



THE EFFECTS OF MAGNO-PARVOCELLULAR INTEGRATION TRAINING ON FLUENCY AND VISUAL EVOKED POTENTIALS IN POOR READERS

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Abstract

Previous studies have documented abnormally low coherent motion (CM) sensitivity as well as lower Visual-Evoked Potential (VEP) amplitudes in poor readers. Both measures are correlated with the operation of the magnocellular (M-Cell) visual system, generally, and specifically its ability to provide motion information necessary for fluent reading. The current investigation replicated these findings and sought to normalize CM and VEPs using software designed to facilitate proper integration of M-Cell and parvocellular inputs (PATH Training). Comprehension, attention, vocabulary, and phonological decoding measurements were made before and after training. Objective fluency recordings were made using the Visagraph and structured reading practice was provided using the Guided Reader from the Reading Plus program. Significant changes occurred in VEP amplitude, CM threshold, and some of the fluency measures, suggesting PATH training is associated with positive, neural reorganization. Limitations and implications of the findings are discussed, with suggestions for future research

Key Words

fluency, magno/parvo visual pathways, path training, reading disability, visual-evoked potentials

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The American Psychiatric Association has defined a reading disability (RD) as a significant deficit in a person's actual reading level from what is appropriate for their chronological age.¹ Dyslexia is a specific type of RD characterized by inaccurate word decoding ability, the inability to recognize words while reading, erroneous spelling,² and poor phonological awareness (PA),³ or the inability to recognize certain word sounds.⁴ Many scientists now believe that RD's, such as dyslexia, not only result from abnormal PA, but that some visual processing dysfunctions also contribute. In particular, much attention has been given to the magnocellular (M-Cell), or dorsal stream deficit hypothesis.⁵⁻⁷

The Magno- and Parvo-cellular Visual Pathways

The M-Cell pathway consists of large cells that conduct information originating primarily from the retinal rod cells that are found most densely in the parafovea. These M-Cells are useful in detection of differences in illumination and motion detection, but not color processing. By contrast, the parvocellular (P-Cell) pathway primarily receives input from the color-sensitive retinal cone cells. The P-cells are found mostly surrounding the fovea of the retina, where cone receptors are most densely located.⁸ Information transmitted through the M-cell pathway is sent through the M-ganglion cells to the lateral geniculate nucleus (LGN) of the thalamus. This information from the LGN is then sent to layer VI of the primary visual cortex, then along the dorsal pathway to the parietal lobe of the brain where it is further processed. This dorsal pathway to the parietal lobe is commonly referred to as the "where" pathway because it is

responsible for determining the object's position in space.⁹ Because the M-Cell pathway is critical for motion detection, it has the potential to impact the reading process in several possible ways.

Among other things, most versions of the M-Cell deficit theory posit abnormal neuronal development in the larger cellular pathways of the brain, and that this can lead directly or indirectly to abnormalities with the temporal aspects of information processing.^{5,7,10-12} Critics of the M-Cell deficit hypothesis have noted that the evidence has been mixed depending on the task, and subject population, with some studies showing no differences between normal and dyslexic readers.¹³ More recent reviews of the M-Cell deficit theory have concluded that the "evidence is broadly consistent with the idea that the dorsal visual stream is affected in developmental disorders. However, the potential for a unique profile of visual abilities that distinguish some of the conditions is posited, given that for some of these disorders ventral stream deficits have also been found."⁷

In a recent meta-analysis of the literature on coherent motion threshold perception (CMT), a common task used to indirectly measure M-Cell functioning, the mean effect size for differences between dyslexics and age-matched controls was large ($d = 0.747$, $n = 2334$). The authors conclude that it is important to examine motion perception deficits in RDs, but that the deficits in CM are consistent with either a global noise exclusion deficit,¹⁴ or a dorsal stream impairment involving the M-Cell system. Boden and Giashi reviewed the literature on the M-Cell system and reading.¹⁵ Out of seven possible mechanisms by which M-Cell deficits could impact

reading, they argue that disordered oculomotor control and visual attention are the most likely means by which reading could be negatively influenced.

In a series of studies that tested the hypothesis that oculomotor control, visual attention, and reading performance are linked, Solan et al employed educational, perceptual, and cognitive tests to first establish that poor reading performance was correlated with visual attention problems¹⁶ and putative measures of M-Cell functioning, such as the CMT task.¹⁷ During the CMT test¹⁸ participants observe two rectangular patches on the screen, side by side, separated by 5 degrees, each with 150 white dots presented on a black background. In one rectangle, all dots appear to move randomly in a Brownian motion (random walk), while in the other rectangle a varying percentage of the dots appear to move horizontally. Participants must select the rectangle that contains the horizontal motion, under increasing levels of discrimination difficulty. CMT has been shown to correlate with reduced cortical activity in dyslexic as compared to control adult readers, bilaterally in the area of the occipital-parietal junction (MT). MT in humans is located at the occipital-parietal junction bilaterally. It receives and integrates inputs from the M-Cell and P-Cell systems.

Enhancing M-Cell/P-Cell Pathway Integration

Solan et al¹⁹ demonstrated that temporal vision therapy for middle school poor readers both improved M-Cell processing (as indexed by CMT), and raised reading level significantly (half of the participants' reading level was raised by at least two years). The therapy in that study emphasized development of top-down visual attention, and may have indirectly enhanced M-Cell functioning through repeated processing of low to mid-range spatial frequencies and selection of moving targets. It is also possible that attention training acted indirectly to enhance the selection and/or processing of stimuli from the visual environment.

The studies of Solan, Shelley-Tremblay and colleagues suggest that visual attention is malleable and so is CMT, the index of M-Cell processing.^{16,19,20} What has been missing thus far in the literature has been evidence that demonstrates more directly what mechanism of action best explains the changes in CMT, attention, and fluent reading observed in the literature.

Interestingly, the work with Visual Evoked Potentials (VEP) in the hearing and deaf communities provided the needed bridge to allow for such a study.

VEPs and Reading Disability

Samar et al²¹ investigated the M-Cell deficit hypothesis in congenitally deaf individuals with dyslexia. These authors used high and low contrast reversing checkerboard patterns to yield VEPs that stimulated P-Cell and M-Cell pathways, respectively. Deaf, poor readers displayed an abnormal absence of contrast-sensitive VEP responses at occipital sites during early visual processing (75 ms post-stimulus), whereas deaf good readers showed the expected early contrast-sensitive occipital VEP responses.

Romani et al²² confirmed the presence of M-cell malfunction in individuals with dyslexia and normal hearing using VEP as well. They used a similar checkerboard pattern stimulus to stimulate the M-Cell pathway selectively. They reported an N70 and P100 under low (M-Cell) and high (P-Cell) spatial frequency version of their stimuli. The VEP amplitudes of dyslexic subjects significantly differed from those of non-dyslexic control subjects at the N70 component, but only under the low spatial frequency condition. Thus, it appears that their dyslexic subjects' visual abnormality was somewhat functionally isolated to the M-Cell pathway.

In a related study using reversing checkerboards with middle school students, Branan et al varied the luminance, spatial frequency, and reversal rate of their stimuli in a group of RD students with normal hearing.²³ Under the low luminance (M-Cell) condition, VEP amplitudes were significantly lower for poor readers than for normal readers. Taken in conjunction with the other studies, these data suggest that VEPs may be an important indicator of the presence of visual dysfunctions associated with poor reading.

The VEP studies suggest that poor readers have significantly lower amplitude re-

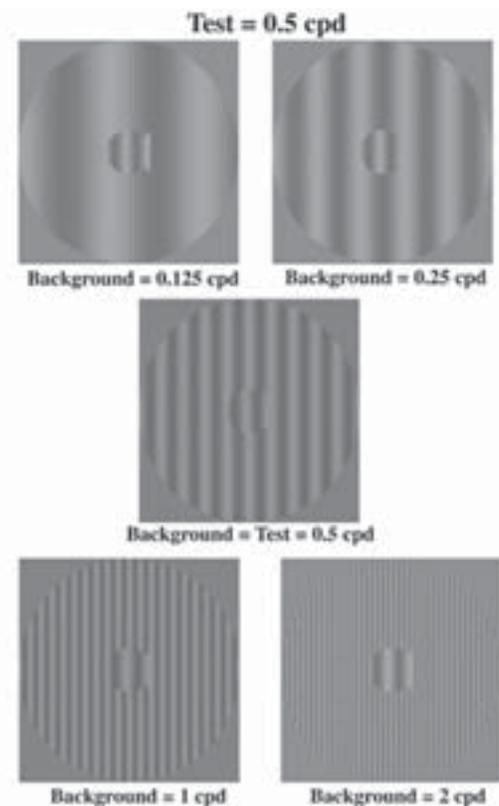


Figure 1. Sample Frequency Patterns Used in PATH Therapy (0.5 cyc/deg with Different Backgrounds)

sponses to M-Cell selective stimuli. What remains to be demonstrated is whether VEP amplitudes can be increased using a training regimen. Attention plays a large role in the training methods employed by the Solan group. Changes in attention may be able to account for the improved CMT threshold. This makes it difficult to determine if the effects reported by Solan et al resulted in changes in M-Cell functioning. What is needed is a relatively "low-level" way to selectively train the M-Cell pathway and facilitate its interaction with the rest of the visual system necessary for fluent reading.

One such training program is the PATH software.²⁴ The designer of PATH has argued that developmental abnormalities within the M-Cell visual pathway can contribute to RDs in children. PATH training uses a series of grayscale stripes that differ in width and contrast with each trial. (Figure 1) A target area in the shape of a fish, also of grayscale stripes, is located in the middle of the background stripes. The stripes in the fish move either to the left or the right, and the child must discriminate the direction the stripes are moving in each trial.

Experiments have found that PATH improves reading fluency by improving

Table 1. Educational Tests* and Instruments

Ref	Title	Author/Developer	Publisher & City/Available from
24	PATH Therapy	Lawton	Perception Dynamics Institute: Del Mar, CA
26	Reading Plus	Taylor	Taylor Associates: Huntington, NY
25	Gates-MacGinitie Reading Tests, 4th ed (GMRT)*	MacGinitie et al	Riverside Publishing: New York
18	Coherent Motion Threshold (CMT)	Hansen et al	Dept of Physiology, Anatomy and Genetics, Sherrington Building, Parks Road, Oxford, UK OX1 3PT
27	Woodcock Johnson Non-word Test (WJN)*	Woodcock et al	Riverside Publishing: Itasca, IL
28	Peabody Picture Vocabulary Test (PPVT)*	Peabody	American Guidance Service: Circle Pines, NM
29	Das-Naglieri Cognitive Assessment Test (CAS)*	Naglieri & Das	Riverside Publishing: Itasca, IL
30	Gray Oral Reading Tests, Third Edition (GORT)*	Weiderhold & Bryant	PRO-ED: Austin, TX
31	Test of Word Reading Efficiency (TOWRE), Subtest of the Comprehensive Test of Phonological Processing*	Wagner et al	PRO-ED: Austin, TX
32	Visagraph III™	Taylor	Taylor Associates: Huntington, NY

direction discrimination ability.²⁴ Prior to training, children with RDs are three times as likely to give the incorrect direction of the moving stripes compared to “normal” readers. Following training, the direction discrimination for RD subjects improved between three and four fold. Additionally, the participants’ reading speeds increased compared to pre-training.

The purpose of this study was to analyze the effects of the PATH program on grade-school childrens’ VEPs, CMT, visual attention, and reading. We trained students with RDs with the PATH program followed by a Guided Reading story from the Reading Plus program and compared their VEP results with the VEPs recorded prior to training. The PATH training has been shown to improve fluency and speed of reading,²⁴ but it is not known if a child with a RD who undergoes PATH training would have a positive change in their VEPs.

Materials & Methods

Participants

Elementary and middle-school students (n = 13, m = 9, f = 4) from Catholic schools in Mobile, Alabama, were referred by school reading specialists due to below normal classroom reading performance. Participants (mean grade level = 4.6, mean age 10.13 years, SD = 1.75) were pre-screened by means of

Gates-MacGinitie Reading Tests Fourth Edition²⁵ (GMRT) and found to be on average .92 years (SD = 1.14) behind. Students reported normal or corrected to normal vision. Parent and school reports were used to confirm the absence of primary visual problems. Parents of students (n = 7) who were also being treated for ADHD were instructed to not administer the medications for 12 hours prior to testing or training.

Testing Materials and Protocols

In order to participate, subjects underwent a screening process. All tests were conducted in the psychophysiology laboratory in the Psychology Department at the University of South Alabama. For the screening process (Pre-Test), students took a series of seven educational tests, along with a VEP recording. The subjects were tested a total of three times, but the results from the second round of testing are not presented in this paper due to a mechanical malfunction in the VEP instrument. Thus, the third round of testing is referred to as the Post-Test to designate any assessments made after the completion of training, while Pre-Test represents all assessments made prior to any training.

Measurement Instruments

All tests and instruments are detailed in Table 1. Detailed descriptions of each measure are presented in Appendix A.

Reading Therapy

The PATH training uses a series of gray-scale stripes that differ in width and contrast with each trial, which is displayed in Figure 1. A target area in the shape of a fish, which also consists of grayscale stripes, is located in the middle of the background stripes. The stripes in the fish move either to the left or the right, and the child must discriminate which direction the stripes are moving in each trial. The width of the striped patterns on striped backgrounds, and amount of movement are designed for maximal activation of motion sensitive cells. The contrast of the center stripes is also varied using a proprietary algorithm. Additional detail can be obtained in the work of Lawton.²⁴ A description of Reading Plus, which was used after PATH, is included in Appendix B.

VEP Task

The stimuli presented to the subjects were designed to stimulate the M-Cell pathway. The stimuli, consisting of 5 x 5 alternating black and dark grey checkerboards patterns, were designed according to those utilized by Samar et al.¹⁷ A normal checkerboard and a reverse checkerboard were presented in an alternating pattern, with 400 alternations at 500 ms per alternation. A white plus sign placed in the middle of the screen gives participants a focal point. Each section of the checkerboard measured 2.4 inches by 1.8 inches. The patterns of the checkerboard were composed to produce an approximate 0.2 Michaelson contrast ratio. The 0.2 Michaelson contrast ratio is yielded by the equation $(\text{luminancemax} - \text{luminancemin}) / (\text{luminancemax} + \text{luminancemin})$.¹⁷ The brightness of each check was assessed with a digital luminance meter. The average luminance measured for the black checks was 5.00 cd/m², while the average luminance for the dark grey checks measured to be 7.35 cd/m².

The checkerboard stimuli were displayed on a 15 inch standard flat screen monitor. The subject sat in a chair at arm’s length away from the computer screen. The participants were asked to sit as still as possible without talking and to focus on the white plus sign located in the center of the checkerboard. The opposite checkerboard pattern interchanged 400 times, with each alternation occurring every 500 ms for a total time of three minutes and 20 seconds.

VEP Recording Sessions

Following the pre-tests and Visagraph, subjects underwent the VEP recordings. These recordings occurred both before

and after the PATH training program. The VEP session entailed the placement of a forty electrode QuikCap cap on the head of the participant, fitted more securely with a Velcro chin strap. Separate electrodes were also placed on the right and left temples, below the left eye to record eye blinks, and on the tip of nose to act as a reference point. Scalp EEG was recorded from channels in the occipital and parietal areas including: PO1, PO2, O1, Oz, and O2. Impedances were kept below 5 milliohms. EEG was digitized at 1000 Hz, with a 60 Hz online notch filter. EEG was filtered from .1 to 30 Hz prior to averaging. VEP epochs were formed for artifact-free trials from -100 to 500 msec around checker stimulus onset.

Procedure

Each PATH training session also took place in the psychophysiology laboratory on the University of South Alabama campus. The IRB of the University of South Alabama approved the study, and all children and parents signed consent forms prior to the initiation of the study. All subjects ($n = 13$) received standardized tests of comprehension, vocabulary, attention, oral reading, non-word decoding, and dyslexia symptoms. These were administered along with VEPs, CM, and objective Fluency (eye tracking) measurements that were made before training (Pre-Test). Participants attended training sessions three times per week for 6 weeks. The training entailed 18, 30-minute sessions using the PATH software. For all participants, the PATH sessions were followed immediately by reading two stories from the Guided Reader module of the Reading Plus program, which equated to about twenty minutes of reading and comprehension questions from a grade-normalized series of stories. This was done because the developer of PATH requires that reading occur for each participant following training, and Reading Plus provided as excellent means to control the difficulty and duration of reading practice in a grade-normed format.

RESULTS

VEPs

Visual evoked potential recordings were processed, and grand average VEPs were created for all subjects, pre and post-training. VEPs showed the anticipated P155 peak.¹⁷ As seen in Figure 2, Pre and Post VEP mean amplitudes were compared using separate ANOVAs that revealed significant changes in the VEPs at Oz and

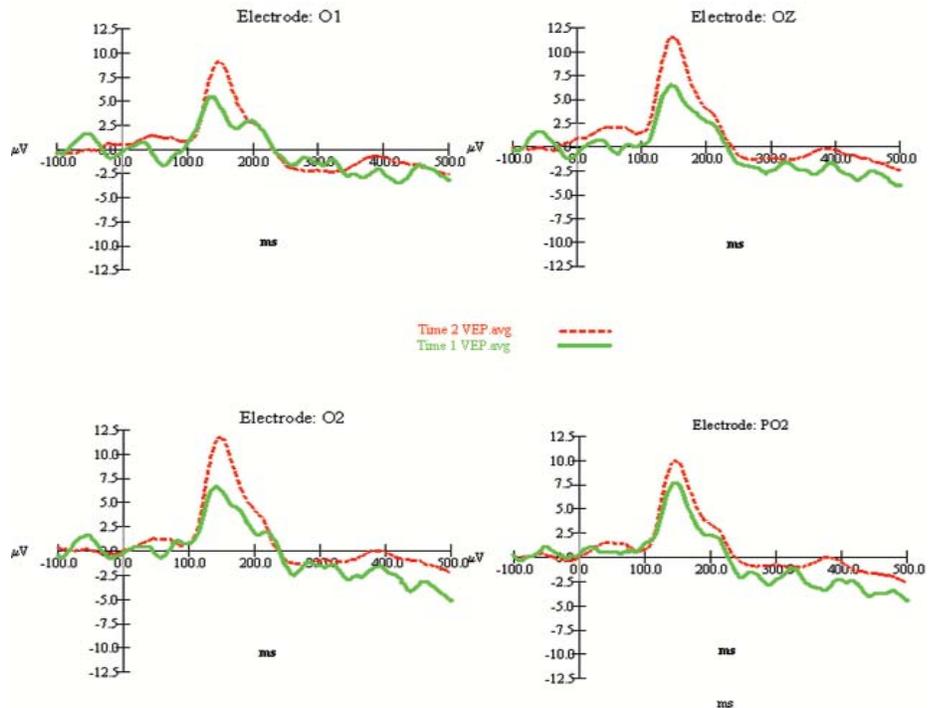


Figure 2. Visual Evoked Potentials at Time 1 and Time 2.

O2, [(1,12) = 7.96, $p = .015$; $f(1,12) = 6.21$, $p = .028$, respectively].

CMT

Our second primary measure of M-Cell functioning was performance on the CMT task. Participants pretest mean CMT score was 17.78 (SD = 15.18), which is highly elevated compared to thresholds for normal readers in previous studies.¹⁵ A univariate ANOVA was performed to compare the pretest mean to the posttest mean, 6.43 (SD = 5.43), yielding significant results, $f(1,12) = 8.898$, $p = .012$.

Other Measures

A MANOVA on the educational tests including the GORT, and TOWRE revealed no significant increase in performance, with the PPVT only showing a significant change from Pre-Test to Post-Test on a planned comparison, $p = .025$ (see Table 2). The WJN approached significance ($p = .053$). The GMRT reading comprehension test exhibited no significant improvement from Pre-Test (average Grade Equivalent 3.6) to Post Test (3.78), or a change of .18 school years (10 month year). A t-test on the CAS Expressive Attention (CAS-EA) Test Scaled Score (similar to Stroop Test, see above) yielded a non-significant trend toward improvement, $t(12) = 1.889$, $p = .083$. The mean CAS-EA scaled score changed from 8.3 to 9.61.

The Visagraph III™ yielded fluency measurements for eye movements with dependent variables of Fixations, Duration of Fixation, Regressions, and Rate. Table 3 displays the mean values for each measure at Pre-Test and Post-Test. Univariate ANOVAs revealed significant reductions in Fixations and Regressions. The change in Rate was not significant, but the increase of 32 words per minute may nonetheless be of interest to clinicians and educators.

Discussion

VEP results revealed the expected P155 peak,¹⁷ which has been associated with M-Cell contribution to the motion processing function of cortical area MT, as assessed by PET scans.⁴ The low amplitude of the P155 peak at Pre-Test is consistent with the idea of a deficit in the M-cell system. Furthermore, the significant increase in amplitude of this peak at Post-Test indicates that PATH therapy may be effective at ameliorating M-Cell/P-Cell interaction deficits. Convergent evidence for changes in the visual system was provided by a significant decrease in CMT, indicating a greater sensitivity to lateral motion embedded in noise following training. One issue of primary interest was if the PATH training would lead to changes in visual attention and to top-down enhancement of visual functioning, as opposed to more

Table 2. Effects of training on Educational Dependent Measures

Pairwise Comparisons for Educational Tests					
			Mean Difference Pre-Post	Std. Error	Sig.
WJN	1	2	-2.000	.921	.053
	2	1	2.000	.921	.053
GORT	1	2	.500	2.148	.820
	2	1	-.500	2.148	.820
PPVT	1	2	-.926	.358	.025*
	2	1	.926	.358	.025*
TOWRE	1	2	-1.833	1.942	.365
	2	1	1.833	1.942	.365

WJN = Woodcock Johnson Non-word Test; GORT = Gray Oral Reading Test; PPVT = Peabody Picture Vocabulary Test; TOWRE = Test of Word Reading Efficiency

* Denotes significant change, alpha = .05

Table 3. Visagraph Eye Movement Data from the Right Eye

Descriptive Statistics					
	Mean	Std. Deviation	N	F	P
Pre Fixations Rate	180.2308	58.65884	13	5.153	*.042
Post Fixations Rate	160.5385	57.33907	13		
Pre Duration of Fixation	.3292	.04192	13	1.105	.314
Post Duration of Fixation	.3515	.10073	13		
Pre Regression	46.9231	22.92183	13	6.399	*.026
Post Regression	36.9231	17.85806	13		
Pre Reading Rate	102.7692	45.68215	13	3.055	.106
Post Reading Rate	134.4615	59.13630	13		

* Denotes significant change, alpha = .05

basic M-Cell/P-Cell integration. While the CAS did improve slightly, the change was not significant, and it seems unlikely that visual selective attention can account solely for the large changes in VEP amplitude and CMT observed in the present data set.

The PPVT was the only reading skills-related test that showed significant improvement post training. This test is often substituted for the Wechsler Adult Intelligence Scale (WAIS) verbal intelligence score and, depending on the version, correlates with the WAIS at $r = .83$. This is interesting because intelligence is usually thought to be relatively stable. However, a series of studies by Posner et al²⁹ highlight the ability of dynamic, computer-presented arrays to reconfigure anterior attention networks. The attention training, similar to PATH, employed in his research utilizes the mass repetition of visual stimuli, requiring subjects to sustain attention and make many trial-by-trial decisions. His results have shown that training has its greatest effects on measures of intelligence, as assessed by Kaufman's Brief Intelligence Test.

The GMRT reading comprehension test revealed no significant improvement from Pre-Test. The training took place in the summer for most students, so this may represent an educationally but not statistically important change. The Visagraph measurements showed progress in the number of reflexive regressions and fixations made by the children. These two components of fluency have previously been diagnostic of poor reading,²⁶ and their amelioration denotes that some

of the ocular-motor efficiency needed for fluent reading may be enhanced by the current training regimen.

Despite progress in the eye movement measurements and VEPs, direct measures of reading ability, such as comprehension, oral reading ability, or decoding were not significantly improved by the training. Thus, if the study were to be repeated, the PATH manufacturer has recommended a longer duration of product use to achieve gains in reading, which would ideally be at least one semester.

Conclusions

This study is the first to document that poor readers who demonstrate low amplitude VEPs can increase those VEPs to more normal levels using repeated practice. These changes were accompanied by additional improvements in CMT and fluency as measured objectively by fixations and regressions. Future studies should attempt to utilize additional functional neuroimaging methods including fMRI, PET, and other hemodynamic measurements to determine more precisely the nature of the system that is being affected by PATH training. In addition, extensive educational and psychological testing would permit the accurate placement of future participants into diagnostic subgroups of dyslexia.

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Note

The authors have no proprietary interest in any of the tests or instruments used in this study.

Sources (for tests)

See Table 1.

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Appendix A. Measures

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*Gates-MacGinitie Reading Tests-Fourth Edition (GMRT)*²⁵

The Gates-MacGinitie Reading Test, Fourth Edition (GMRT) (MacGinitie & MacGinitie, 2000) is a silent paper and pencil multiple-choice reading test that reveals each subject's actual reading level. Test forms used in this study ranged from the second to tenth grade levels. In the second grade level, the student was instructed to match the picture that corresponded with the provided sentence. On the remaining levels, students read passages and then answer questions on the passages.

In order to qualify for participation in the study, subjects must have tested two or more years behind in their reading level in the results from the GMRT. The participants completed only the comprehension section of the test for the grade level they would be entering in the fall, and a Grade Equivalent was established for each subject based on his or her comprehension score.

*Woodcock Johnson Non-word Test (WJNWT)*²⁷

The Woodcock Johnson Non-word Test (WJNWT) evaluates the participant's ability to acquire phonemic or sound information from a list of clusters of letters that do not form actual words. The student is instructed to sound out each item on the list to the best of their ability. Depending on how many items are pronounced correctly, the WJNWT derives an Age Equivalent score, as well as a Grade Equivalent Score.

*Peabody Picture Vocabulary Test (PPVT)*²⁸

The Peabody Picture Vocabulary Test (PPVT) (Dunn & Dunn, 1981) is an assessment of verbal ability for ages 2- ½ to 90+ years. The administrator orally presents a stimuli word in English, and the subject must point to the picture on the page that best corresponds to the stimuli word. The illustrations are presented in a flip book. There are four black and white illustrations per page of the book, and each participant must choose their answer from one of the four pictures.

*Das-Naglieri Cognitive Assessment Test (CAS)*²⁹

The Das-Naglieri Cognitive Assessment Test (CAS) is a clinical tool used to mea-

sure a child's intelligence formulated from his or her performance on a series of cognitive tasks. One precise task noteworthy to this study is the receptive attention subtest, which tests the subject's ability to alter his or her attention and to selectively attend to specific stimuli. One part of this subtest is very similar to the Stroop test. First the subject must read the names of colors (Red, Blue, Green, Yellow) on the first page while being timed. The next page consists of several colored blocks arranged in rows, and the student must recite the color of the ink the blocks are printed in going across the page while being timed. This page utilizes the same four colors as the previous page. The last page is composed of the names of the four colors once again; however, the color words are all printed in one of the three other colors of ink. For instance, the word "Blue" is printed in yellow ink. The participant is asked to state the color of the ink each word is printed in while being timed. This page normally takes longer than the previous two because the participant must focus and alter his or her attention during this task.

*Gray Oral Reading Tests, 3rd Edition (GORT)*³⁰

The Gray Oral Reading Tests, Third Edition (GORT) assesses a student's oral reading ability, taking into account rate, accuracy, and comprehension. Because the GORT consists of two corollary forms, A and B, each containing 14 stories with five multiple choice questions, it is productive in measuring a change in oral reading ability due to the effects of a reading training program. The GORT is additionally useful in the diagnosis of oral reading disabilities.

Test of Word Reading Efficiency (TOWRE) from the Comprehensive Test of Phonological Processing.³¹

The Test of Word Reading Efficiency (TOWRE) is a phonological test, assessing fluency and accurate pronunciation. The two TOWRE subtests utilized for this study evaluate Sight Word Efficiency and Phonemic Decoding Efficiency. The participant has 45 seconds to correctly read as many of the words on the two lists as possible. The TOWRE is instrumental in indicating progress in sight word reading and phonemic skills.

M-Cell Functioning

Coherent Motion Threshold (CMT)¹⁸

The Coherent Motion Threshold (CMT) is performed on a computer. For this test, the participant was instructed to sit at an arm's length away from the computer screen. During testing, the screen was black with the exception of two adjacent rectangular patches consisting of white dots. In one of the rectangles, the white dots move in a Brownian motion, but in the other rectangle, a varying percentage of dots move horizontally back and forth, while the remainder of the dots move in the Brownian motion. The participant is instructed to select the rectangle consisting of the horizontally moving dots, while the levels of discrimination difficulty increase and decrease.

Eye Movement Recording

Visagraph

Prior to training, participants participated in a Visagraph IIITM session, a 5 minute eye movement recording. The Visagraph IIITM uses infrared light to track subjects' eye movements while reading a brief paragraph on their grade level as determined by the Reading Plus program. The administrator fits the Visagraph IIITM on the participant's face so that the white lines of the eyepieces are aligned with the center of the participant's pupils. This alignment allows the infrared system to track the pupils' movements across the page. As the student is reading, the computer screen displays a simulation of the movements of each eye. Next, the subject answers ten comprehension questions corresponding to the paragraph previously read.

Finally, the computer supplies several measures derived from the infrared recording, including fixations, duration of fixation, regressions and rate. A fixation concerns the amount of "eye-stops" or hesitations between saccadic eye movements that take place for every 100 words in the paragraph. Furthermore, the duration of fixation equates to the time length in ms in which a fixation lasts. A regression refers to the amount of right-to-left movement of the pupil, which is opposite of the conventional direction of reading. However, the regression count does not take into consideration the end-of-line return sweeps. The rate refers to the number of words read by the student per minute. The rate is calculated by an algorithm, dividing amount of time it took for the student to read the paragraph by the

number of words contained in the specific paragraph read by the student.

Appendix B. Reading Plus

Reading Plus²⁶ is a computer-based reading program from Taylor Associates. The participants were assigned to the Guided Reading (GR) program of Reading Plus, only. GR enhances student's reading rate and comprehension. Each level of Guided Reading has a selection of approximately 20 stories for each student to choose from. Once the student selects the story he or she wishes to read, the student is instructed to fill in the blanks of some sentences that introduce vocabulary words present in the chosen story. Next, the story is presented in two formats: Independent Rate and Guided Rate. The former format presents the story in paragraph form to allow the student to read at a convenient pace. After this rate is established, stories are then presented in the Guided-Rate format. This format presents the story in a line by line fashion. Following each story a series of reading comprehension questions is asked.

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