THE EFFECT OF VISUAL-SPATIAL STIMULATION ON EMERGENT READERS AT RISK FOR SPECIFIC LEARNING DISABILITY IN READING

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This study compared word recognition for words written in a traditional flat font to the same words written in a three-dimensional appearing font determined to create a right hemispheric stimulation. The participants were emergent readers enrolled in Montessori schools in the United States learning to read basic CVC (consonant, vowel, consonant) words and who were being taught with similar educational methodology. Analysis of error types for readers in the lower 20th percentile showed that vowel or consonant substitutions were more frequent for males than females ($p < 0.07$), errors in which the students rhymed the word incorrectly with the previous word were more frequent in males ($p < 0.026$), and word guessing errors were more frequent in older students ($p < 0.022$). Letter/word transpositions (e.g., b/p; t/f; whole word, such as nap/pan were moderately more frequent for traditional flat print words ($p < 0.043$). Among the 23 students who scored in the lowest 10th percentile (fewer than 42 out of 52 traditional flat print words read correctly), 9 increased their score by at least 10% in the three-dimensional appearing font when compared to their traditional flat print score; 5 of them increased by at least 20%. The largest improvement was from 35 traditional flat print words to 44 three-dimensional appearing prints, which translates to a 25.7% gain. For the student at risk for either a specific learning disability in reading or dyslexia, the use of three-dimensional font may provide enough a right hemispheric catalyst to increase the number of words recognized and read correctly.

The No Child Left behind Act of 2001 and the Individuals with Disabilities Education Act of 2004 direct the schools of the United States of America to teach all children to read. The National Reading Panel (2000) specifies that the use of explicit and systematic classroom reading instruction must include phonemic awareness, phonics, oral reading fluency, vocabulary, and comprehension strategies in order to be considered best practice. Although instruction that includes these components is present in state common core content standards such as those required of Ohio schools (English Language Arts Common Core State Standards , http://www.ode.state.oh.us), there are children who, for a myriad of reasons, cannot read on grade level. In October of 2011, forty one percent of Ohio students achieved less than a proficient score on the Grade 3 Reading Achievement Test (Ohio Department of Educational Testing, 2011). In 2010 sixty-eight percent of American public school students were not reading at grade level (Children's Defense Fund, 2010). Dyslexia is a specific learning disability and it explains the reason that at least some of these students are not reading at grade level. According to research conducted by Williams and Lynch (2010), *In the public schools in the United States, the terms reading disability and learning disability are more likely to be used than dyslexia because most states do not have programs specifically addressing dyslexia.* (p.68)

Howes, Bigler, Burlingame, and Lawson (2003) proposed that children (age nine to twelve) with reading difficulties fell into three subsystems: the Phonological Deficit Hypothesis, the Dual Route Model, and the Phonological Core Variable Difference Model. All three models resulted in serial memory deficit; the Dual Route in verbal and serial memory deficits; and the Phonological Core Variable Difference Model in visual-spatial and serial memory deficits. In reporting Howes et al., our interest focuses on the visual-spatial component, as this component was a factor in our study. Participants in Howes et al. were tested for their visual-spatial memory (right hemisphere activity) using the Visual Selective Reminding and Memory for Location subtest of the Test of Memory and Learning (TOMAL). A comparison was made among children with reading difficulties and two control groups, their chronological aged peers without reading difficulties and a group of younger readers determined to have a lower reading level. The testing indicated that children with reading difficulties were significantly outperformed by their chronologically same-aged peers, but scored similarly to younger readers. Using the Dual Route Model students with reading difficulties divided into the two subtypes, phonological and surface dyslexia, were significantly lower on visual-spatial memory. Using the Phonological Core-Variable Model children with reading difficulty divided into clusters: serial memory deficit only, combined verbal learning and serial memory deficit, combined visual-spatial and serial memory deficits, and serial memory deficits. On the visual-spatial memory tasks, the verbal learning and serial memory deficit cluster exhibited skills at the same level as those of the two control groups. Overall the Phonological Core-Variable Difference Model accounted for 28% more variance in visual-spatial memory than either of the other two models. Howes et al. stated that *verbal and visual-spatial deficits appear to differentially characterize memory problems of specific dyslexia subtypes, whereas all subtypes show serial memory impairments* (p.243).

Findings of Howes et al. (2003) leave unexplored the possibility that each subtype, while having a specific area of deficit, may concurrently have a specific area of strength. Variance reported for the cluster combined verbal learning and serial memory deficit in serial memory is .474 with a visual-spatial variance of .178 and a verbal variance of .375. This finding contrasted with the cluster results for visual-spatial and serial memory deficits of .343 in serial memory with a visual-spatial variance of .423 and verbal variance of .052. These variances possibly indicated areas of strengths as well as weaknesses. Students in the cluster who combined verbal learning and serial memory deficit had a smaller variance than their typical peers in the visual spatial component of the TOMAL. The results of Howes et al, suggest a question: are the strengths of the various subtypes revealed in their research indicative of parallel hemispheric variances? For example, are the majority of individuals with verbal learning and serial memory deficit characteristically stronger in visual-spatial tasks and if so, is this right hemispheric strength being used to compensate for left hemispheric weakness during language processing tasks?

Strengthening the premise of the importance of visual-spatial attention on reading, Lorusso, Facoetti, Paganoni, Pezzani, and Molteni (2009) determined that single hemispheric stimulation was a possible contributor to visual-spatial attention since such stimulation affects phonemic awareness and reading performance. Lorusso et al. classified children as dyslexic based on reading speed and reading errors, such as substitutions, omissions, fragmentations, or repetitions. Their study tested the effects of visual hemisphere-specific stimulation on reading and found that reading accuracy improved only in the group receiving hemisphere specific presentations, and not in the control group receiving traditional center presentation of stimulus. Furthermore, the researchers contented that *pressure on one hemisphere may result in a greater degree of automization of the component process* (p.208).

Lorusso et al. (2006) used a study by Bakker, Bouma, and Gardien (1990) as support for the concept of right hemispheric over-reliance in early reading strategies. Bakker et.al contended that young readers who skipped the visual-spatial stage of right hemispheric dominance and only use left hemispheric strategies at the onset of learning to read developed a *guessing* type of dyslexia where students are more likely to try to guess a word than to sound it out.

In 2002, Robertson and Baker determined that initial reading is mediated by the right hemisphere. The authors contend that skilled readers use a hemispheric shift from initial right cerebral hemisphere to the left cerebral hemisphere as their reading abilities develop. Individuals determined to have both a language and perceptual deficit do not make a hemispheric shift to the left cerebral hemisphere following initial reading instruction. In an article by Cooper, Ness, and Smith (2004), the authors discuss a case study that refers to the gifted student struggling to read as an individual with a *functional disruption in the brain that does not allow for cross-modal integrations, which are necessary for reading* (p.90). Tangent, and in support of the concept of functional disruption, Stothers and Klein (2010) determined that perceptual organizational test results were strong predictors of reading comprehension. These processes, referred to as nonverbal, were predictors of decoding and reading speed. The authors state that in their study right hemisphere functions work in conjunction with visual perception to affect language processing. *Just as left hemisphere deficits associated with phonological dyslexia impair word decoding and reading speed, right hemisphere deficits associated with nonverbal LD may impair reading comprehension* (p.213). The research of Stothers and Klein reinforced the position that *nonverbal* *integrative processes are used by readers with and without disabilities to understand text* (p.209); this research team determined that nonverbal, right hemisphere –biased processes that rely on perceptual organization significantly influence reading comprehension scores.

In 2005, researchers Smit-Glaude, Van Strien, Licht, and Bakker investigated the premise that *better visual spatial performance relative to verbal performance is thought to reflect a right hemisphere bias whereas better verbal than visual spatial performance is assumed to be indicative of a left hemispheric bias* (p.221). Their research used a selection of single target words designed to appeal to both left and right hemispheric preferences. To stimulate right hemisphere processing letters were flashed on the left field of vision and vice versa. Further right hemispheric stimulation was added by presenting perceptually demanding letters in type face with shadows or block appearance. Smit-Glaude et al. determined that the specific stimulation of the right hemisphere (possibly) had beneficial effects on emergent word reading for early readers showing relatively poor perceptual and relatively poor verbal skills but who were not *the worst of all poor readers* (p.236). Those students considered right hemisphere dominant did not benefit from left hemisphere stimulation while students who were left hemisphere dominant did increase early word reading with right hemisphere stimulation. Therefore, an early bias for right hemispheric word processing in emergent readers was an advantage. However, right hemisphere stimulation in children who were left hemisphere dominant and a risk for reading difficulty was the *most profitable to word and text reading in the long run* (p.242).

The concept of dyslexia as a distinct learning disability, a reading difficulty, first appeared in medical literature in 1896 when an ophthalmologist in Britain, W. Pringle Morgan, described the struggle to read for a young man named Percy. Percy received seven years of intensive direct instruction but never read at more than a basic level despite what was considered to be an advanced intelligence (Eide & Eide, 2011). Today, in the 21st century, who are the early readers whose reading difficulties are not responding to the daily reading curriculum offered in their schools? Are these early readers with poor perceptual and poor verbal skills children not yet labeled as a having a specific learning disabilities in reading such as dyslexia?

The definition of dyslexia varies throughout disciplines. From the perspective of educators, dyslexia is referred to as a specific learning disability. The Individuals with Disabilities Education Improvement Act of 2004 (IDEIA), a United States federal law, included dyslexia in the definition of Specific Learning Disability as: *A deficit in one or more of the basic psychological processes involved in understanding or in using language, spoken or written, that may manifest itself in the imperfect ability to listen, think, speak, read, write, spell, or to do mathematical calculations. The term includes such conditions as perceptual disabilities, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia* (IDEIA, 2004,§ 1401(26) (A); 34C.F.R. § 300.7(c) (10))

Williams and Lynch (2010) began their discussion of dyslexia and the American public school teacher with the definition of dyslexia established by the International Dyslexia Association. This definition describes dyslexia as a specific learning disorder with a neurological origin characterized by difficulties with: *accurate and/or fluent word recognition and by poor spelling and decoding abilities (*p.66) The definition states that there is an unexpected compromised phonological component that is not related to cognitive abilities or the quality of classroom instruction.

Looking at dyslexia from a medical perspective, the National Institute of Neurological Disorders and Stroke (2011), defines dyslexia as a: *brain-based type of learning disability that specifically impairs a person's ability to read. These individuals typically read at levels significantly lower than expected despite having normal intelligence. Although the disorder varies from person to person, common characteristics among people with dyslexia are difficulty with spelling, phonological processing (the manipulation of sounds), and/or rapid visual-verbal responding.* (Retrieved from http://www.ninds.nih.gov/disorders/dyslexia/dyslexia.htm)

Current research in neuroscience determined that the majority of dyslexia cases can be considered developmental. Developmental dyslexia manifests in early childhood and lasts throughout life. The trend in neuroscience is to concentrate on early detection of dyslexia in the emergent stages of reading, where *red flags* suggest that a young child may be at risk for dyslexia (Hudson, High, & Al Otaiba, 2007).

Just as definitions vary by discipline, research on the relationship between dyslexia and strengths in visual-spatial skills has resulted in contradictory findings. In 2001, seven researchers (Winner, Von

Karolyi, Malinsky, French, Seliger, Ross, and Weber) conducted three studies, concluding that deficits associated with dyslexia are not counterbalanced by visual-spatial talent. Russeler, Scholz, Jordan, and Quaiser-Pohl (2005) focused on the specific ability of second grade students to rotate mentally images of letters, pictures, and three-dimensional objects. The researchers found no significant relationship between developmental dyslexia and strong visual-spatial skills. However, in 2003, Von Karolyi and Winner, joined by two other researchers, Gray and Sherman, refocused the scope of the previous studies by examining global visual-spatial skills. The research team determined that individuals with dyslexia demonstrated superior global (or holistic) visual-spatial abilities, as opposed to local (or part-by-part) ability.

Von Karolyi (2001) continued her studies on the manifestation of visual-spatial strengths/talents in individuals with dyslexia. In her pilot study, Von Karolyi conducted a probe to assess the Diverging Abilities Hypothesis where strengths in processes controlled by one hemisphere of the brain are associated with deficits in specific processes in the alternate side of the brain. To test this hypothesis, Von Karolyi used a Celtic Matching Task designed to determine local visual-spatial processing mediated by left hemisphere brain activity. Her pilot study compared ten adults with reading disabilities to nineteen adults with no reported reading disabilities. The group with reading disabilities performed faster than the control group on the Celtic Matching Task. The results were significant at a pilot study level of $p<.089$. These results led Von Karolyi to pursue a study with a larger sample population ($n=66$).

The second study also used the Celtic Matching Task to determine visual-spatial ability and added the Impossible Figures Task. The Impossible Figures Task assessed individual ability to quickly determine if a figure can exist in a three-dimension space which is a global visual-spatial ability, an ability mediated by the right hemisphere of the brain. In the Celtic Matching Task boys with dyslexia performed significantly worse than the boys in the control group. On the Impossible Figures Task, overall individuals with dyslexia, regardless of gender, were significantly faster than the control group. Von Karolyi concluded, cautiously, that her research supported the Diverging Abilities Hypothesis.

Tafti, Hameedy, and Baghal (2009) studied students in Tehran who were identified with dyslexia. The results of the Cornoldi Memory Test found a significant difference in favor of the student with dyslexia as compared to the typical student in the area of pictorial (nonverbal) memory. Students with dyslexia had a significantly higher performance in visual-spatial tasks as compared to visual-semantic and verbal-memory tasks.

Brunswick, Martin, and Marazano (2010) tested the hypothesis that dyslexia is associated with superior visual-spatial skills. The team tested adult readers, twenty with known dyslexia, and a control group of twenty-one *unimpaired adult* readers using tests to measure *everyday* visual-spatial ability: Rey Osterriech Complex Figure which asked participants to copy figures; The Ambiguous Figures test which asked participants identify chimeric figures such as duck-rabbit; a Test of Commonplace Visual Spatial Knowledge such as which way the Queen‗s head faces on a British postage stamp and coin; the Herman Virtual Reality environment test which use a 3D software with colored graphics to create a virtual environment where the participants were asked to remember and complete tasks based on this memory; and the Gollin Incomplete Figure Test, where participants were timed on their ability to recognize developing images. Using all these tests, none of which have a reading component to them, the authors found no support for the premise that the entire group of individuals with dyslexia exhibited superior visual-spatial skills. However, a distinct gender difference in visual-spatial recognition was determined. Men with dyslexia demonstrated a significantly higher level ($p<.01$) of accuracy on the Wechsler Adult Intelligence Scale-Revised, 1981 when compared to women with dyslexia, and when compared to men without dyslexia, when reproducing designs using colored blocks. In the test of commonplace visual-spatial knowledge there was a significant relationship ($X2= 7.51$; $df=3$, $p=.05$): men recalled the direction of the queen‗s head on a stamp *more accurately that either the dyslexic women or the unimpaired men (*p. 424). Other tests in series confirmed that there may be a gender specific visual-spatial advantage rather than a *disorder in general* (p.424).

Facoetti et al. (2009) also researched the effects of exogenous spatial attention on phonological decoding. The researchers emphasized that spatial attention enhanced perception in visual tasks, allowing for decisions to be made on selected stimulus. Although *visual spatial attention is more important for non-word reading than word reading* (p. 1011), focused spatial attention was specifically involved in the sub-lexical route to reading, a route that involves spelling-to-sound mapping. Facoetti et al. concluded that specific instruction in visual-spatial attention had improved the reading performance of children with dyslexia.

In response to previous research on the possible influence of visual-spatial ability in the reading processes of students with reading difficulties such as dyslexia, we determined to assess whether right hemispheric stimulation during the emergent stage of reading would increase early word recognition. To decrease the influence of difference in reading instruction, our pilot and our main study sought emergent readers who were learning to read basic CVC (consonant, vowel, consonant) words and who were being taught with similar educational methodology. For this reason we chose emergent readers in Montessori schools in the same city in Midwestern United States of America.

Montessori preschool preparation in reading and writing is based on the principles and practices outlined by Dr. Maria Montessori (Montessori, 1967; Richardson, 1997). In Montessori education, indirect preparation for reading begins with the exploration of concrete materials including sandpaper letters and three-dimensional movable alphabet letters. *Because one of the underlying neuropsychological deficits in dyslexia is a problem in phonemic awareness and segmentation, one can appreciate the importance and significance of Montessori's early language exercises and their indirect preparation in the development of writing and reading* (Richardson,1997, p.249). Sandpaper letters are used to gradually develop phonemic awareness, the ability to associate phonemes and graphemes. As the child learns to discriminate the sensorial qualities of common materials, they prepare for object nomenclature. The movable alphabet exercises accompany sandpaper letters as children build words using three-dimensional wooden letters that can be held and manipulated. Both sandpaper letters and the movable alphabet incorporate a three dimensional quality. This structured, multisensory approach to reading is designed to promote phonological processing in early childhood students. Montessori materials and methods are used world-wide, and have a strong sense of educational tradition. Selecting our sample population from Montessori schools allowed this study to experience one less major variable: the influence of different teaching methods.

Pilot Study

The sample for the pilot study was selected from the student population of five private Montessori schools during the early Fall Semester of 2009. For the 116 students, ages five to seven years old, who participated in the pilot study, the average percentage of total words correct were 87.38% (45.44 out of 52 total phonetic words) for the traditional flat print format, with a standard deviation of 18.11%, or 9.42 words. In comparison, for the three-dimensional print format, the average percentage of total words correct was 87.31% (45.41 out of 52), with a standard deviation of 17.69%, or 9.20 words. When comparing the number of correct words for traditional flat print font, females (n=63) did better than males overall (n=53) (88.12% vs. 86.5%), although the difference was not significant. Each participant was shown various sequences of three-letter phonetic words: sequences were printed in New Times Roman font, and displayed in black ink on a white background. Moreover, participants were presented the sequences in two possible print formats: (1) traditional flat print format or (2) a three-dimensional print format where the print appears three-dimensional, perceptual demanding letters identical to the flat print but with shadows and a subtle block appearance. The order in which the print formats were presented to the participants was random. Print was presented in lower case. Figure 1, found in Appendix One, illustrates the difference in the print types.

Initially, the experiment required that participants read aloud the sequence of twenty-six words presented to them, and measurements of the number of words pronounced correctly and the speed at which the entire sequence was read were recorded. If pronunciation errors were made, the types of error (e.g., letter reversals, added syllables) were also documented. Upon completion of this first trial, a second trial immediately followed in which the participant read the same collection of phonetic words with the following modifications: (1) if the print format in the first trial was the three-dimensional print format, then the first set of print format of the second trial was the traditional flat print format, and vice versa; (2) the sequence was *shuffled*; i.e., the phonetic words were randomly permuted. These two trials were repeated at a later date, resulting in a total of four experimental measurements for each child participating in the pilot study. In addition, study participants were also questioned about print format preference.

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Major Study

The expanded study consisted of 214 emergent first-grade readers, ranging in age from 70 months to 95 months, sampled from three public Montessori schools in the same Midwestern city as the pilot study. All participating students (and parents) were required to sign an informed consent form. Teachers in the schools were in support of the research. District permission to do research in the schools and university IRB procedures were followed. Permission was obtained from the school district and each school principal to test students individually during the school day. The two primary researchers conducted the tests in the morning, during September, October, and November, 2010. The procedure for testing was the same as in the pilot study except response time was not recorded since time was not found significant in the pilot. Students were tested in their classrooms with the researchers sitting at a small table in the back of the classroom. Researcher A, a Ph.D. special education faculty member, recorded the exact word spoken by the student while Researcher B, an Ed.D. Faculty in Montessori education presented the cards in sequence directly to the center of the student‘s visual field. Students who could not pronounce the word were permitted to state SKIP. No form of reinforcement was used following pronunciation. To be considered an emergent reader and not an outlier, the student must have read five or more words out of the first twenty-six words presented. Words for the test were chosen by Researcher C, a Fellow of the Academy of Orton Gillingham Practitioners and Educators with knowledge of the presentation of dyslexia. In order to support ease of decoding for emergent readers the following rational supported the choice of words:

1. use of word families
2. emphasis on /ă/: easiest of short vowels; 16 out of 26 words
3. /ĭ/ and /ŭ/ are not easily confused with /ă/[:]
4. no /ŏ/: visual similarity to the letter ‗a‘;
5. no /ĕ/: auditory similarity to /ă/ and /ĭ/;
6. no ‗d‘: to avoid b/d confusion
7. no ‗l‘: occasionally mistaken for capital-i (I)
8. no ‗qu‘ or ‗x‘: complex (two sounds)
9. no ‗y‘: lesser known, often challenging

Researcher A&B entered the data into spreadsheets. Experimental design and data analysis were performed by Researcher D, a Ph.D. Statistician.

Analysis

Of the 214 students participating in the study, fifty-six showed improved reading fluency (i.e., pronounced more words correctly) with the three-dimensional print format. Sixty-three students performed worse with the three-dimensional print, and ninety-five showed no difference. For these three groupings, the average (percentage) total number of correct traditional flat print format words was 44.44 (85.46%), 47.08 (90.54%), and 51.16 (98.38%), respectively; ANOVA indicates that there is a significant difference in these results ($p < 0.001$). Students who actually improved their scores with the three-dimensional format had an average plain score that was 2.68 words fewer than those who did worse. For students who showed no difference, their flat print scores were nearly perfect, since the maximum score was fifty-two (suggesting that proficient readers would not be affected by typesetting differences).

Table 1 compares the mean number of words correctly read in flat and three-dimensional print. A chi-squared test revealed that there was not a statistically significant difference ($p > 0.5$) in the performance among female students when compared to male students. Also, there does not appear to be a significant difference in the average age in the three groups, as the average age of each group was between 79-80 months.

Table 1. Comparison of the Mean Number of Words Correctly Read

Score	Total	F	M	x Flat	SD	x 3D	SD	x Change	SD
All Students (N=214)									
Higher	56	31	25	44.39	7.60	46.93	6.69	2.54	1.97
Lower	63	36	27	47.08	6.93	44.00	7.47	-2.59	1.96
ND	95	46	49	51.16	2.06	51.16	2.06	0	0
Students Scoring at or Below the 25th Percentile for Flat Print (n=50)									
Higher	28	18	10	39.25	7.93	42.79	7.31	3.54	2.25
Lower	17	8	9	38.47	8.24	35.35	8.18	-3.12	1.65
ND	5	1	4	44.20	1.30	44.20	1.30	0	0
Students Scoring at or Below the 10th Percentile for Flat Print (n=23)									
Higher	13	8	5	32.92	7.66	37.54	7.81	4.62	2.29
Lower	10	5	5	33.90	7.98	30.50	7.32	-3.40	1.65
ND	0	0	0	0	0	0	0	0	0

Key
3D= Print that appears to be three dimensional; Flat= standard print same font as 3D
Higher= Score was higher on 3D print, lower on flat print
Lower= Score was lower on 3D print, higher on flat print
ND= No difference between flat and 3D print
F = Female: M=Male
SD= Standard Deviation
x Flat= Mean of the number of words read correctly with flat print
x 3D= Mean of the number of words read correctly with 3D print
x Change= Difference of mean between number of words read correctly with flat print compared to 3D

In the major study, N=173 (86 female, 87 male) exhibited high fluency, reading at least 90% (i.e., made 6 or less mistakes, at least 46 of 52 words correct) of the traditional flat print format phonetic words correctly. Among these students, 10% failed to read as proficiently when exposed to the three-dimensional print format. As a result, there is a statistically significant difference in the number of correct words between the two print formats: students pronounced more words correctly in the traditional flat print format ($p < 0.01$). However, the difference appears to be practically minimal, since the sample mean difference of 0.35 words, or 0.67%. In contrast, for the 41 participants (27 female, 14 male) who scored in the 20^{th} percentile or lower in the number of traditional flat print format words correctly, there is not a statistically significant difference in the number of words correctly pronounced between the two print formats ($p < 0.13$), although there was an average improvement rate of 1.83% (0.95 words) with the three-dimensional print format. When comparing high fluency readers with low fluency readers, there is a statistically significant difference in improvement with the three-dimensional print format ($p < 0.04$).When the students who missed six or more traditional flat print words are compared to students who missed three to five words, a significant effect in the typesetting appears: The students who missed six or more demonstrate an average increase of 0.92 words correct with the three-dimensional print format, whereas the students who missed between three to five words show an average decrease of 0.57 words correct ($p < 0.04$). This result provides some indication that students who have the most difficulty may benefit from the three-dimensional typesetting.

At the 10% significance level, further analysis reveals that there does appear to be noteworthy gender and age effects (age categorization was based on the sample median age of 79 months): females scored 10.61% (5.52 words) higher than males ($p < 0.09$), and older students scored 0.88% (0.46 words) higher than younger students ($p < 0.03$). It is worth noting that seven girls actually did markedly worse (a difference of 5 or more words) with the three-dimensional print. Upon examination of the error types of the lower 20^{th} percentile, we find the following:

1. Substitution errors: vowel or consonant substitutions were more frequent for males than females ($p < 0.07$). In addition, these errors occurred more frequently with the traditional flat print in comparison to the three-dimensional print format ($p < 0.027$).
2. Pattern following: errors in which the student rhymed the word incorrectly with the previous word were more frequent in males ($p < 0.026$).
3. Word guessing errors were more frequent in older students ($p < 0.022$).
4. Letter/word transpositions (e.g., b/p; t/f; whole word, such nap/pan) were moderately more frequent for traditional flat print words ($p < 0.043$).

5. Among the 23 students who scored in the lowest 10th percentile (fewer than 42 out of 52 traditional flat print words correct), 9 of them increased their score by at least 10% when compared to their traditional flat print score; 5 of them increased by at least 20%. The largest improvement overall was from 35 to 44 words read correctly using three-dimensional print, which translates to a 25.7% gain. For the student having the most difficulty, the three- dimensional print had the potential to increase the number of words read. However, typesetting format is not a flawless remedy for students with reading difficulties, as demonstrated by the 10 students for whom reading scores decreased with the three-dimensional print format.

Table 2 presents a summary of the data obtained in the major study (N=214).

Table 2. Gender Distribution of Performance on Three-Dimensional Print Format

	Higher	%	Lower	%	ND	%	Total
Female	31	27.43	36	31.86	46	40.71	113
Male	25	24.75	27	26.73	49	48.51	101
Total	56		63		95		214

Key
Higher= score was higher on three dimensional print, lower on flat print
Lower= score was higher on flat print, lower on three dimensional print
ND= no difference between flat and three dimensional print
%= percent of sample population

Overall, the female students (31.86%) read more words with flat print than with three-dimensional print. Table 2 also shows that in the major study (N=214) approximately 25% of female students and 25% of male students read more words with three-dimensional print than with the flat print. Figure 2 illustrates the percentage increase of reading fluency with the three-dimensional print format among students of varying abilities. For those students who scored at or below the 10th percentile in number of words correct with traditional flat print font, the median score improvement was 5.405%, with a maximum of 25.71%; note the relatively large range of improvement percentages. Among students who scored between the 10th and 25th percentile, the median score improvement was 2.17%: the two outliers in the boxplot correspond to one student with an increase of 11.36% and another student with a decrease of 8.89%. For students scoring between the 25th and 75th percentile, the median score improvement was 0%. All three outliers scored lower with the three-dimensional print format.

Discussion

Our population was nearly equally distributed between males and females. Within this population the majority of our participants read more than 46 out of 52 CVC basic words (i.e., 20th percentile and higher) presented in flat print. This outcome is consistent with the selection of words, words which should be automatic to the post emergent first grade reader. When fluent readers, those who read over 46 words correctly, are compared to those who read less than 46 words correctly, the effect of three-dimensional print is significant. .The better reader read on average fewer words correctly with three-dimensional print while the less proficient reader read on average slightly more. This finding agrees with the Robertson and Bakker (2002) and Smit-Glaude et al. (2005) that fluent readers have made a hemispheric shift to left brain dominance. When comparing these two groups, those who read more than 46 words correctly to those who read less than 46 words correctly, there was an overall improvement with the three-dimensional print.

When we look at the twenty-three participants out of 214 who read fewer than 42 out of 52 basic words, we isolate our students most at risk for being potentially identified with dyslexia. In this group, 14 out of 23 (61%) increased the number of words read when reading three- dimensional print, as compared to flat print . Even though not significant because of a large variability, the full data set for this subdivision shows overall average of 1.13 words improvement for three-dimensional print. This finding supports the results of Smit-Glaude et al. (2005) who determined that those students most at risk for dyslexia increased word recognition with right hemisphere stimulation.

Removing from the results the ninety-five students who could read both fonts proficiently, the 109 remaining readers were relatively evenly distribution between those who read more words with three-dimensional print (n=56) and those who read fewer words with three-dimensional print (n=63). Females outnumbered males in groups, 31/25 and 36/27 respectively.

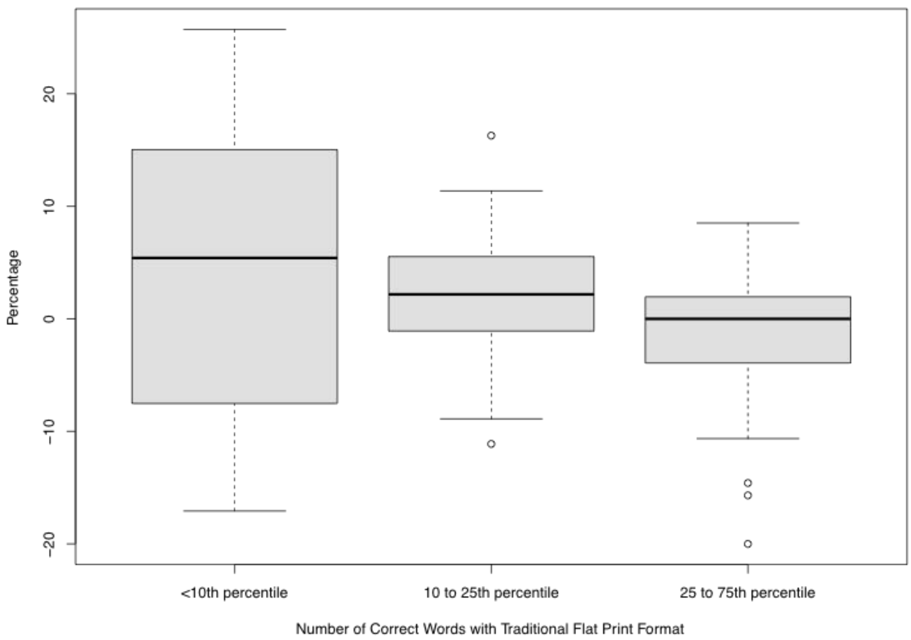

Figure 2: Distribution of Improvement Percentages with 3D Print Format

Overall the students who were having the most difficulty reading CVC words in plain font improved their scores by nearly three words when reading three- dimensional print; however, sixty-three out of the 214 students were compromised by three dimensional print. From an educational perspective, the fact that three-dimensional print is affecting word recognition in any form in emergent readers is significant. This has shown that reading can be affected by a subtle three-dimensional difference in print.

In the group of participants scoring in the lower 20^{th} percentile in recognition of CVC words in flat print, there were more females than males (refer to Table 2). Within this group of low emergent readers, females read on an average five more words than males. For the struggling readers, there was a significant but small gender difference pertaining to the substitution of vowels or consonant: male participants substituted 3.2 more words per 52 than females, with substitutions, and transpositions occurring for both genders more frequently in the flat than the three dimensional print. Although not significant, but noteworthy, seven female participants actually performed worse (a difference of 5+ words) with the three-dimensional print. Male participants in this group of struggling readers more frequently than female participants followed the sequence pattern (cat, bat, sat), not recognizing that a change in pattern had occurred.

Younger students, those below 79 months (median age at time of testing), read nearly as well as the older readers (.46 fewer words). When comparing both the students who read more words with three dimensional print and the students who read more words with three- dimensional print to the students unaffected by three-dimensional print, there was no significant difference in the average age of the participant. Older students were not reading better, and younger students were not on the average reading less words using three-dimensional print.

Similar to Von Karolyi (2001), we did not find total support for a diverging abilities hypothesis. The twenty-three students in the most compromised reading group improved their score by three words using three-dimensional print. Only one student in the pilot study read fewer than five words on flat print and all words correctly on three-dimensional print. This student was a kindergartener who had recently undergone an eye operation on her right eye. Her results were outlier and referred to her ophthalmologist. Overall, the results of this study alert us to possibilities, but at the same time caution us against indiscriminant use of three-dimensional print. Ten students, in this already compromised group read fewer words with three-dimensional print. These findings on the effect of three-dimensional print are not a panacea for students at risk for dyslexia, but rather another possible tool to increase early word recognition, a tool that has to be used with care, after testing for the effects of three-dimensional print. We concur with Helland and Ashjornsen (2003) who concluded that when assessing for dyslexia, visual-spatial skills should be considered as a separate indicator *along with an evaluation of language comprehension and mathematical skill (*p.218).

Limitations

Students in the study were all the first graders who returned their informed consent forms, and the sample population was not screened for the effects of disabilities such as Attention Deficit Disorder or Developmental Delays. It was in consideration of this factor that the researchers eliminated the students who read fewer than five words out of the possible fifty-two words from the study. It is also a concern that undiagnosed vision problems may play a role in the reading process, and the design of this study could not eliminate this variable in our sample population.

Implication for Future Research

Children with autism show preference for a variety of forms of visual spatial stimulation, right hemispheric, when learning to read, for example, use mental images of words to enhance word retrieval (Whalon, Al Otaiba, & Delano, 2009). In fact, children with autism who cannot speak are taught to communicate using the Picture Exchange System (Bondy & Frost, 2001). Future research might investigate whether students with high functioning autism having difficulty with the emergent stage of reading might benefit from the use of three-dimensional print as a right hemisphere catalyst to word acquisition

This study did not start with the pre-primary schools where children experience the very beginning of letter recognition. Future studies might assess the impact of three-dimensional alphabets on letter recognition, taking into account that our study found an effect for gender. Knowing that early word recognition is influenced by three-dimensional versus flat print, a study that looks at the effect of print on alphabet recognition in pre-primary classrooms may identify children at risk for reading difficulty.

Himelstein (2011), reporting for the Wall Street Journal, stated that some individuals with dyslexia find it easier to learn a language based on characters, such as Japanese, since characters are more like pictures than letters. According to the reporter‘s source, Maryanne Wolf, professor of Child Development and Director of Center for Reading and Language Research at Tufts University, individuals with dyslexia are visual thinkers who analyze patterns. Future studies might look at methodology based on pattern analysis and the visual-spatial element of the letters as a possible alternate method of reading instruction for those individuals not mastering language with the traditional phonics-based, sound-blending approach.

Eide and Eide (2011) in their book *The Dyslexic Advantage* propose that the advanced visual-spatial ability needed to detect impossible figures (Von Karolyi, 2001) is a valuable asset in areas such as contracting, interior design, and architecture. According to Eide and Eide many children with dyslexia display a passion for models, mechanical puzzles, and drawing, and these passions manifest long before the onset of reading difficulty. To further determine the academic effect of visual- spatial ability, future studies might compare traditional reading methods with a strengths-based approach to reading, an approach that assesses and, when appropriate, incorporates a strong visual-spatial component. Silverman and Freed (1996) have developed teaching strategies to address the visual-spatial component of reading in over 200 students and have determined that visual imagery is an important part of the reading experience for a visual-spatial learner.

Our study described the positive effect of three dimensional print on the word recognition ability of the struggling reader. In order to coordinate a student‘s strength with the instructional method being used, teachers might well consider the positive effect of three- dimensional print as one of the learning tools easily and quickly available with any word processor. We agree with the position taken by Williams and Lynch (2010) that:

Successful instructional programs for students with dyslexia (or specific learning disability in reading) should focus not only on a student‘s weakness, but also on their strengths…effective instruction for students with dyslexia also uses multisensory instruction...auditory, tactile, kinesthetic, and visual spatial to send information through multiple pathways to the brain. (p.68)

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Appendix 1

can
A IS FOR APPLE
can
A IS FOR APPLE

Figure 1: Example of Print Difference between Flat and Three Dimension