Article • # The Impact of Binocular Vision and Tracking Intervention on Academic Performance: An In-School Vision Therapy Pilot Program

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ABSTRACT

Background: Convergence insufficiency (CI) and saccadic deficiency (SD) are common visual conditions that can cause negative effects on a child's learning. It is postulated that with early vision therapy (VT) intervention to treat these visual conditions, associated learning difficulties and frustrations could be avoided as a child progresses through school.

Methods: Twenty-nine second grade students were evaluated for a binocular vision or oculomotor disorder. Subjects diagnosed with a disorder were enrolled in an in-school VT program, grouped based on their diagnosis. Seventeen subjects completed the VT program. At the end of VT, those who completed therapy were evaluated to monitor their progress and academic performance.

Results: Subjects diagnosed with CI showed a statistically significant improvement in their near point of convergence (NPC) break value (p=0.042). Subjects diagnosed with SD showed a statistically significant improvement in their Developmental Eye Movement (DEM) test adjusted horizontal score (p=0.008), DEM ratio (p=0.037), Northeastern State University College of Optometry (NSUCO) saccade testing accuracy (p=0.043), head movement (p=0.003), and body movement (p = 0.010) scores, as well as mathematics standardized testing (p=0.034) scores. Subjects who were not enrolled in VT showed a statistically significant improvement in their math standardized test scores (p=0.018). When comparing all subjects who were enrolled in VT to all subjects who were not, there was a statistically significant difference in the pre-therapy math (p=0.036) and reading (p=0.003) standardized test scores, in the post-therapy math standardized test scores (p=0.012), and in the difference between pre- and post-standardized math scores (p=0.047).

Conclusion: In-school VT has the potential to create improvements in visual performance for children, especially those with SD. This type of program also has the potential to improve standardized test scores in math (especially in those with SD) and reading. Further research is needed to determine whether a longer course of VT or a program structured differently may improve results in children with CI.

Keywords: convergence insufficiency, mathematics, oculomotor dysfunction, reading, saccadic deficiency, vision and learning, vision therapy

Introduction

Visual skills, including visual motor, oculomotor, binocular, accommodative, and visual perceptual skills, play an important role in a child's academic performance. An inefficient visual system can hinder a child's learning,[1] specifically convergence insufficiency (CI) and saccadic deficiency (SD), which are two common visual conditions of school aged children.[1,2] Convergence insufficiency (CI) is a deficiency of positive fusional vergence in which the patient is unable to compensate for their exophoric posture during near tasks. Common symptoms associated with CI include diplopia, headaches, asthenopia, and blurred vision associated with near work.[3] US population studies show a prevalence of 7.7% to 13%.[4-6] Saccadic deficiency (SD) is a type of oculomotor dysfunction in which the patient has difficulty accurately and efficiently performing saccadic eye movements used during reading. Common symptoms associated with SD include skipping/switching words while reading, losing one's place while reading, and excessive head and body movements while reading, among others.[7] Oculomotor dysfunction can be found in 24% of the normal population,[8] with higher prevalence in those with emotional issues (50%)[9] and learning difficulties (up to 94%).[8,10] Both of these conditions can be effectively treated with in-office optometric vision therapy (VT).[3,11,12]

Based on the signs and symptoms of difficulty with near work and reading that they manifest, binocular vision and oculomotor dysfunctions can have a significantly negative effect on academic performance in school-aged children. While the dysfunctions may be present at an early age, the age when the patient manifests symptoms varies, depending on the patient's ability to compensate for the binocular vision or oculomotor issue. Some children with vision dysfunctions may present with difficulty with attention and learning to read in early elementary grades, while others may not present until adolescence or young adulthood with symptoms or regression in academic performance. A higher incidence of SD in people with learning difficulties (up to 94%) implies that this dysfunction has a large impact on the learning process.[8,10] Furthermore, the Convergence Insufficiency Treatment Trial (CITT) Study Group found improvement in academic behaviors, particularly in the areas of attention to detail/reduction of errors on school work and the parents' overall concern with their child's academic performance after VT treatment of CI.[13]

Some level of vision screening in the school system is mandated in 42/50 states.[14] While the intention of these vision screenings is to detect potential vision problems for referral/diagnosis by an eye care professional, the testing is limited and variable from state to state and is generally performed by laypersons, giving the results limited credibility and failing to meet the standards of comprehensive care.[15] Therefore, follow-up care is important, especially in the event of failure of a vision screening. However, compliance with follow-up care can also be challenging. Previous studies show that despite referral rates, only 46.6%-65% of children attended follow-up appointments after failure of a vision screening.[16-19] Other studies cite compliance as low as 8%.[20] This challenge of compliance roots from barriers to follow-up care after vision screenings. The most commonly reported issues among families who did not follow up include lack of parental awareness, failure/difficult communication with parents or guardians, lack of awareness of the importance of eye care, and logistical/scheduling issues.[16,21] To combat this struggle with follow-up compliance, studies have been done on the establishment of school-based vision clinics, generally in the form of temporary or mobile eye clinics, to provide complete eye examinations and spectacle correction for children with uncorrected or undercorrected refractive error.[17,22,23] However, there is little research evidence of VT implementation in school-provided services despite the connection that binocular vision and oculomotor dysfunctions have to learning difficulties.[1,2,24] It is postulated that with early VT intervention to treat these visual conditions, associated learning difficulties and frustrations could be avoided as a child progresses through school. The purpose of this pilot study was to evaluate the success of implementation of a school-based VT program in a second-grade population by evaluating their performance on diagnostic testing pre- and post-therapy, as well as comparison of their performance on standardized testing pre- and post-therapy and perceived changes in the academic performance and behaviors from the subjects' classroom teachers post-therapy.

Methods

Institutional review board approval was attained for this research as it follows the tenets of the Declaration of Helsinki. Students in the second-grade class of a local elementary school were recruited for the study with informed consent after explanation of the nature and possible risks and benefits of the study. Each enrolled subject was assigned a patient identification number for anonymity during data collection and analysis. Sensorimotor evaluations were performed on each subject in a quiet, isolated room in the school building. The protocol was based on common parts of a comprehensive eye examination, as well as the evaluations associated with the CITT Study Group, and included the following:[25]

- Personal, family, social, medical, and ocular history
- Convergence Insufficiency Symptom Survey (CISS)
- Visual acuity at distance and near (Snellen)
- Versions
- Stereopsis (Randot)
- Unilateral and alternating cover test with prism neutralization at distance and near
- Negative fusional vergence (NFV) (blur/break/recovery) at near with prism bar
- Positive fusional vergence (PFV) (blur/break/recovery) at near with prism bar
- Near point of convergence (NPC) (break/recovery) with accommodative target
- Push-up amplitude of accommodation (OD only)
- Accommodative facility +/-2.00 (binocular)
- Dry retinoscopy
- Subjective refraction
- Autorefraction (Retinomax) (as needed)
- Lag of accommodation
- Developmental Eye Movement (DEM) test
- Northeastern State University College of Optometry (NSUCO) Pursuit and Saccade Test

Dilated fundus examination and cycloplegic refraction were not performed as part of the evaluation. The parents were educated in the recruitment materials that the evaluations being performed were not ocular health evaluations and that they did not replace an annual eye exam. Furthermore, if ocular health concerns were detected during the initial evaluations based on the above testing, the parent(s) of these subjects were informed of the condition and recommended referral to an eye care professional for further evaluation. Minimum eligibility requirements for the study included best-corrected visual acuity of at least 20/25 in each eye at distance and near with willingness to wear correction and positive global stereopsis. Patients were then placed in diagnostic groups based on their initial sensorimotor evaluations.

- Convergence Insufficiency (CI) – must meet the phoric posture and one of the other following criteria (based on the CITT):[25]
    - Exophoria at near ≥4 prism diopters larger than the distance heterophoric posture
    - CISS score ≥16

- NPC ≥6 cm break
- PFV ≤15 prism diopters in either blur or break OR outside Sheard's criterion

- Convergence Excess (CE) – must meet all of the following criteria:[26]
  - Esophoria at near ≥3 prism diopters larger than the distance heterophoric posture
  - Outside Percival's criterion (1/3 of the difference between the blur of the PFV and NFV is greater than the base-in blur)
- Saccadic Deficiency (SD) – must meet one of the following criteria:[26]
  - DEM test results >1 standard deviation below normal limits in the category of Total Errors or Ratio
  - NSUCO Pursuit and Saccade Testing scores below appropriate age level (according to Maples' norms)

Subjects who fell into a diagnostic group were enrolled in a VT program based on their diagnosis. Those with both a binocular vision condition and an oculomotor condition were placed based on their binocular vision diagnosis. While the study did not specifically address accommodative dysfunction as a separate diagnosis, accommodation was treated in therapy, so subjects with accommodative issues underwent treatment, assuming they fell into one of the diagnostic categories listed above. Spectacles were provided to subjects enrolled in VT that had uncorrected or undercorrected refractive error prior to therapy. Prescribing guidelines were as follows (adapted from the CITT Manual of Procedures[27]):

- ≥1.00 D hyperopia
- ≥0.50 D myopia
- ≥0.75 D astigmatism
- ≥0.75 D anisometropia in spherical equivalent
- ≥1.50 D anisometropia in any meridian

Table 1. Convergence Insufficiency Therapy Activities[26-28]

Monocular Phase	Anti-Suppression Phase	Binocular Phase
Hart Chart Saccades	Bar Reader Accommodative Rock	Accommodative Rock
Marsden Ball	Pegboard Rotator	Brock String
N/F Hart Charts	N/F GTVT	Barrel Card
Ann Arbor Tracking I		Lifesaver Cards
Lens Sorting		Vectograms BO and BI
Hart Chart Rows/ Columns		Computer Orthoptics BI and BO
Pegboard Rotator		Aperture Rule
Accommodative Rock		Eccentric Circles
Ann Arbor Tracking II		Vectograms Jump Vergence
		Computer Orthoptics Jump Vergence
		Aperture Rule Jump Vergence
		Eccentric Circles Jump Vergence
		Loose Prism Facility

Table 2. Saccadic Deficiency Therapy Activities[6-28]

Monocular Phase	Anti-Suppression Phase	Binocular Phase
Wall Saccades	Bar Reader Accommodative Rock	Hart Chart Saccades
Hart Chart Saccades	Pegboard Rotator	Dot-to-Dots
Pegboard Rotator	N/F GTVT	Loose Lens Accommodative Rock
Marsden Ball		Computer Orthoptics BI and BO
N/F Hart Charts		Ann Arbor Tracking I
Loose Prism Steps		Ann Arbor Tracking II
Dot-to-Dots		Letter Chart Accommodative Rock
Ann Arbor Tracking I		Aperture Rule
Lens Sorting		Hart Chart Rows/ Columns
Hart Chart Rows/ Columns		Computer Saccades
Flashlight Pursuits		Binocular Accommodative Facility
Accommodative Rock		Computer Orthoptics Jump Vergence
Ann Arbor Tracking II		Aperture Rule Jump Vergence

- The following changes could be made based on the examiner's discretion:
  - For hyperopia, the prescription could be reduced by up to 0.75 D
  - For myopia and astigmatism, if a change in the prescription does not improve the visual acuity by at least 1 line

Subjects enrolled in VT were organized by diagnostic group and then randomly placed in groups of 2-3 subjects for therapy. They were then given 12 to 16, 45-minute sessions of VT over a span of 6 to 8 weeks (2 sessions per week). VT sessions were held in an unused room within the school building during school hours. The protocol for each diagnostic group differed slightly to focus on training different skills based on the diagnosis. Subjects went through the protocol methodically, starting with monocular oculomotor and accommodative therapy and then moving to anti-suppression and binocular therapy as normative values were achieved and goals were met (Tables 1 and 2).[26-29]

After the 16th session, post-therapy evaluations were performed on the subjects who underwent VT. The post-therapy evaluations included the following tests:

- CISS
- DEM test
- PFV and NFV at near
- NSUCO Pursuit and Saccade test
- Unilateral and alternating cover test with prism neutralization at distance and near
- NPC

Standardized test scores were acquired in the areas of mathematics and reading via the Northwest Evaluation Association's Measures of Academic Progress test (NWEA-MAP) pre- and post-therapy for all subjects. The topics covered in the mathematics section included operations and algebraic thinking, number and operations, measurement and data, and geometry. Topics covered in the reading section included literature and informational text, vocabulary use and functions, language and writing, and foundational skills. Pre-therapy standardized testing was done in the Fall of 2014, VT was performed in the Spring of 2015, and post-therapy testing was done in the Fall of 2015. The raw scores pre- and post-therapy were compared for significant improvement in performance. Additionally, the subjects' classroom teachers were surveyed via questionnaire after 8 and 16 sessions of therapy inquiring about their perceptions of any changes in each subject's performance in reading, overall academics, and self-confidence.

Results

Analysis of the data was accomplished using SPSS for Windows 21. Twenty-nine subjects were initially enrolled. Three subjects were eliminated due to visual acuity, nystagmus, and not completing a minimum of 12 therapy sessions. All patients were enrolled in the second grade at a traditional public school. Three of the 26 eligible subjects were enrolled in special education. Some subjects did receive Title I services, but those numbers were not available. Of the 26 eligible subjects, 10 were male (38.5%) and 16 were female (61.5%). After pre-therapy evaluation, 17 subjects were diagnosed with a binocular vision or oculomotor dysfunction: five subjects were diagnosed with CI, 13 were diagnosed with SD, and one was diagnosed with convergence excess. The remaining nine subjects were not diagnosed with a binocular vision or oculomotor dysfunction and were not enrolled in VT. For the 17 subjects who completed a minimum of 12 therapy sessions, the average number of sessions completed was 15.29 sessions. In total, 20 of the original 26 subjects had pre- and post-NWEA math and reading scores. The other six subjects did not have both pre- and post-therapy standardized test data, presumably due to lack of enrollment in the school either for the pre- or post-therapy standardized testing.

Convergence Insufficiency

Table 3 reveals the number, mean, standard deviation, range, and confidence interval for the pre-testing and post-testing of the individuals with CI.

Table 3. Pre/Post Testing Results of Patients with Convergence Insufficiency

	Test	N	Mean	Standard Deviation	Range	Confidence Interval	
						Lower Limit	Upper Limit
Pre-Testing	BO Blur	4	11.25	9.50	21	-3.86	26.36
	BO Break	5	16	8.34	17	5.65	26.35
	BO Recovery	5	13	8.89	19	1.97	24.03
	NPC Break (TTN)	5	7.7	2.64	7	4.43	10.97
	NPC Recovery (TTN)	5	10.7	3.87	10	5.90	15.50
	CISS	5	9	8.86	21	-2.00	20.00
	NWEA-Math	5	174	9.41	24	162.32	185.68
	NWEA-Reading	5	168.8	12.91	33	152.77	184.83
Post-Testing	BO Blur	3	13.33	14.47	26	-22.61	49.27
	BO Break	5	13.60	9.32	22	2.03	25.17
	BO Recovery	5	10.80	10.83	26	-2.64	24.24
	NPC Break (TTN)	5	2.80	2.49	5	-0.29	5.89
	NPC Recovery (TTN)	5	5.80	3.56	8	1.38	10.22
	CISS	5	11.60	5.46	14	4.82	18.38
	NWEA-Math	4	182.75	5.12	12	174.60	190.90
	NWEA-Reading	5	181.00	11.18	24	167.12	194.88

Table 4. Wilcoxon Signed Rank Test Results for Convergence Insufficiency Patients

Pre-Post Tests	Z	Asymp. Sig. (2-tailed)	Effect Size	Power	Sample Size for β = 0.2
Post BO Blur - Pre BO Blur	0	1.000	0.000	0.041	187
Post BO Break - Pre BO Break	-0.365	0.715	0.163	0.063	106
Post BO Recovery - Pre BO Recovery	-0.365	0.715	0.163	0.054	143
Post NPC Break - Pre NPC Break (TTN)*	-2.032	0.042	0.909	0.856	4
Post NPC Recovery - Pre NPC Recovery (TTN)*	-1.753	0.080	0.784	0.549	7
Post CISS - Pre CISS	-1.095	0.273	0.490	0.081	102
Post NWEA-Math-Fall 2015 - Pre NWEA-Math-Fall 2014	-1.473	0.141	0.737	0.427	11
Post NWEA-Reading-Fall 2015 - Pre NWEA-Reading-Fall 2014	-1.214	0.225	0.543	0.358	10

Pre-post analysis of the individuals with CI was accomplished. Table 4 shows the Wilcoxon Signed Rank Test results, revealing the Z value, p value, effect size, power, and the sample size required for a $\beta = 0.2$. For patients diagnosed with CI, the following variables were not statistically significant from pre-VT to post-VT (Table 4): 1) pre-base out (BO) blur and post-BO blur; 2) pre-BO break and post-BO break; 3) pre-BO recovery and post-BO recovery; 4) pre-NPC recovery and post-NPC recovery; 5) pre-CISS and post-CISS; 6) pre-NWEA math scores and post-NWEA math scores; and 7) pre-NWEA reading scores and post-NWEA reading scores. For the comparison of pre-NPC break to post-NPC break, the Wilcoxon Signed Rank Test revealed a statistically significant difference in the NPC break after the VT program, $z = -2.032$, $p = 0.042$, with a large effect size ($r = 0.909$) and a power of 0.856. The mean rank scores in NPC break statistically improved pre-VT to post-VT.

During data analysis, patients were classified as “cured” if they no longer met the criteria for placement in their diagnostic group. None of the CI patients were classified as cured at the end of data analysis. Four of five CI patients passed two of the three diagnostic criteria (CISS score, positive fusional vergence, NPC) for CI, and one of five passed one of the diagnostic criteria.

At the end of therapy, teachers were surveyed on their perceived improvement in each subjects’ reading performance, overall academic performance, and self-confidence.

Table 5. Pre/Post Testing Results of Saccadic Deficiency Subjects

	Test	N	Mean	Standard Deviation	Range	Confidence Interval	
						Lower Limit	Upper Limit
Pre-Testing	DEM Total Vertical (Raw)	11	55.73	9.83	40	49.13	62.33
	DEM Adjusted Horiz (Raw)	10	99.39	46.03	157	66.46	132.32
	DEM Total Errors (Raw)	10	27.90	23.54	70	11.06	44.74
	DEM Ratio (Raw)	10	1.80	0.85	2.83	1.19	2.41
	NSUCO Saccade Ability	11	5.00	0.00	0	5.00	5.00
	NSUCO Saccade Accuracy	11	3.27	0.91	3	2.66	3.88
	NSUCO Saccade Head Mov	11	2.45	0.82	3	1.90	3.00
	NSUCO Saccade Body Mov	11	3.64	1.12	3	2.89	4.39
	NWEA-Math	7	172.86	13.84	38	160.06	185.66
	NWEA-Reading	7	170.43	8.85	21	162.24	178.62
Post-Testing	DEM Total Vertical (Raw)	11	49.64	6.10	21	45.54	53.74
	DEM Adjusted Horiz (Raw)	11	68.57	15.17	48.4	58.38	78.76
	DEM Total Errors (Raw)	11	12.64	11.42	35	4.97	20.31
	DEM Ratio (Raw)	11	1.38	0.27	0.91	1.20	1.56
	NSUCO Saccade Ability	11	5.00	0.00	0	5.00	5.00
	NSUCO Saccade Accuracy	11	4.09	1.14	4	3.32	4.86
	NSUCO Saccade Head Mov	11	4.82	0.41	1	4.54	5.10
	NSUCO Saccade Body Mov	11	4.82	0.41	1	4.54	5.10
	NWEA-Math	8	181.63	17.46	54	167.03	196.23
	NWEA-Reading	8	173.00	12.07	32	162.91	183.09

Table 6. Wilcoxon Signed Rank Test Results for Saccadic Deficiency Subjects

Pre-Post Tests	Z	Asymp. Sig. (2-tailed)	Effect Size	Power	Sample Size for β = 0.2
Post DEM Total Vertical (Raw) - Pre DEM Total Vertical (Raw)	-1.207	0.227	0.364	0.415	23
Post DEM Adjusted Horiz (Raw) - Pre DEM Adjusted Horiz (Raw)	-2.666	0.008	0.843	0.524	20
Post DEM Total Errors (Raw) - Pre DEM Total Errors (Raw)	-1.886	0.059	0.596	0.460	22
Post DEM Ratio (Raw) - Pre DEM Ratio (Raw)	-2.090	0.037	0.661	0.321	74
Post NSUCO Saccade Ability - Pre NSUCO Saccade Ability	0.000	1.000	0.000		
Post NSUCO Saccade Accuracy - Pre NSUCO Saccade Accuracy	-2.021	0.043	0.609	0.462	21
Post NSUCO Saccade Head Mov - Pre NSUCO Saccade Head Mov	-2.992	0.003	0.902	0.999	3
Post NSUCO Saccade Body Mov - Pre NSUCO Saccade Body Mov	-2.565	0.010	0.773	0.907	14
Post NWEA-Math-Fall 2015 - Pre NWEA-Math-Fall 2014	-2.117	0.034	0.800	0.190	24
Post NWEA-Reading-Fall 2015 - Pre NWEA-Reading-Fall 2014	-1.185	0.236	0.448	0.069	117

In the CI group, five of five subjects were perceived by their classroom teacher to have shown improvement in all three areas.

Saccadic Deficiency

Table 5 reveals the number, mean, standard deviation, range, and confidence interval for the pre- and post-testing of the subjects with SD.

Pre-post analysis of the individuals with SD was accomplished using the Wilcoxon Signed Rank Test. Table 6 reveals the Wilcoxon Signed Rank Test results showing the Z value, p value, effect size, power, and the sample size required for a $\beta = 0.2$. For patients diagnosed with SD, the following variables were not statistically significant from pre-VT to post-VT (Table 6): 1) DEM total vertical pre to post; 2) DEM total errors pre to post; 3) NSUCO saccade ability pre to post; and 4) NWEA reading scores pre to post. Comparison of pre-DEM adjusted horizontal to post-DEM adjusted horizontal revealed a statistically significant improvement after the VT program, $z = -2.666$, $p = 0.008$, with a large effect size ($r = 0.843$) and a power

Table 7. Pre/Post/Difference Results of Non-VT Group and VT Group

	Test	N	Mean	Standard Deviation	Range	Confidence Interval	
						Lower Limit	Upper Limit
Non-VT Group	Pre-NWEA-Math	7	183.71	5.41	18	178.71	188.72
	Pre-NWEA-Reading	7	189.43	11.60	36	178.70	200.16
	Post-NWEA-Math	7	195.43	4.43	12	191.33	199.53
	Post-NWEA-Reading	7	188.71	17.74	55	172.31	205.12
	NWEA-Math Difference	7	11.71	7.20	20	5.05	18.38
	NWEA-Reading Difference	7	-0.71	8.71	25	-8.77	7.34
VT Group	Pre-NWEA-Math	13	173.46	11.21	38	166.68	180.24
	Pre-NWEA-Reading	13	170.00	9.81	33	164.07	175.93
	Post-NWEA-Math	13	182.15	13.60	54	173.93	190.37
	Post-NWEA-Reading	14	175.50	11.69	32	168.75	182.25
	NWEA-Math Difference	12	7.25	11.27	44	0.09	14.41
	NWEA-Reading Difference	13	6.69	11.84	42	-0.46	13.85

of 0.524, as well as pre-DEM ratio to post-DEM ratio, z = -2.09, p = 0.037, with large effect size (r = 0.661) and a power of 0.321. In comparing the pre-NSUCO saccade testing to post-NSUCO saccade testing, the areas of accuracy (z = -2.021, p = 0.043), head movement (z = -2.992, p = 0.003), and body movement (z = -2.565, p = 0.010) all showed statistically significant improvement with large effect sizes (r = 0.609, r = 0.902, and r = 0.773, respectively) while head movement and body movement revealed power of 0.999 and 0.907. For the comparison of pre-NWEA math scores to post-NWEA math scores, the Wilcoxon Signed Rank Test revealed a statistically significant difference in the NWEA math scores after the VT program, z = -2.117, p = 0.034, with a large effect size (r = 0.800) and a power of 0.190. The mean rank scores in NWEA math scores did statistically improve pre-VT to post-VT.

During data analysis, patients were classified as "cured" if they no longer met the criteria for placement in their diagnostic group. Eight of eleven of the SD patients were classified as cured at the end of data analysis. Of the three who were not classified as cured, two passed half of the diagnostic criteria (NSUCO, DEM), and one did not pass either test at a normative level.

At the end of therapy, teachers were surveyed on their perceived improvement in each subjects' reading performance, overall academic performance, and self-confidence. In the SD group, eight of eleven subjects were perceived to have shown improvement in their reading performance, seven of eleven subjects were perceived to have shown improvement in their overall academic performance, and ten of eleven subjects were perceived to have shown improvement in their self-confidence.

Table 8. Wilcoxon Signed Rank Test Results for Non-VT Group

	Pre-Post NWEA Math Scores	Pre-Post NWEA Reading Scores
Z	2.375	0.169
Asymp. Sig. (2-tailed)	0.018	0.866
Effect Size	0.898	0.064
Power	0.993	0.031
Sample Size for β = 0.2	2	2211

Vision Therapy vs. Non-Vision Therapy Academic Performance

For this study, nine individuals were not diagnosed with CI or SD in the pre-therapy evaluation and were not enrolled in VT. This group will be known as the non-VT group. Of the nine individuals, seven completed both pre-NWEA math and reading testing as well as post-NWEA math and reading. Pre-testing, post-testing, and difference analysis of the individuals in the non-VT group compared to the VT group was accomplished. Table 7 shows the number, mean, standard deviation, range, and confidence interval for the pre-testing

Table 9. Mann Whitney U Test Results for Non-VT Group and VT Group

	Pre NWEA Math	Pre NWEA Reading	Post NWEA Math	Post NWEA Reading	Difference Pre-Post NWEA Math	Difference Pre-Post NWEA Reading
Mann-Whitney U	19.000	8.000	14.000	26.500	18.500	27.500
Z	2.102	2.976	2.502	1.680	1.990	1.430
Asymp. Sig. (2-tailed)	0.036	0.003	0.012	0.093	0.047	0.153
Effect Size	0.470	0.665	0.559	0.367	0.457	0.320
Power	0.787	0.964	0.896	0.431	0.182	0.357
Sample Size for Non-VT Group for $\beta = 0.2$	3	3	1	15	23	12
Sample Size for VT Group for $\beta = 0.2$	5	6	2	30	38	22

scores, post-testing scores, and the difference between pre- and post-testing scores for the non-VT group. Table 7 also includes this data for the VT group, which is a merger of the CI and SD subjects.

In addition to the pre-post analysis of standardized test scores for the subjects enrolled in VT, pre-post analysis was also performed for the non-VT subjects using the Wilcoxon Signed Rank Test (Table 8). For the non-VT group, there was not a statistically significant difference from pre-NWEA reading scores to post-NWEA reading scores. For the comparison of pre-NWEA math scores to the post-NWEA math scores, the Wilcoxon Signed Rank Test revealed a statistically significant difference in the scores, $z = -2.375$, $p = 0.018$, with a large effect size ($r = 0.898$) and a power of 0.993. The mean rank NWEA math scores statistically improved as the students aged a year.

Pre-testing, post-testing, and difference analysis of the individuals in the non-VT group compared to the VT group was accomplished. The Mann Whitney U test was used in the comparison of standardized testing for non-VT vs VT subjects (Table 9). When comparing the non-VT group to the VT group, the following variables were not statistically significant (Table 9): 1) post-NWEA reading scores; and 2) difference between pre-post-NWEA reading scores. There was, however, a statistically significant difference in the pre-NWEA math scores ($z = 2.102$, $p = 0.036$), pre-NWEA reading scores ($z = 2.976$, $p = 0.003$), post-NWEA math scores ($z = 2.502$, $p = 0.012$), and in the difference between pre-post-NWEA math scores ($z = 1.990$, $p = 0.047$) all with a medium effect size ($r = 0.470$, $r = 0.665$, $r = 0.559$, and $r = 0.457$, respectively). The power analysis revealed high power for pre-NWEA math scores (0.787), pre-NWEA reading scores (0.964), and post-NWEA math scores (0.896). Additionally, the mean rank for the pre-NWEA math scores, pre-NWEA reading scores, post-NWEA math scores, and the difference between pre-post NWEA math scores were significantly higher in the non-VT group as compared to the VT group.

Discussion

Based on qualifying criteria, eight of the seventeen subjects had normal test results in their diagnostic area and were therefore defined as cured. All eight were in the SD treatment group, indicating the in-school VT program to be effective for SD. While none of the CI patients could be classified as cured under these criteria, four of five passed two of the three diagnostic criteria (CISS score, positive fusional vergence, NPC), and one of five passed one of the diagnostic criteria.

Statistically, SD therapy was more successful than CI therapy. All subjects who were considered cured were in the SD treatment group. The investigators speculate that this could be attributed to the design of the VT program. All subjects were started on monocular visual skills before moving to binocular skills. Many of these monocular skills are oculomotor in nature. Therefore, the SD subjects were receiving therapy directly corresponding to their diagnosis earlier in the treatment plan than the CI subjects. It is speculated that if therapy were continued beyond this study, the CI subjects could also reach normal limits due to the fact that four of the five subjects did pass two of the three diagnostic criteria for CI as dictated by the study. This is promising for future studies where in-school VT for CI could be extended and home therapies added. In-office VT typically lasts longer for CI versus oculomotor dysfunction, and the timeline for this study may have been too aggressive to cure the CI group. Additionally, the practice of oculomotor skills is likely to be more frequently used in the classroom and at home in activities of daily living. Therefore, these patients may have had more reinforcement of the skills taught in VT outside of school than did the CI subjects, as home exercises were not assigned.

Interestingly, the improvement in standardized test scores was statistically significant on the NWEA test for math but not reading for SD subjects. Given that the therapy plan had a strong oculomotor component, this is contrary to the perceived impact of saccades on reading skills versus solving math problems. The significant improvements in saccadic function on DEM horizontal, DEM ratio, and NSUCO are not surprising given the VT activities dedicated to these skills. Saccadic therapy would not be expected to improve vertical DEM times that reflect visual processing and automated naming speed, as the purpose of the vertical test is to remove automaticity as a confounder from the final assessment of the patient's oculomotor function.[30]

Analysis was also performed in which the two VT groups (CI and SD) were combined and compared to the non-VT group. When directly comparing the non-VT group to the VT group, the pre-therapy NWEA math and reading scores were significantly higher in the non-VT group when compared to the VT group. This supports the fact that visual conditions such as CI and SD can affect learning.[1,2] The post-therapy NWEA math scores were also significantly better in the non-VT group in comparison to the VT group. Therefore, while all of the groups improved in math, the non-VT subjects continue to have stronger math skills than the students who were enrolled in VT. However, the post-therapy NWEA reading scores were not statistically significant between the non-VT and VT groups, implying that the non-VT subjects and VT subjects function at a similar level in reading post-therapy. The question arises as to what variable caused the VT group to improve pre-evaluation to post-evaluation so that there was no longer a difference between the non-VT group and the VT group post-therapy. Since the non-VT group did not show a statistically significant improvement in their reading skills pre- to post-, we can assume that simply aging by one year was not enough to cause improvement. Furthermore, since age did not improve the non-VT group from pre-evaluation to post-evaluation, this is not likely to be the primary cause for improvement in the VT group either. Therefore, the logical reason for there not being a difference between the non-VT group and VT group in the post-evaluation of the NWEA reading scores would be that the VT provided to the VT group improved the reading scores of the VT group to a point where the scores of the VT group were similar to the non-VT group.

Overall, teachers' impressions of VT results were positive in both groups. Since teachers observe the children firsthand in academics and directly observe student confidence, their opinions lend powerful support to VT success. This may explain the difference between functional improvements and success measures using purely objective data. Teachers had the opportunity to observe improvements in both groups prior to and during therapy before data points may have reflected changes. Teachers were not blinded to which students were participating in VT; therefore, their opinions may have been influenced.

Limitations

Given the nature of the study, there were many limitations. As a pilot, the purpose of this initial study was to test the implementation of an in-school VT program and to assess the challenges associated with this endeavor while attaining data for preliminary analysis, ultimately to assess the strengths/weaknesses of the study design and concept.[31] Recruitment of subjects was limited due to lack of participation and human resources to support a larger-scale study. The small number of subjects limits the conclusions that can be made from the study's results. Even though the study found statistical differences, the small sample size produced very low power results. Statistically, this can lead to a type-two error. To increase the power of the results, the study would need to increase the sample size. Due to time limitations for the investigators, five investigators alternated the responsibilities of the pre-therapy evaluations, therapy, and post-therapy evaluations. Since different investigators were involved in the evaluation and treatment of the subjects throughout the study, this could have led to inter-examiner inconsistency. This should be considered, particularly when comparing the pre- and post-therapy evaluations, as different examiners performed each of these stages due to time constraints. Furthermore, for similar time limitations, only those who completed therapy were re-evaluated at the end of the study to assess changes in binocular vision/oculomotor status. Ideally, all subjects would have been re-evaluated post-therapy. This is something to consider in future studies that would provide more patent comparisons.

Another limitation of the study was the organization and mode of the therapy sessions. To accommodate as many subjects as possible, therapy was generally performed in groups of three subjects with two therapists present. Therefore, the subjects were not receiving one-on-one attention for the entire therapy session as they might in some other in-office therapy programs, which limits their supervision and possibly their motivation and ultimate success. Beyond this, the program was strictly limited to in-office therapy and did not assign specific home therapy to be performed between sessions. Since the therapy was performed in an unused office in their elementary school during school hours, parents were not present for the therapy sessions. Therefore, the likelihood of homework being completed and enforced seemed low. Since in-office therapy combined with home therapy to reinforce skills learned in-office is deemed the most effective VT combination, it is possible that the subjects could have seen more progress in the 6-8 weeks if home therapy had been incorporated into the study.[32]

The lack of dilated fundus examination and cycloplegic refraction as a part of the initial evaluations is another limitation of the study. Evaluation and diagnosis of anterior and posterior segment organic pathology was not considered an excluding factor in participation in the study as long as the subject met the visual, binocular, and oculomotor demands to complete the testing. For example, one subject was found to have nystagmus in pre-therapy evaluations and was excluded due to the pathological nature of the eye movement dysfunction. Cycloplegic refractive testing could have been advantageous in the diagnosis of uncorrected or undercorrected hyperopia that was potentially undetected in dry refractive testing. However, this was eliminated from the study protocol, as it was not practical considering the school-based setting of this pilot study. Due to the inclusion of objective refractive testing in combination with extended accommodative testing, we felt that significant amounts of latent hyperopia could be sufficiently detected without the use of pharmacological intervention. Having said this, future studies could include this in order to improve the sensitivity for detection of refractive error and potentially improve therapy outcomes with its correction. Furthermore, accommodative dysfunctions were not included in the study, though we acknowledge that these are also significant visual diagnoses that can affect learning, the inclusion of which would strengthen future studies. Finally, the questionnaires given to the teachers regarding their perception of the subjects' progression while in therapy were not standardized or masked and were written by clinical optometrists without a background in survey standardization.

Conclusion

In conclusion, in-school VT has the potential to create both objective and subjective improvements in the visual performance of enrolled children, especially those with SD. Academically, this type of program has the potential to improve standardized test scores in reading performance as well as math, especially in those with SD. Teachers appear to appreciate the improvements in children partaking in VT in school, even when objective measures do not show statistically significant improvements. Further research is needed to expand upon this pilot study and to determine whether a longer course of VT or a program structured differently might improve results in children with CI.

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