significant paths, and had a non-significant chi-square (CS=6.578 @ 3 degrees of freedom, $p<0.05$). The SRMR (0.0517) and CFI (0.966) agreed with a good fit to the data; however, the RMSEA (0.128) pointed to a poorly fitting model.

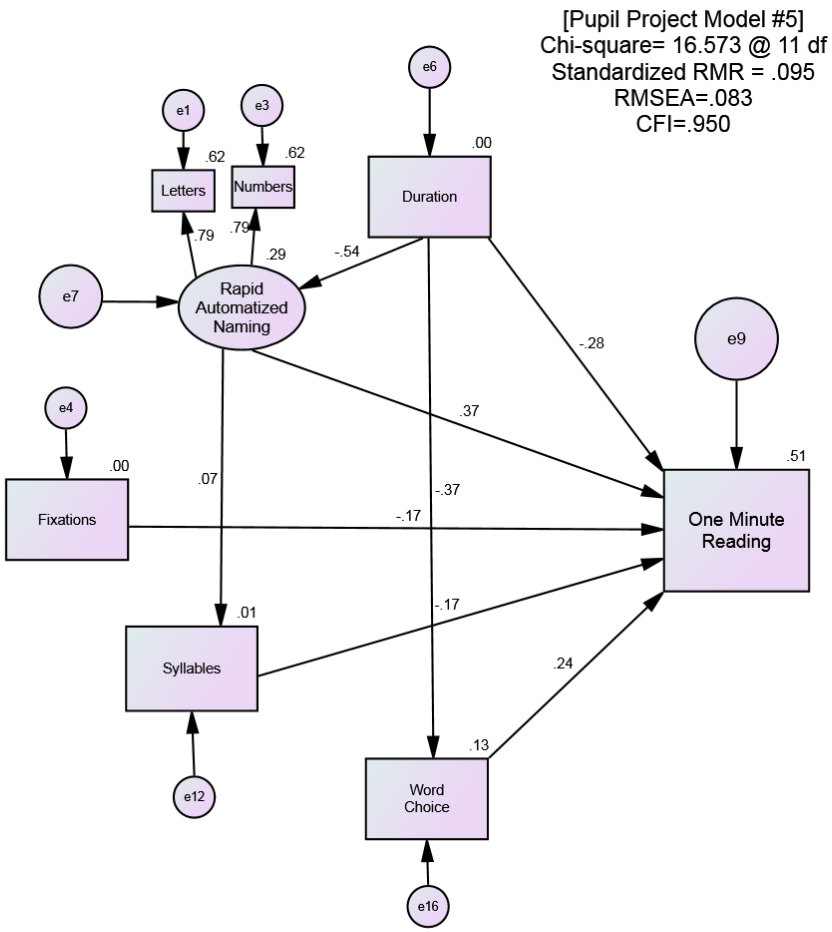


Path	Correlation Coefficient	Probability
RAN --> Duration of Fixation	-0.536**	**<0.001**
Word Choice -->Duration of Fix.	-0.365**	**<0.001**
Phonetic --> RAN	0.218**	**0.048**
One Mintute Reading --> Phonetic	-0.047	0.592
One Minute Reading --> RAN	0.385**	**0.005**
One Minute Reading --> Fixations	-0.134	0.119
One Minute Reading --> Word Choice	0.262**	**0.005**
One Minute Reading --> Duration	-0.258**	**0.026**

Figure 14 – New Hypothesis Model: Model #4

****.Path is significant at the 0.05 level.**

**.Path is significant at the 0.1 level.*

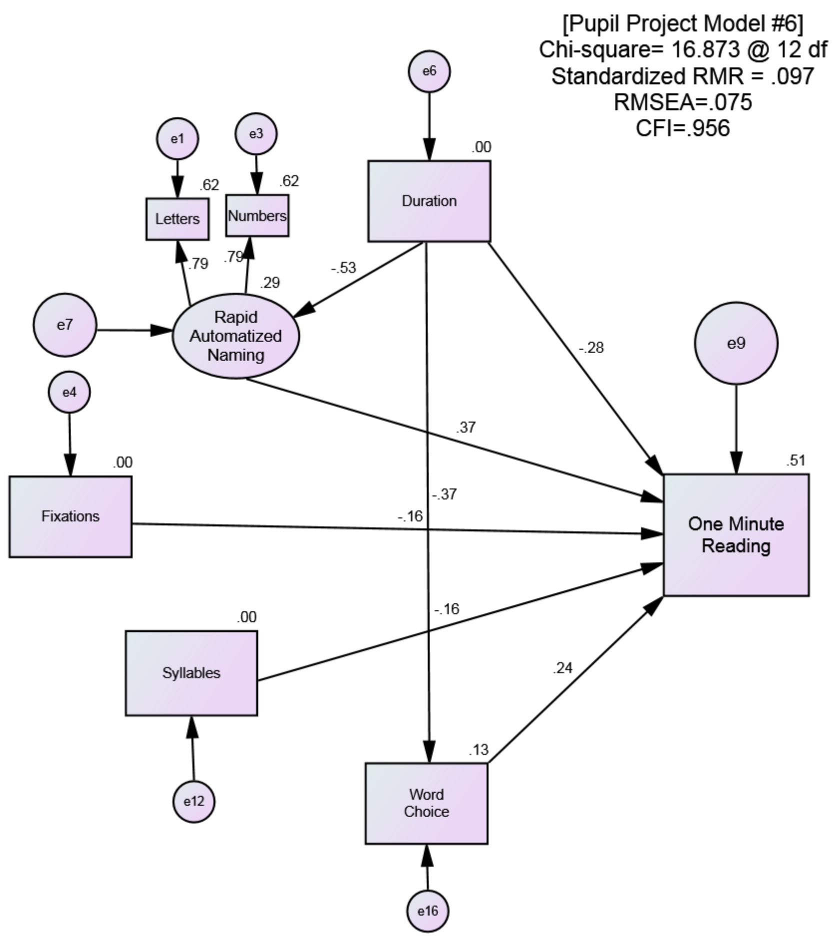


Path	Correlation Coefficient	Probability
RAN --> Duration of Fixation	-0.536	**<0.001****
Word Choice -->Duration of Fix.	-0.365	**<0.001****
Syllables--> RAN	0.072	0.584
One Mintute Reading --> Syllables	-0.167	**0.050****
One Minute Reading --> RAN	0.369	**0.005****
One Minute Reading --> Fixations	-0.165	**0.050****
One Minute Reading --> Word Choice	0.240	**0.008****
One Minute Reading --> Duration	-0.280	**0.014****

Figure 15 – New Hypothesis Model without erroneous loadings: Model #5

****.Path is significant at the 0.05 level.**

**.Path is significant at the 0.1 level.*

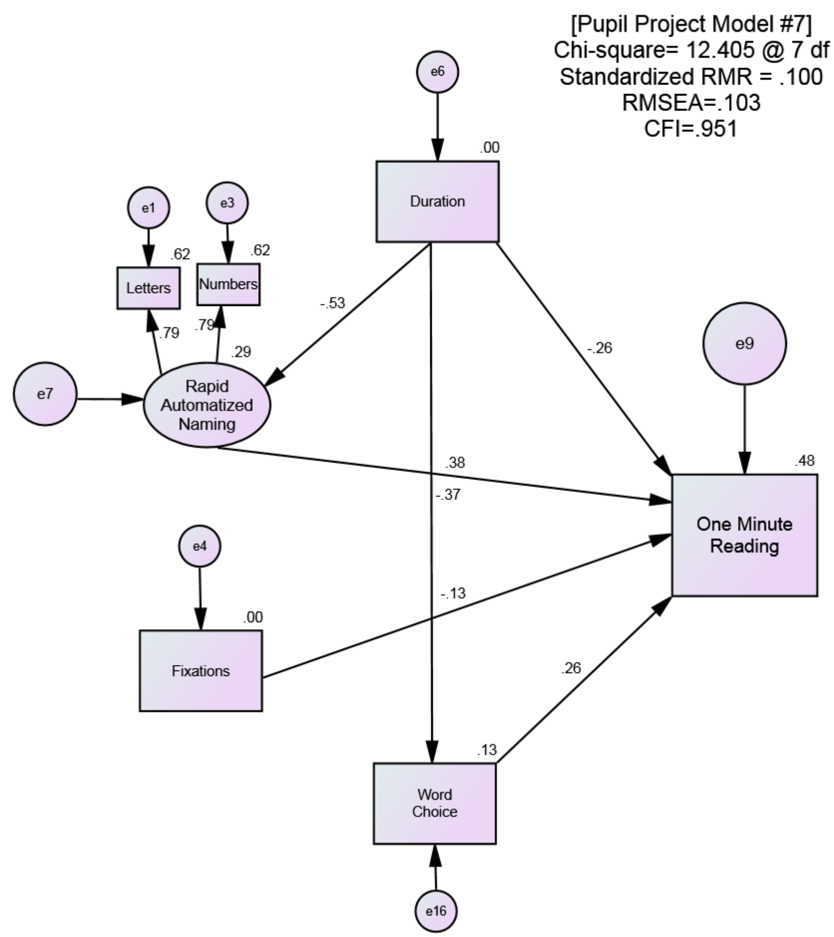


Path	Correlation Coefficient	Probability
RAN --> Duration of Fixation	-0.534**	**<0.001**
Word Choice --> Duraation of Fix.	-0.365**	**<0.001**
One Mintute Reading --> Syllables	-0.161*	*0.056*
One Minute Reading --> RAN	0.366**	**0.005**
One Minute Reading --> Fixations	-0.164**	**0.050**
One Minute Reading --> Word Choice	0.239**	**0.008**
One Minute Reading --> Duration	-0.279**	**0.013**

Figure 16 – New Hypothesis Model without RAN to Syllables: Model #6

****.Path is significant at the 0.05 level.**

**.Path is significant at the 0.1 level.*

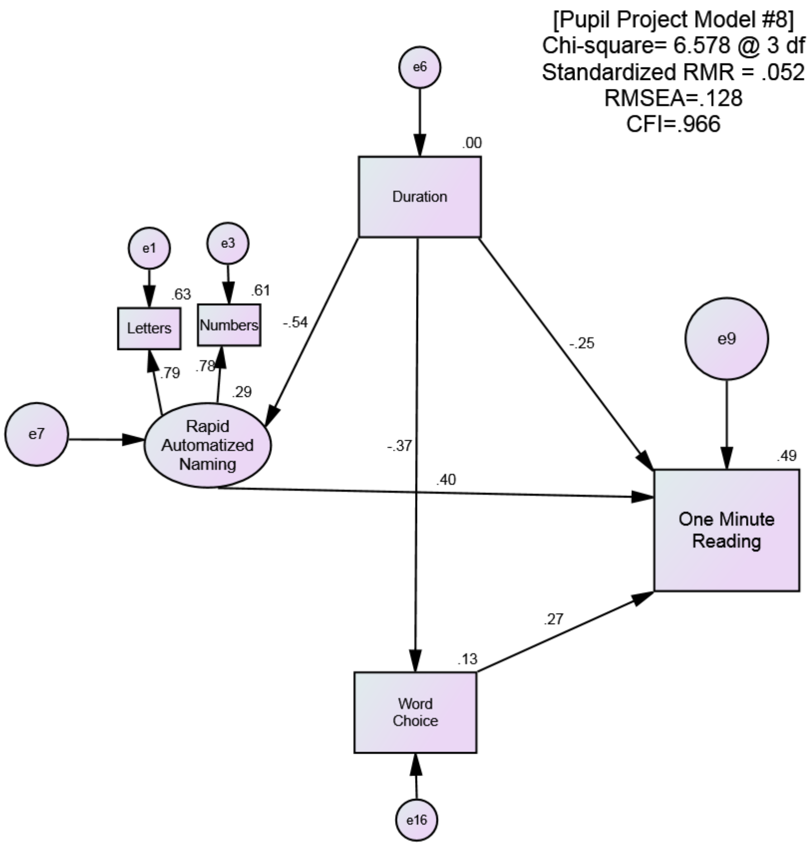


Path	Correlation Coefficient	Probability
RAN --> Duration of Fixation	-0.535**	**<0.001**
Word Choice -->Duration of Fix.	-0.365**	**<0.001**
One Minute Reading --> RAN	0.375**	**0.005**
One Minute Reading --> Fixations	-0.133	0.125
One Minute Reading --> Word Choice	0.260**	**0.005**
One Minute Reading --> Duration	-0.258**	**0.026**

Figure 17 – New Hypothesis Model w/o Syllables: Model #7

****.Path is significant at the 0.05 level.**

**.Path is significant at the 0.1 level.*



Path	Correlation Coefficient	Probability
RAN --> Duration of Fixation	-0.535**	**<0.001**
Word Choice --> RAN	-0.365**	**<0.001**
One Minute Reading --> RAN	0.399**	**0.003**
One Minute Reading --> Word Choice	0.269**	**0.004**
One Minute Reading --> Duration	-0.250**	**0.031**

Figure 18 – Final New Hypothesis Model: Model #8

****.Path is significant at the 0.05 level.**

**.Path is significant at the 0.1 level.*

Discussion

Analysis of factors

Fixation variables

The first factor proposed in this analysis was a fixation factor including duration of fixation, number of fixation, and number of regressions; however, several analyses failed to support this specific factor construction. The initial model (figure 2) showed poor loading of duration of fixation (0.28) on this fixation factor. Conversely, number of fixation (0.65) and number of regressions (0.70) had appropriate loadings. Correlation analysis supported a relationship between number of fixation and number of regression ($r=0.470$, $p<0.01$), but failed to support a relationship between duration of fixation and number of fixations ($r=0.147$, $p>0.05$) or number of regressions ($r=0.166$, $p>0.05$). Given these results, duration of fixation was considered a separate variable and not included in the fixation factor. Additionally, step down multiple regression analysis revealed that number of regressions fails to remain significant in the presence of number of fixations; the variation in word reading predicted by these final two fixation characteristics appears to be explained by the number of fixations alone.

Orthographic Variables

The second factor included in the initial analysis was an orthographic skills factor which included receptive coding, sentence sense, and word choice. This factor was not supported by the initial model or subsequent analysis. Sentence sense (0.48) loaded poorly on the factor while receptive coding (0.70) and word choice (0.64) loaded well. In correlation analysis, both receptive coding and sentence sense failed to correlate significantly with one minute reading; this was also true in subsequent multiple regression analyses. The failure of receptive coding to predict variance in word reading may be due to ability of the child to use phonetic skills to determine the correct answer. While the word is shown visually, the child could still remember how the word sound and determine if the letter or letters were in the word. This task does not rely solely on orthographic skill. Sentence sense requires not only orthographic skills, but also the ability to determine if the sentence makes sense. Higher level language skills are also measured in this task (Lyres, 2008). The only orthographic variable significantly correlated with one minute reading was word choice. Because the words phonics cannot be used to determine the correct answer and the words not are out of context, orthographic processing more purely tested using word choice compared to the other two orthographic variables.

Phonologic Variables

Only two variables were used to represent the phonologic factor; neither variable significantly correlated with word decoding skills in any analysis. Interestingly, despite their establishment as phonologic processing indicators, the variables did not load well onto the same factor. The phonemes (1.89) variable loading indicated possible concerns with the two variables and the syllables (0.33) loading was poor. In regression analysis each variable appeared to explain nearly equal, though insignificant, variance in single word decoding. The unusual loadings for these factors may be explained by the relative difficulty of phonemes and a possible ceiling effect (Franzel, 2013).

Rapid Naming Variables

Three variables were expected to load onto the rapid naming factor – rapid naming (pictures), DEM vertical time (numbers), and rapid automatized naming of letters (letters). Only pictures failed to load well on the rapid automatized naming factor (0.51). Simple correlation analysis revealed that pictures failed significantly correlate with one minute reading. In a stepwise analysis, numbers approached significance ($p=0.054$) in the presence of letters while in a stepwise analysis including the other reading factors phonics, fixation, and orthographic – rapid naming of letters was no longer significant when rapid naming of numbers entered the equation. This suggests that the two variables contribute significant unique variance to reading.

Analysis of Models

Eight total models (figure 19) were generated in the SEM analysis. No model appeared to fit the data best using all fit parameters; however it was possible to compare the fit parameters in each model in order to determine the best fit model. Model 4 had the highest CFI and lowest RMSEA; unfortunately, the model also contained the erroneous loading of phonemes to phonological skills which was larger than one and implied multicollinearity problems with the data. Model 1 also had this problem. Model 8 had an appropriate CFI and the lowest SRMR, but the RMSEA was large. Model 3 had the only significant chi square ($p<.05$), a large RMSEA, and a poor CFI. Models 5 and 7 contained paths which were non-significant ($p>0.1$). Model 2 poorly represented the data with a CFI less than 0.95 and a RMSEA greater than 0.08. Model 6 had a non-significant chi square and appropriate CFI, SRMR, and RMSEA values. Model 6 also explained the largest amount of variance in word reading.

Model	Insig. Chi	RMSEA	SRMR	CFI	Rsquared	Problem(s)
1	0.050	0.081	**0.093**	0.947	0.477	Yes
2	0.050	0.093	**0.099**	0.932	0.504	No*
3	0.001	0.169	**0.059**	0.941	0.484	No
4	**0.100**	**0.063**	**0.091**	**0.968**	0.488	Yes
5	**0.100**	0.083	**0.095**	**0.950**	0.509	Yes
6	**0.100**	**0.075**	**0.097**	**0.956**	0.515	No*
7	0.050	0.103	0.100	**0.951**	0.484	Yes
8	0.050	0.128	**0.052**	**0.966**	0.493	No

Figure 19 – Summary of Models: Numbers in **bold** indicate good fit.
**Contains paths that approach significance, p<0.1.*

Consistent with Badian's (1997) triple deficit hypothesis, the best fit model (model 6) included a phonetic, rapid automatized naming, and orthographic component which uniquely contributed to single word decoding in the DST one minute reading task. In addition to Badian's cornerstone components, the duration of fixation and to a lesser degree number of fixations observed while a child reads below grade level passages explains unique variance in one minute reading. The popular association between regression eye movements and reading disability appears to be explained nearly completely by the number of overall fixations during word reading. While this model is consistent with Badian's research, the data contradicts Vellutino et al.'s (1975) statements that orthographic processing fails to contribute independently to reading disabilities.

Vellutino et al. (1975) failed to include enough participants in the study to find a significant effect between the normal and dyslexic readers. Given a moderate effect size (Cohen's d=0.5) at least 50 people would have needed to be in each group if a significant effect was to be found. Vellutino et al.'s study only included 33 total students. While difference between groups failed to reach significance, there was still a difference between the two groups. This was especially true for the second grade readers in which the effect size (Cohen's d=0.471) was moderate compared to the sixth grade readers in which the effect size was relatively small (Cohen's d=0.222). (Cohen's d is a measure used to assess the size of a difference effect where the values for small, moderate, and large effect sizes are 0.2, 0.5, and 0.8 respectively.) The moderate effect size in the second grade readers suggests that Vellutino would have found a significant difference between these non-Hebrew normal and poor readers had he used a larger sample size even with the presumed ceiling effect.

Analysis of Hypotheses

1. When sight word vocabulary is used fixation characteristics including duration of fixation, number of fixations, and number of regressions should predict single word decoding skills.

Using the best fit model (model 6), the first hypothesis that word reading skills are predicted by fixation characteristics was tested by constructing a direct path between one minute reading and duration of fixation and a separate path between one minute reading and number of fixations. The original hypothesis predicted the three fixation variables – duration of fixation, number of fixations, and number of regressions - would combined to explain significant variance in word reading, the best fit model did not completely support this theory. Duration of fixation was found to be a significant individual predictor in word reading as evidenced by the significant path between duration of fixation and one minute reading. Additionally, the path between one minute reading and number of fixations approached significance. This indicates that there are two different fixation characteristics that explain unique variance in word reading.

Studies have shown that duration of fixation and number of fixations increase with word or sequence length and lack of exposure (Hawelka & Wimmer, 2005; Hyona J & Olson 1995). Given these results, fixation characteristics were evaluated using reading passage two years below grade level to insure adequate exposure to all words in the paragraph a prevent confounding results.

Duration of fixation has been shown to be increased in dyslexia (Palvidis, 1978). This increase in duration of fixation is believed to be due to poor visual attention (Steinman, Steinman, Garzia, 1996). Typical psycho-educational evaluations of children with reading deficits do not include eye movement evaluations. This result suggests that duration of fixation can be useful in evaluating children with reading disabilities.

The number of fixations observed in the eye movements during reading has been shown to be increased in children with dyslexia. This is believed to be due to sublexical analysis of words by dyslexic children; instead of reading words in whole chunks, dyslexic children read smaller pieces of the word using short saccade lengths. (De Luca, Di Pace, Judica, Spinelli, Zoccolotti, 1999; De Luca, Borelli, Judica, Spinelli, Zoccolotti, 2002) This could be due to a phonologic deficit much like beginning readers sound out each word, or it could be due to poor orthographic skills. In either instance, sight word recognition would be compromised. It could also be due to combination of both problems (Franzel, 2013). These results suggest that in addition to fixation duration, number of fixations should be evaluated in children with learning disabilities.

2. In addition to phonetic processing and rapid automatized naming, the two main components of the double deficit hypothesis, orthographic processing should predict significant independent variance in single word decoding ability.

The path between word choice and one minute reading was used to test the second hypothesis which stated that orthographic processing predicts unique variance in single word decoding. This path was found to be significant implying that orthographic processing delays are contributing to word decoding deficits in the dyslexic children from the Pupil Project population. This is similar to Holland et al.'s (2004) findings that orthographic skills are a good predictor of reading skills in the normal reader. These findings suggest that orthographic processing should be tested in all children with a reading disability.

3. Orthographic processing in addition to phonologic processing and rapid automatized naming skills in Pupil Project patients will predict single word reading for subjects with dyslexia in a triple deficit pattern as first described by Badian (1997).

The best fit model included a phonetic component (syllables), rapid automatized naming component (rapid naming of letters and DEM vertical time), and an orthographic component (word choice); these paths were used to evaluate the hypothesis that phonologic, rapid automatized naming, and orthographic skills will predict single word decoding skills in a triple deficit pattern. Each path to one minute reading was at least approaching significance. These findings suggest that a triple deficit is explaining the word decoding abilities for children in our population. Given this information, it would be more effective to provide remediation for children with dyslexia in all three of these areas rather than providing phonics intervention alone.

4. Duration of fixation will significantly contribute to variance in orthographic processing either directly or indirectly via rapid automatized naming.

The direct path between duration of fixation and word choice in the final model was used to verify our last hypothesis that duration of fixation predicted variance in orthographic processing. The first part of the hypothesis states that the relationship between duration of fixation and orthographic processing is indirectly mediated through rapid automatized naming; however, the best fit model indicates this relationship is more direct. Model two was used to test the indirect path hypothesis; there is a pathway between word choice and the rapid automatized naming factor. Conversely, model six was used to test the direct path hypothesis. Model two (CS=19.623 @ 12 degrees of freedom, $p<0.05$; RMSEA=0.093; CFI=0.932) has poor fit parameters compared to model six (CS=16.873 @ 12 degrees of freedom, $p<0.1$; RMSEA=0.075; CFI=0.956). The more significant direct path model allows us to infer that duration of fixation is an earlier visual skill than word choice. This path provides better understanding of how successive visual processing contributes to word reading skills.

Final Conclusions

For our population, the most significant predictor of single word decoding skills was rapid automatized naming followed by duration of fixation, orthographic processing (word choice), and finally number of fixation and phonologic skills (syllables). With the second and third largest path coefficient duration of fixation (0.28) and word choice

(0.24) respectively confirm a link between visual processing, and word reading skills. In addition, duration of fixation predicts a very large portion (29%) of the variance in rapid automatized naming skills, the best predictor (path coefficient=0.38) of word reading skills. Given this fact and the non-significant contribution of rapid automatized naming to phonologic skills, rapid automatized naming can be seen as largely visual for the Pupil Project population and the importance of visual deficits in dyslexia is emphasized. Phonetic skills were not significantly able to predict word decoding at the $p<0.05$ level. Additionally, when total (direct plus indirect) effects were calculated, duration of fixation had that largest contribution to one minute reading (-0.563) followed by rapid automatized naming (0.366), orthographic processing (0.239), number of fixations (-0.164), and phonologic processing (-0.161) (figure 20). Considering the relatively large contribution of visual measures, these results cast doubt on the efficacy of phonics intervention for similar populations.

Parameter	Correlation	Probability*
Duration of Fixation	-0.563	**0.010**
Rapid Automatized Naming	0.366	**0.011**
Word Choice	0.239	**0.012**
Fixations	-0.164	***0.084***
Syllables	-0.161	**0.037**

Figure 20 – Model #6: Total effects of testing variables on one minute reading.

The average estimated prevalence of dyslexia in children in the United States is around ten percent (Shaywitz, 1998). Currently, the default intervention for these children is phonics remediation. While this is certainly helpful for many children, the current research points to a sub-population for which phonetic skills are not a major factor in their reading deficit. Visual and rapid naming skills were found to be the most important in Holland et al.'s research using normal readers as suspects, and similar results were found in the current study. The results from this population, though small and very specific, suggest that additional visual and automaticity interventions are needed for some dyslexic readers.

Future Directions

The current study supported Holland et al.'s (2004) research that rapid automatized naming significantly predicts variance in orthographic skills (word choice) while current and past studies support a significant path between duration of fixation and rapid automatized naming (Brooks et al., 2012). This significant path between duration of fixation and rapid automatized naming alludes to the possibility that duration of fixation serves as an earlier visual process compared to rapid automatized. Additionally, there was a significant path between duration of fixation and orthographic processing (word choice) further supporting the theory that duration of fixation is an earlier visual process. Future experimental studies will evaluate the validation of this claim by adding coherent motion, which taps into early visual processing (Talcott et al., 2000). This experiment would test the hypothesis that coherent motion significantly predicts variance in duration of fixation, duration of fixation predicts variance in word choice, and finally word choice significantly predicts variance in single word decoding.

Future studies could also evaluate the use of different phonologic measures including rime. They could use different tests of single word decoding ability such as the letter word identification subtest on the Woodcock Johnson III or the word reading section of the WIAT III. Different subclasses of dyslexia could also be examined including children with dyslexic dysgraphia. Larger and different subject pools can also be used to verify these results in other similar populations.

References

Arnell KM, Klein RM, Joanisse MF, & Busseri MA, Tannock R (2000). Decomposing the relation between rapid automatized naming (RAN) and reading ability. *Canadian Journal of Experimental Psychology*, **63**, 173-184.

Ayton LN, Abel LA, Fricke TR, & McBrien NA (2009) Developmental eye movement test: what is it really measuring? *Optometry and Vision Science*, **86**, 722-30.

Badian NA (1997). Dyslexia and the Double Deficit Hypothesis. *Annals of Dyslexia*, **47**, 69-87.

Barsch RH (1965). The concept of language as a visual-spatial phenomenon. *Intervention in School and Clinic*, **l**, 2-11.

Bavelier D, Tomann A, Hutton C, Corina D, Liu G, & Neville H (2000). Visual attention to the periphery is enhanced in congenitally deaf individuals. *The Journal of Neuroscience*, **20**, 1-6.

Berninger V (2007). *PAL-II user's guide.* San Antonio, TX: Pearson.

Boets B, Vandermosten M, Cornelissen P, Wouters J, & Ghesquiere P (2011). Coherent motion sensitivity and reading development in transition from pre-reading to reading stage. *Child Development*, **82**, 854-869.

Brooks EM, Franzel AS, & Garzia RP (2012). Path Analysis of Direct and Indirect Effects of Duration of Fixation to Word Reading Skills. Poster presentation at the American Academy of Optometry Conference, Phoenix, AZ.

Bruck M (1992). Persistence of dyslexics' phonological awareness deficits. *Developmental Psychology,* **28**, 874-886.

Cairns NU & Steward MS (1970). Young children's orientation of letters as a function of axis of symmetry and stimulus alignment. *Child Development*, **41**, 993-1002.

Chase C, Dougherty RF, Ray N, Fowler S, & Stein J (2007). LM speed-matching ratio predicts reading children. *Optometry and Vision Science*, **84**, 229-236.

Comrey AL (1973). *A first course in factor analysis.* New York, NY: Academic Press.

Corballis MC & Beale IL (1993). Orton revisited: dyslexia, laterality, and left-right confusion. In DM Willows, RS Kruk & E Corcos (Eds.). *Visual processes in reading and reading disabilities*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Cornelissen P, Richardson A, Mason A, Fowler S, & Stein J (1995). Contrast sensitivity and coherent motion detection measured at photopic luminance levels in dyslexics and controls. *Vision Research,* **35**, 1483-1494.

Cornelissen PL, Hansen PC, Gilchrist I, Cormack F, Essex J, & Frankish EC (1998a). Coherent motion detection and letter position encoding. *Vision Research*, **38**, 2181-2191

Cornelissen PL, Hansen PC, Hutton JL, Evangelinou V, & Stein JF (1998b) Magnocellular visual function and children's single word reading. *Vision Research*, **38**, 471-482.

Ciuffreda KJ, Bahill AT, Kenyon RV, & Stark L (1976) Eye movements during reading - case reports. *American Journal of Optometry and Physiological Optics*, **53**, 389-395.

De Luca M, Di Pace E, Judica A, Spinelli D, & Zoccolotti P (1999). Eye movement patterns in linguistic and non-linguistic tasks in developmental surface dyslexia. *Neuropsychologia*, **37**, 1407-1420.

De Luca M, Borrelli M, Judica A, Spinelli D, & Zoccolotti P (2002). Reading words and pseudowords: An eye movement study of developmental dyslexia. *Brain and Language*, **80**, 617-626.

Denckla MB & Rudel RG (1976). Rapid 'automatized' naming (R.A.N.): Dyslexia differentiated from other learning disabilities. *Neuropsychologia*, **14**, 471-497.

Eisenberg L (1978). Definitions of dyslexia: Their consequences for research and policy. In AL Benton & D Pearl (Eds.). *Dyslexia: An appraisal of current knowledge*. New York, NY: Oxford University Press.

Facoetti A, Lorusso ML, Pagononi P, Cattaneo C, Galli R, Umilta C, & Mascetti GG (2003) auditory and visual automatic attention deficits in developmental dyslexia. *Cognitive Brain Research*, **16**, 185-191.

Fischer W, Liberman I, & Shankweiler D (1978). Reading reversals and developmental dyslexia: A further study. *Cortex*, **14**, 496-510.

Fletcher JM & Satz P (1979a). Unitary deficit hypothesis: Has Vellutino led us astray? *Journal of Learning Disabilities*, **12**, 22-26.

Fletcher JM & Satz P (1979b). Has Vellutino led us astray? A rejoinder to a reply. *Journal of Learning Disabilities*, **12**, 35-37.

Fletcher JM, Foorman BR, Shaywitz SE, & Shaywitz BA (1999). Conceptual and methodological issues in dyslexia research: A lesson for developmental disorders. In H Tager-Flusberg (Ed.), *Neurodevelopmental disorders*. Cambridge, MA: MIT Press

Franzel AS, Viola SG, McCarthy M, Marks LR, Minier JR, Garzia RP, & Bassi CJ (2005). Associations among tests of visual-perceptual skills, eye movement skills, intelligence, and achievement in students with academic difficulties. Poster presentation at the American Academy of Optometry, San Diego, CA.

Franzel AS, McCarthy M, Marks LR, Minier JR, Galbrecht D, Viola SG, Garzia RP, & Bassi CJ (2006).Further associations among tests of vision, eye movements, and achievement in students with academic difficulties. Poster presentation at the American Academy of Optometry, Denver, CO.

Franzel AS, Garzia RP, Galbrecht D, O'Brien B, Minier JR, McCarthy M, Marks LR, Viola SG, & Bassi CJ (2007).Associations between duration of fixation and reading skills in students with academic difficulties. Poster presentation at the American Academy of Optometry, Tampa, FL.

Franzel AS (2013). Personal conversation.

Gates AI (1936). *The improvement of reading: A program of diagnostic and remedial methods*. New York: Macmillian.

Gerbing DW & Hamilton JG (1996). Viability of exploratory factor analysis as a precursor to confirmatory factor analysis. *Structural Equation Modeling: A Multidisciplinary Journal*, **3**, 62-72.

Getman, G (1965). The visuomotor complex in the acquisition of learning skills. In J Hellmuth (Ed.), *Learning disorders*. Seattle, WA: Special Child Publications.

Getman, G.N. (1985). A commentary on vision training. *Journal of Learning Disabilities*, **18**, 505–512.

Hair JF, Black WC, Babin BJ, & Anderson RE (2010). *Multivariate data analysis, 7th edition*. Upper Saddle River, NJ: Prentice Hall.

Hawelka S & Wimmer, H (2005). Impaired visual processing of multi-element arrays is associated with increased number of eye movements in dyslexic reading. *Vision Research*, **45**, 855-863.

Holland J, McIntosh D, & Huffman L (2004). The role of phonological awareness, rapid automatized naming, and orthographic processing in word reading. *Journal of Psychoeducational Assessment*, **22**, 233-260.

Hyona J & Olson RK (1995). Eye fixation patterns among dyslexic and normal readers: Effects of word length and word frequency. *Journal of Experimental Psychology*, **21**, 1430-1440.

Jones MW, Obregon M, Kelley ML, & Branigan HP (2008). Elucidating the component process involved in dyslexic and non-Dyslexic reading fluency: an eye-tracking study. *Cognition*, **109**, 389-407.

Kephart NC (1964). Perceptual-motor aspects of learning disabilities. *Exceptional*

Children, **31**, 201-206.

Lehmkuhle S, Garzia RP, Turner L, Hash T, & Baro JA (1993). A defective visual pathway in children with a reading disability. *New England Journal of Medicine*, **328**, 989-996.

Livingstone MS, Rosen GD, Drislane FW, & Galaburda A (1991). Physiological and anatomical evidence for a magnocellular deficit in developmental dyslexia. *Proceedings of the National Academy of Sciences USA*, **88**, 7943-7947.

Lovett MW (1987). A developmental approach to reading disability: accuracy and speed criteria or normal and deficit reading skill. *Child Development*, **58**, 234-260.

Lyres, R (2008). *Process Assessment of the Learner* [PDF document]. Retrieved from Pearson Assessment Online Website: www.pearsonassessments.com/NR/rdonlyres/ palrev.ppt

Manis FR, Seidenberg MS, & Doi LM (1999). See Dick RAN: Rapid naming and the longitudinal prediction of reading subskills in first and second graders. *Scientific Studies of Reading*, **3**, 129-157.

Manis FR. Doi LM, & Bhadha B (2000). Naming speed, phonological awareness, and orthographic knowledge in second graders. *Journal of Learning Disabilities*, **33**, 325-333.

Monroe M (1932) *Children who cannot read*. Chicago: University Chicago Press.

O'Brien M, Nabhan T, Parker C, Brooks E, & Franzel A (2011). Association between duration of sight word fixation and reading. Poster presentation at the ***Southeastern College of Optometry***, Atlanta, GA.

O'Connor PD, Sofo F, Kendall L, & Olsen G (1990). Reading disabilities and the effects of colored filters. *Journal of Learning Disabilities*, **23**, 597-603.

Orton ST (1937) *Reading, writing, and speech problems in children*. New York: Norton.

Orton ST (1925). "Word blindness in school children. *Archives of Neurology and Psychiatry*, **14**, 581-615.

Pavlidis GT (1978). The dyslexic's erratic eye movements: case studies. *Dyslexia Review*, **1**, 22-28.

Pavlidis GT (1981). Do eye movements hold the key to dyslexia? *Neuropsychologia*, **19**, 57-64.

Pennington BF (2006). From single to multiple deficit models of developmental disorders. *Cognition*, **101**, 385-413.

Raykov T & Marcoulides GA (2006). *A first course in structural equation modeling.* Mahwah, NJ: Lawrence Erlbaum Associates.

Rayner K (1985). Do faulty eye movements cause dyslexia? *Developmental Neuropsychology*, **1**, 3-15.

Richards TL & Berninger VW (2008). Abnormal fMRI connectivity in children with dyslexia during a phoneme task Before but not after treatment. *Journal of Neurolinguistics*, **21**, 294-304.

Robinson HM (1946). *Why pupils fail in reading*. Chicago: University of Chicago Press.

Rutter M (1978).Prevalence and types of dyslexia. In AL Benton & D Pearl (Eds.). *Dyslexia: An appraisal of current knowledge*. New York, NY: Oxford University Press.

Shaywitz SE (1998). Dyslexia. *New England Journal of Medicine*, **338**, 307-312.

Shaywitz SE & Shaywitz BA (2005) Dyslexia (specific reading disability). *Biological Psychiatry*, **57**, 1301-1309.

Solan HA & Richman J (1990). Irlen lenses: A critical appraisal. *Journal of the American Optometric Association*, **61**, 789-796.

Spicer J (2005). *Making sense of multivariate data analysis.* Thousand Oaks, CA: Sage Publications.

Stanley G, Smith GA, & Howell EA (1983). Eye-movements and sequential tracking in dyslexic and control children. *British Journal of Psychology*, **74**, 181-187.

Stein J (2001). The magnocellular theory of developmental dyslexia. *Dyslexia*, **7**, 12-36.

Stein J & Walsh V (1997). To see but not to read; the magnocellular theory of dyslexia. *Trends in Neuroscience*, **20**, 147-152.

Steinman BA, Steinman SB, & Garzia RP (1996). Reading with an M neuron: How a defective magnocellular pathway interferes with normal reading. In RP Garzia (Ed.). *Vision and reading*. St. Louis, MO: Mosby.

Talcott JB, Hansen PC, Assoku EL, & Stein JF (2000). Visual motion sensitivity in dyslexia: Evidence for temporal and energy integration deficits. *Neuropsychologia*, **38**, 935-943.

Wagner RK & Torgesen JK (1987). The nature of phonological processing and it's causal role in the acquisition of reading skills. *Psychological Bulletin*, **101**, 192-212.

Willis, J.A. (March 2007). Toward Neuro-logical Reading Instruction. *Educational Leadership*, **64**, 80-82.

Willows DM, Kruk R, & Corcos E (1993). Are there differences between disabled and normal readers in their processing of visual information? In DM Willows, RS Kruk & E Corcos (Eds.). *Visual processes in reading and reading disabilities*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Willows DM & Terepocki M. (1993). The relation of reversal errors to reading disabilities. In DM Willows, RS Kruk & E Corcos (Eds.). *Visual processes in reading and reading disabilities*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Witton C, Stein JF, Stoodley CJ, Rosner BS, & Talcott JB (2002) Separate influences of acoustic AM and FM sensitivity on the phonological decoding skills of impaired and normal readers. *Journal of Cognitive Neuroscience*, **14**, 866-874.

Wolf M & Bowers PG (1999). The double deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology*, **91**, 415-438.

Vellutino FR, Steger JA, Kaman M, & De Setto L (1975). Visual form perception in deficient and normal readers as a function of age and orthographic-linguistic familiarity. *Cortex*, **11**, 22-30.

Appendix A

fim ________________
sep ________________
lat ________________
dob ________________
huz ________________
yain ________________
bire ________________
nool ________________
pote ________________
jeek ________________
snitting ________________
bathtail ________________
inteakness ________________
overtodded ________________
rebenderable ________________

mud	shear	gentle	debate
rat	sand	tongue	ritual
cow	porch	bright	impact
fly	yard	fourth	saddle
bond	wound	vary	junior
claim	cure	speech	palace
aim	verse	atom	master
ice	slave	weight	lumber
horn	grave	iron	signal
pot	spite	jury	fellow
hat	prize	paint	native
barn	grace	devil	estate
key	chain	merit	appeal
cup	frame	magic	secure
code	faint	entry	budget
sky	snake	china	wisdom
lady	brief	urban	defeat
fort	swift	vague	cousin
dawn	camera	alert	classic
till	cellar	title	permit
myth	birth	motor	highway
vein	track	minor	weapon
task	broke	quiet	intense
fate	crowd	piano	gesture
lord	scheme	usual	passion
drama	fence	uncle	suspect
dozen	branch	penny	finance
seek	break	event	witness
pick	choose	puddle	soldier
ease	slight	equal	captain

Figure 1 – pseudoword and single word decoding. *Right*: Sample pseudoword decoding list. *Left*: One Minute Reading subtest of the dyslexia screening test (DST).

Say: **Say *got*.**

If the child responds correctly, say: **Now say /ot/.**

Pause for the child to respond. Then say: **What sound is missing?**

The correct response is /g/.

Item 6

Say: **Say *umbrella*.**

If the child repeats the word correctly, say: **Now say umbrella without /um/.**

The correct response is /brella/.

Figure 2 – Phonics testing. *Top*: sample syllables task from processing assessment of the learner reading and writing (PAL-RW II). *Bottom*: sample phonemes task from the PAL-RW II

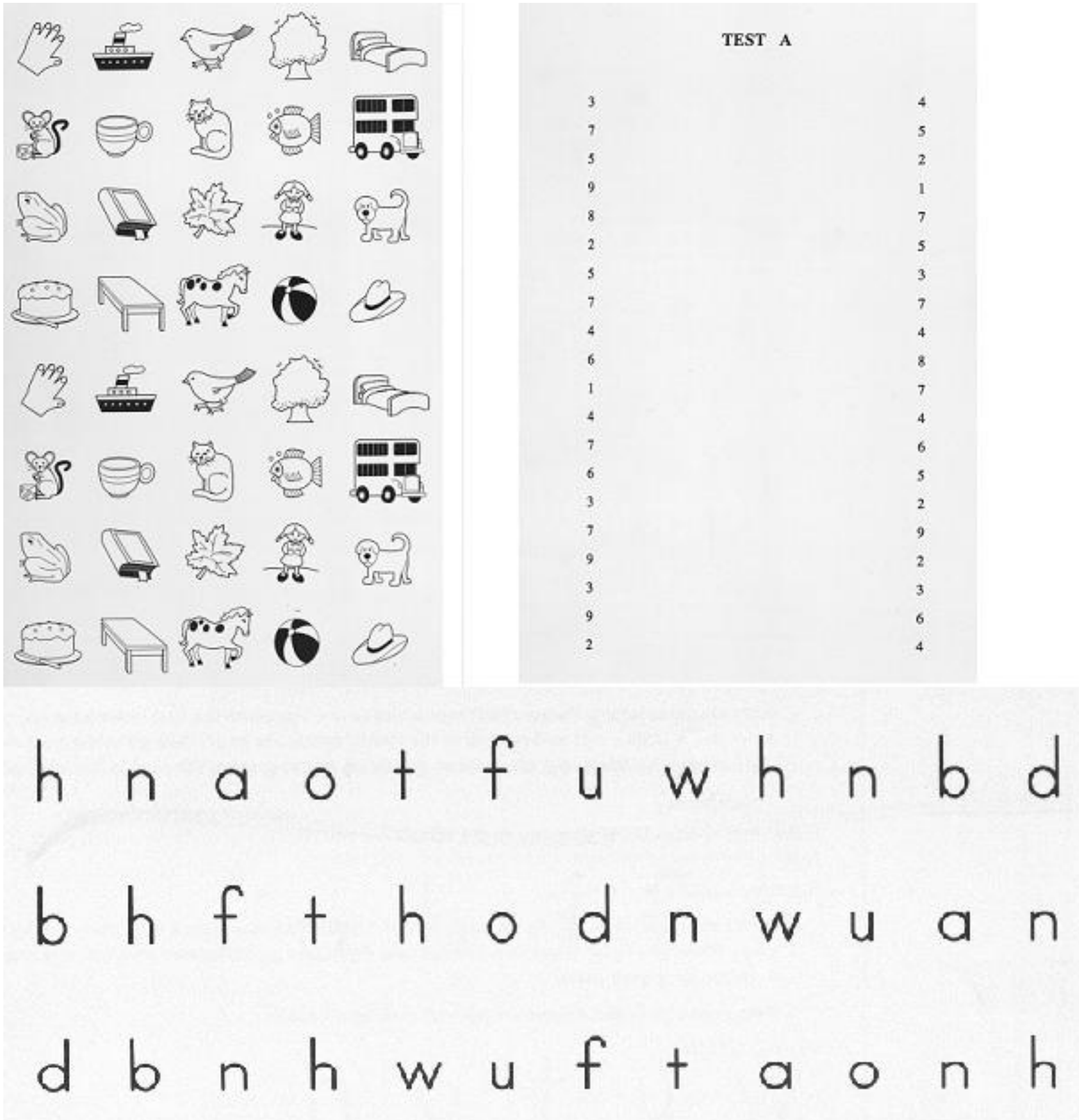


Figure 3 – Rapid naming of pictures, numbers and letters. *Top right*: Rapid naming subtest of the dyslexia early screener (DEST). *Top left*: vertical portion of developmental eye movement test (DEM). *Bottom*: RAN letters subtest of PAL-RW II.

SA	was	wuz	whas
1.	snowman	snoaman	snomann
2.	bekaws	becauz	because
3.	chaynj	chaynge	change
4.	siez	size	sise
5.	wrong	rawng	wroung

Figure 4 - Orthographic testing. Items from word choice subtest of PAL-RW II.

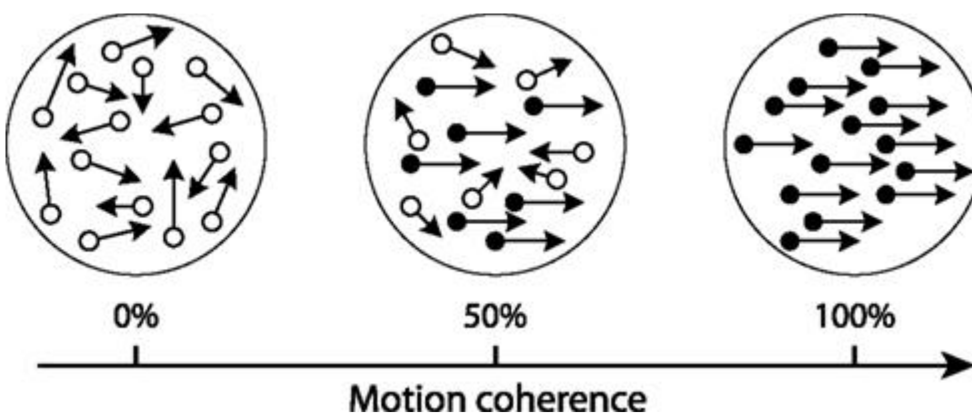
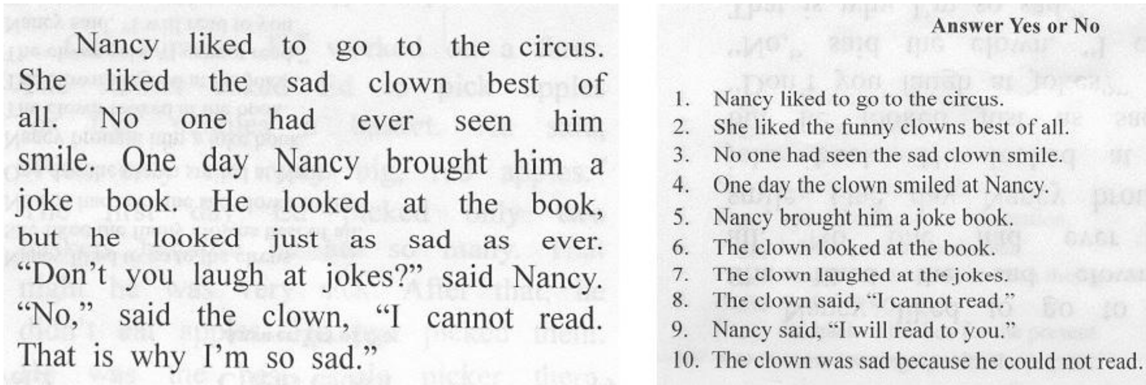


Figure 5 – Coherent Motion. Subjects are asked to determine if some dots are going in a specific direction while other dots move randomly. The threshold is determined by how few dots must move in the same direction before only random motion is seen.

Sample	a.	The little girl lost her new brush and comb.
	b.	The little girl lost her knew brush and comb.
	c.	The little girl last her new brush and comb.
1.	a.	The next morning there was a rid toy car.
	b.	The next morning there was a red toy car.
	c.	The next mourning there was a red toy car.
2.	a.	The tree his many uses.
	b.	The tree has many uses.
	c.	The free has many uses.

Figure 6 – Sentence Sense. Sample items from sentence sense subtest of PAL RW-II.

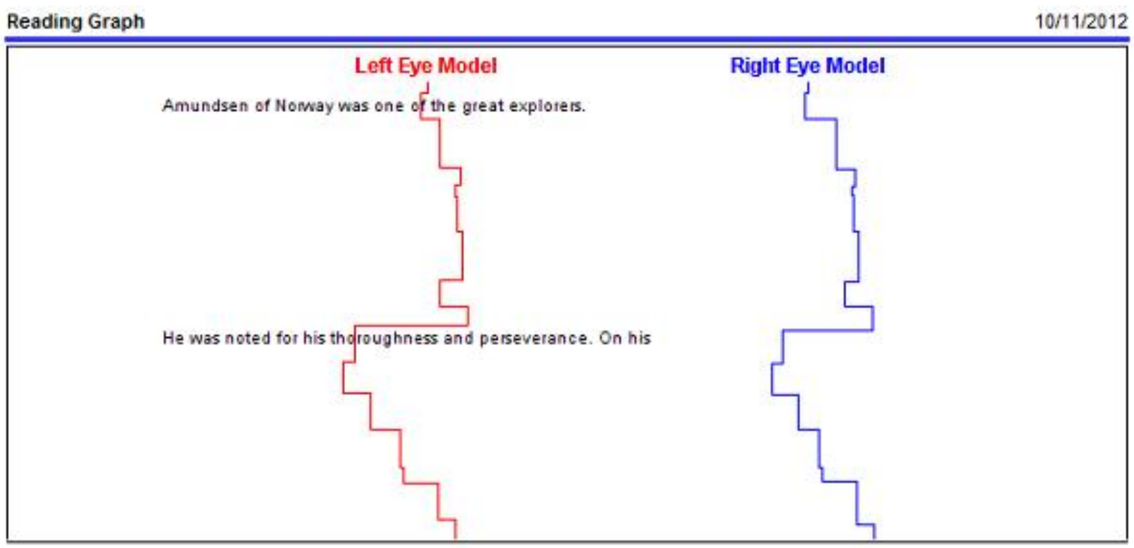


Nancy liked to go to the circus. She liked the sad clown best of all. No one had ever seen him smile. One day Nancy brought him a joke book. He looked at the book, but he looked just as sad as ever. "Don't you laugh at jokes?" said Nancy. "No," said the clown, "I cannot read. That is why I'm so sad."

Answer Yes or No

1. Nancy liked to go to the circus.
2. She liked the funny clowns best of all.
3. No one had seen the sad clown smile.
4. One day the clown smiled at Nancy.
5. Nancy brought him a joke book.
6. The clown looked at the book.
7. The clown laughed at the jokes.
8. The clown said, "I cannot read."
9. Nancy said, "I will read to you."
10. The clown was sad because he could not read.

Figure 7 – Visagraph. Sample paragraph and questions from Visagraph II.



Reading Report 10/11/2012

Measurement	Left	Right	Grade Norm	Goal
Fixations/100 words	138	138	77	< 57
Regressions/100 words	40	39	11	< 5
Avg. Span of Recognition	0.72	0.72	1.30	> 1.75
Avg. Duration of Fixation	.28	.28	.23	< .22
Reading Rate (wpm)	154		340	> 544
Reading Rate w/o Rereads	154		-	-
Directional Attack Difficulty	29%		14%	< 9%
Grade Level Efficiency (GLE)	3.7			
Cross Correlation	98%			
Lines Found/ Countable Lines	10/10			

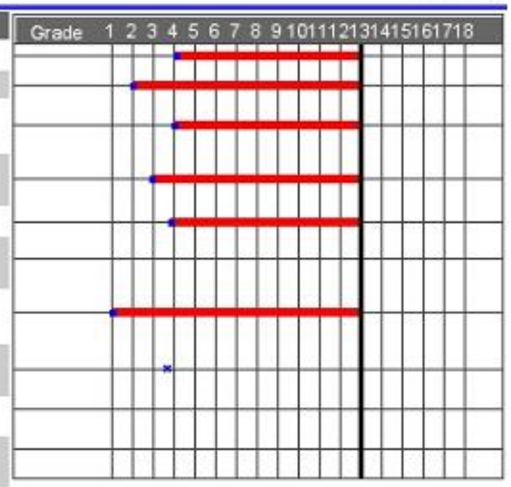


Figure 8 – Visagraph Report. Sample eye tracking *(top)* and report *(bottom)* from Visagraph 2.

Appendix B

Chi-square: an analysis of model fit that will be significant if the model does not explain the data.

CS – chi-square: an analysis of model fit that will be significant if the model does not explain the data.

CFI – comparative fit index: an analysis of model fit in which a value greater than or equal to 0.95 indicates an acceptable fit.

DEM – developmental eye movement test: an evaluation of a child's processing speed and eye movements while reading vertically and horizontally arranged numbers.

DFD/DFDev2 – duration of fixation two years below: a measure of duration of fixation a child has when reading a passage two years below current reading level.

DST – dyslexia screening test: a test battery used to evaluate the risk for dyslexia in children.

EFA – exploratory factor analysis: a statistical method used to evaluate the grouping of common variables.

Fix2 – number of fixations two years below: an evaluation of a child's number of fixations while reading a passage two years below current reading level.

OMR – one minute reading: the number of words a child correctly decodes in one minute.

Orthographic processing: ability to identify words by sight, especially words that don't follow normal phonics rules.

PAL-RW – process assessment of the learner – reading and writing: a test battery used to evaluate the skills necessary for age appropriate reading and writing.

Partial squared: a statistic used in regression analysis to determine the unique portion of variance that an independent variable explains in the dependent variable

Pho – phonemes: a test used to evaluate a child's phonologic skills.

Phonologic processing: ability to sound out words based on letters sounds

Pseudowords: groups of letters that are decoded phonetically.

RAN – rapid automatized naming: a measure of a child's ability to quickly identify letters, numbers, pictures, or colors.

RANL- rapid automatized naming - letters: a test of a child's ability to quickly read letters.

RC – receptive coding: a test of orthographic processing

Reg – number of regressions two years below: the number of a child's right to left eye movements when reading a passage two years below grade level.

RMSEA – root mean squared error of approximation: a model fit index in which a value of 0.08 and lower indicates a good fit.

RN – rapid naming: a test of a child's ability to quickly identify pictures.

SEM – Structural equation modeling: a more advanced analysis used to evaluate complex relationships between variables using multiple regression analysis.

SS – sentence sense: an evaluation of a child's orthographic skills.

Standardized RMR/SRMR - standardized root mean residual: a model fit index in which a value above 0.1 indicates a poor fit.

Syll – syllables: a measure of a child's phonologic skills.

VT – vertical time: an evaluation of a child's ability to rapidly read vertically arranged numbers.

WC – word choice: a measure of a child's orthographic skills.