ORIGINAL STUDY

Outcome Measures of In-Office Optometric Visual Rehabilitation Intervention on Oculomotor Function, Visual Processing Skills, and Reading Efficiency Scores in Children with Formally Identified Academic Difficulties

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ABSTRACT

Background

Oculomotor dysfunction (OMD) and visual information processing (VIP) deficits are often seen in children with reading difficulties. Prior published evidence has shown statistically significant correlations between several metrics, in particular vergence facility and reading efficiency at baseline within an office based vision therapy (OBVT) setting supported by home vision therapy (HVT). However, data on the effects of OBVT on OMD, VIP deficits, and reading performance is currently lacking. The purpose of this study is to investigate whether vision therapy improves VIP deficits in children diagnosed specifically with a dyseidetic based reading problem with confirmed concurrent oculomotor dysfunction.

Methods

Exam records of 143 pediatric patients (age 6-18 years old, 56% male) diagnosed with a dyseidetic based reading problem and who successfully completed OBVT re-enforced with HVT were included in the study. All patients were seen at a practice in Ontario, Canada. All dynamic visual skills and visual processing skills were tested at baseline, and again after every 10 sessions of OBVT. An independent test of reading fluency (TOWSRF-2), and standardized symptom scores using the COVD QoL Questionnaire and CISS symptom survey were also performed.

Results

All patients successfully completed vision therapy between 30-40 sessions. By 10 sessions, OMD and VIP results had significant improvement ($p<0.001$), while vergence facilty and TOSWRF-2 scores showed significant improvement after 20 sessions ($p<0.01$ and $p<0.05$ respectively). At the end of treatment, significant improvements were seen in COVD QoL scores (58 start / 19 finish, $p<0.001$), CISS score (19 start / 6 finish, $p<0.001$) and TOSWRF-2 reading fluency scores (20th percentile start / 47th percentile finish, $p<0.001$).

Conclusion

Office-based vision therapy re-inforced by home vision therapy is an effective treatment method for

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Christian L, Cunningham D, Quaid P. Outcome measures of in-office optometric visual rehabilitation intervention on oculomotor function, visual processing skills, and reading efficiency scores in children with formally identified academic difficulties. Vision Dev & Rehab 2024; 10(1):13-28.

Keywords: Oculomotor Dysfunction, Optometric Vision Therapy, Reading, Vision, Visual Processing

improving monocular and binocular visual skills, visual information processing skills, and reading fluency in children with dyseidetic reading problems.

BACKGROUND

Oculomotor dysfunction (OMD) occurs when there is an absence or delay in the brain's ability to coordinate the eyes to fixate, follow, or move fixation from one target to another accurately and efficiently. Signs and symptoms for OMD primarily involve poor reading stamina, frequent loss of place on a page, unstable fixation, skipping words, re-reading words, or reading one word slowly at a time.[1-3] OMD is closely associated with accommodative and vergence anomalies[1,3,4] such as accommodative insufficiency (AI) and convergence insufficiency (CI), and can be referred to collectively as visual skills deficiencies (VSD) in order to differentiate from pathology related visual losses. In addition to signs and symptoms associated with reduced reading efficiency and ability, other symptoms associated with VSD include headaches, loss of attention, rapid visual fatigue, decreased copying speed, and reduced ability to retain what has been seen, a skill commonly referred to as visual memory or in the educational realm "orthographic mapping" related skills.[5-8]

Published estimates of the prevalence of VSD in children with reading based learning problems range from 19% to 86%[1,3,9] depending on the specific aspect examined. Of interest, the general population has reported incidences for example of accommodative dysfunction in the 8-10% range[10,11] and convergence insufficiency (CI) in the 5-7.5% range.[3,12,13] In terms of attention based connections, the prevalence of CI alone in attention deficit hyperactivity disorder (ADHD) has been found to be as high as 15.9% with over 55% of the DSM symptoms overlapping to the point where significant potential for diagnostic confusion has been highlighted.[14] In addition, the prevalence of accommodative and vergence disorders combined has been estimated to be 9.7 times greater than the prevalence of ocular disease in children ages 6 months to 5 years old, and 8.5 times greater than the prevalence of ocular disease in children ages 6-18 years old.[7] However, despite the high prevalence rate, VSD has received relatively little attention in early learning literature.[1,12,15]

For example, studies by Hoffman[16] and Metsing & Ferreira[8] have reported that learning disability populations have a very high incidence of visual skills deficiencies (>90%), but neither study discussed any treatment options to eliminate or reduce VSD issues to foster more consistent sensory visual input. Similarly, while studies have shown uncorrected hyperopia as low as +1.25DS with poor accommodative function or higher Convergenece Insufficiency Symptom Scores (CISS) with hyperopia >+2.00DS (non-cycloplegia) being associated with poorer academic performance, the correlation between hyperopia and VSD is often overlooked.[1,17] Although research has highlighted high discriminatory testing methods for VSD in children with reading difficulties,[1] it remains to be examined whether the relationship between VSD, visual processing skills and reading efficiency is based on association, or if a causal relationship exists. While VSD directed Optometric vision therapy treatments does not directly treat reading problems per se, the treatment of critical dynamic visual skills such as tracking, accommodation, and vergence control, have been shown to improve reading performance and efficiency.[2,12,18,19]

In 2022, the Ontario Ministry of Education's (MoE) "Effective Early Reading Instruction Guide"[20] used the term "Orthographic (derived from the Greek words "correctly written") Mapping" when discussing how children transition from a laboured pattern of single word/letter decoding to a more fluent pattern of "sight word" reading. The MoE statement correctly connects a child's visual skills, including visual memory skills, to their ability to retain "sight words" in order for fluent reading to occur: *"How do children move from slow decoding of words letter by letter, to being able to read words quicly and easily? Thank orthographic mapping, the process competent readers use to store written words, so they can automatically recognize them on* ***sight****. The more words we have stored in this* ***sight word bank****, the easier reading becomes".*[20]

To provide academic supports for children in school, the MoE and the child's school, in conjuction with educational psychology, often develop a formal "Individualized Educational Plan" (IEP) for children struggling with academics. According to the Learning Disability Association of Canada, in 2002 approximately 1 in 10 children (in Canada) required an Individualized Educational Plan (IEP) in school to support their academic learning[1]; with approximately 86% of IEPs in place primarily for reading.[1,21] The number of IEPs continues to increase by 0.3-0.6% per year; 10% in 2002 to 16.7% in 2018 in elementary school-age children.[22]

Children with a formal IEP in place for reading are often provided additional aids such as assistive technology (i.e., text to talk devices) to help support reading comprehension, since children tend to often understand text better when visual input is removed. More specifically, children with dyseidetic reading problems often have improved comphrehension when read to (i.e. auditory input) versus the child having to read print directly themselves. Because reading to a child with primarily dysphonetic difficulties can also be of benefit, it is essential to determine whether the child primarily has a dyseidetic or dsyphonetic difficulty. Using the Dyslexia Screening Test (DST), for example, will exclude primarily dysphonetic cases to avoid a concurrent phonetic awareness confounder. However, to truly examine reading, VSD issues and visual information processing (VIP) skills such as visual memory should be examined in detail.[1,2,5,16,23-28]

Visual memory is the ability to recall visual information, and is important when reading and subsequently retaining "sight words" or words with letter sequences that cannot be recalled using phonetic rules or patterns,[27] often referred to as "jail words" in phonemic/speech-language circles. The term "jail" is used to imply no conventional phonetic rules can be applied to decode the word and word must be memorised, therefore, the word is a "rule breaker". The ability to read sight words relies on the child's ability to remember eidetically what a word looked like for recall when seen and when asked to spell (the word) from memory., This is a critical step to connect the visual image to both pronunciation and meaning. For example, the word "know" should phonetically be spelt "no". When learning to read, a child is taught to ignore the "k" and "w". Over time, as reading fluency increases, sight words are recognized via visual memory as part of the overall orthographic mapping process.[5,20,29] This often overlooked but critical skill in educational circles is referred to as "selective intention", a term which describes the ability to remember a word although it looks different to its phonetic pronunciation.[28] In the absence of consistent visual input, such as intermittent blurred or double vision, visual memory fails to engage, resulting in difficulties with sight word acquisition, stunting the overall orthographic mapping process. Hence, challenges with reading, specifically with eidetic (i.e. symbol based, and worse with smaller print) encoding, are essentially rooted to a large extent in poor visual memory (VM) skills. This connection has also been recently recognized in the dyslexia research community. Several publications in this field have suggested that vision, specifically refractive error (mainly hyperopia) and binocular vision (vergence and accommodation) deficits, should be investigated and corrected *before* a diagnosis of dyslexia can be considered.[23,24,30]

Therefore, to further examine the effect of VSD and VIP deficits on reading performance, the purpose of this study was to retrospectively investigate whether office based vision therapy (OBVT) re-enforced with home therapy improved visual skill deficiencies, visual informaton processing (in particular visual memory) with any impact on reading fluency in children with a specific dyseidetic based reading issue who were formally diagnosed with concurrent VSD concerns prior to OBVT.

METHODS

A retrospective review of 143 patient files (6-18 years; 56% male) seen in an Optometric Clinic in Ontario (Canada) from January 2017 to January 2021 were reviewed. Files were selected based on the following criteria: best corrected visual acuity of 20/20 in each eye, no history of strabismus or amblyopia, no prior history of vision therapy, a dyseidetic reading disorder using the dyslexia screening test (DST, with an eidetic score ≥70% and dysphonetic score <30%), Type II (Oculomotor) Developmental Eye Movement (DEM) pattern cases if saccades affected, IEP status formally present (accommodated or modified type), which requires reading performance to be in the 10th percentile or less (on provincial testing) and completion of the in-office vision therapy program (OBVT) prescribed. The Type II DEM pattern describes saccadic test results whereby the horizontal saccadic performance test is abnormal and the vertical saccadic performance test is normal compared to DEM normative data. Completion of the program was defined as no clinically significant changes to symptoms and clinical data seen after two consecutive progress evaluations (PEs), and the overseeing doctor formally indicating a successful graduation of the child from the OBVT program. Patients with formally diagnosed ADHD/ADD and Autism Spectrum Disorder (ASD) were excluded from review.

Consent and study process received ethics clearance from the University of Waterloo, Office of Research Ethics and followed the tenets of the Declaration of Helsinki for Human Research.

Clinical Tests:

Files were reviewed for the following clinical data (baseline and all subsequent progress evaluations): near point of convergence, saccadic function, fusional reserve amplitudes (positive and negative break points) at near, vergence facility at near, monocular accommodative facility and near stereopsis. In addition, Visual Information Processing (VIP) tests as outlined below, and symptom scores from both the Convergence Insuffiency Symptom Survey (CISS) and COVD Quality of Life Questionnaire (COVD QoL) were also reviewed. All clinical data was obtained and recorded by registered Optometrists in Ontario (PQ, DC, HM) in the course of clinically administered OBVT therapy. Data for VIP testing and symptom scoring was obtained independently of the overseeing doctor by a team of certified vision therapists.

Symptom Scores Used

Convergence Insufficiency Symptom Survey (CISS, 0-60 scale): This questionnaire was validated as part of the Convergence Insufficiency Treatment Trial (CITT).[31] This questionnaire contains 15 questions each of which have five answers (Never, Infrequently, Sometimes, Fairly often, Always), which are totalled with the final symptom score ranging from 0-60. Any score over 15 is considered a concern and is indicative of significant symptomatology from a VSD standpoint. The CISS score has been accepted as a reasonable symptom scale for VSD generally, despite being developed specifically for convergence insufficiency.[15]

COVD Quality of Life (QoL) questionnaire: This questionnaire contains 31 questions each of which has five answers (Never, Seldom, Occasionally, Frequently, Always), which are totalled with the ultimate symptom score therefore varies from 0-24, with any score higher than 24 being considered a concern and indicative of a significantly symptomatic patient.[15,31]

Oculomotor and Binocular Integration Skills examined:

Near Point of Convergence (NPC): This was assessed using an accommodative target, letter E on a “budgie stick” with VA equivalent to 20/30, with the measurement being recorded as the average distance in centimetres (cm) from the bridge of the nose at which the patient reported double vision or at which point one eye was visibly noted to drift out of alignment. Average of three successive measurements were taken using a ruler for the final value in cm. NPC receded more than 8cm was considered abnormal.[31,32]

Vergence Facility at 40cm: Normal clinical value accepted as approximately 15 cycles per minute (cpm) at 40cm with testing described elsewhere.[1,33] If the patient remained diplopic at any point (i.e. fusion broke down) the number of cycles to that point was noted. This test is both subjective and objective as the responses of the patient are listened to, but given the prism power difference used (i.e. 15 PD relative difference between 12BO/3BI), the eyes can also be observed to converge and diverge allowing essentially an "objective verification of a subjective response". Results are presented in cycles per minute (cpm). Of note, it is important to ensure that testing is done for the full minute, as patients often "fatigue out" in the last 30 seconds, an observation seen frequently in clinic. Scores less than 15cpm at 40cm were considered reduced.

Convergence Amplitude (Break): Also known as positive fusional vergences or PFVs, step vergence was determined at near using prism bars in free space using a 20/30 acuity target (i.e. the "budgie stick"). The break point is recorded as the prism value at which the subject saw double (or fusion breaks) and could not re-fuse. As the eyes can be observed to move inwards with increasing base out prism demand and noted to "break" in terms of fusion and drift outward at the limit, an objective aspect of observation also exists for this test. Results are shown in prism dioptres (PD).

Divergence Amplitude (Break): Also known as negative fusional vergences or NFVs, step vergence was determined at near using prism bars in free space using a 20/30 acuity target (i.e. the "budgie stick"). The break point is recorded as the prism value at which the subject saw double (or fusion breaks) and could not re-fuse. As the eyes can be seen to move outwards with increasing prism demand and be noted to "break" in terms of fusion and drift inwards, objective confirmation is possible. Results shown in prism dioptres (PD).

Monocular Accommodative Facility (MAF): Recorded as cycles per minute (cpm) using +/-2DS lens flipper at near, MAF is tested monocularly. The number of complete cycles (i.e. plus to minus then back to plus) the patient can clear 20/30 print at 40cm in one minute is recorded for each eye. The patient was instructed to clear the text with one lens in place and to report the word "clear" at which point the examiner (not the patient) changed the flipper to the other side. A translucent occluder was used to cover the untested eye to ensure that the appropriate vergence movement was noted (i.e. convergence for clearing minus, and divergence for clearing plus) to confirm responses in the tested eye. This process was done monocularly and the number of cycles cleared in one minute was recorded. If the patient was unable to clear the text, the number of complete cycles up to that point is noted. MAF testing is considered a reflection of the integrity of the accommodative system in isolation with no influence of the vergence system, as the subject is tested monocularly. An abnormal result is any score lower than 8cpm using ±2.00DS flippers at 40cm which is approximately 1 standard deviation below the mean for pediatric normative values for ages 8-14 years.[34,35]

Stereopsis: Depth perception was recorded in seconds of arc using the Titmus stereotest (randot) with habitual correction at the time of testing. Results are reported in seconds of arc.

Visual Information Processing (VIP) tests used:

Saccadic testing: Developmental Eye Movement (DEM) testing[36] was used to assess saccadic function both at baseline and at all PE assessments. When saccadic difficulty was present on DEM testing, only Type II cases (i.e., Oculomotor type; horizontal saccadic tracking deficient, vertical tracking normal) were included for the analysis, as Type II pattern strongly suggests underlying oculomotor dysfuntion etiology. Cases with other types of saccadic dysfunction on DEM testing (i.e. automaticity or mixed types), which can bring into play rapid automated naming aspects (i.e. verbal output issues), could confound any conclusion and were therefore excluded from analysis. Results are shown in percentiles compared to age matched normative data. It should be noted, that although the test provides normative data up to 13 years, this value was used as a reasonable proxy for patients age 14-18 years. An abnormal result is any Type II result (Ocuomotor) as indicated by DEM scoring method.[35-37]

Test of Visual Processing Skills (TVPS) Test Battery (3rd Edition): Consists of seven subtests and a global score. Results reported as percentiles compared to age matched normative data; Visual Discrimination, Visual Memory, Form Constancy, Spatial Relations, Visual Closure, Sequential Visual Memory, and Figure-Ground. In this study, we were particularly interested in Visual Memory and Visual Discrimination data as well as global metrics.

Test Of Silent Word Reading Fluency (TOSWRF-2) test: This three-minute test assesses the ability to decode recognize words quickly and efficiently and does not involve comprehension. TOSWRF-2 tests the rapid, quick recognition of words embedded in lines of other words without spaces. (Pro-Ed; Texas, USA) https://rebrand.ly/iq6qdcb). This test has been shown to correlate well to overall reading fluency and has a large and well accepted normative database. There are four different templates available to avoid memorization issues, which have the potential to occur at PEs following baseline assessment. A different template was randomly used post baseline testing at each subsequent progress evaluation so that two identical templates were never used in sequence. All results shown are as a percentile compared to age matched normative data.

RESULTS

N=143, age range 6-18 years (mean age: 11.6 ± SD 2.4 yrs). 63 females, 80 males. Most common primary diagnoses were saccadic dysfunction (100%, all Type II), accommodative insufficiency or infacility (84%), vergence infacility (78%) and convergence insufficiency (57%).

All analysis was carried out by Statistica 7 (StatSoft Inc., "Statistica," Data Analysis Software System, version 7, 2004). The Student t-test (with appropriate Bonferroni correction for multiple comparisons) was used in addition to correlation co-efficient testing to compare groups as appropriate.

Symptom data: Symptom scores for the CISS and COVD QoL questionnaires improved significantly compared to baseline by the first progresss evaluation (PE#1, Figure 1)

NPC data: NPC significantly improved from baseline to PE #1, PE #2 to PE #3, but not from PE #3 to PE #4. Average baseline NPC (nearest cm) was 13cm, with end of therapy NPC beween

CISS scores	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p<0.0001	p<0.0001	p<0.0001	p<0.0001
PE #1	N/A	N/A	p=0.0019	p<0.0001	p<0.0001
PE#2	N/A	N/A	N/A	p=0.3211	p=0.0063
PE#3	N/A	N/A	N/A	N/A	p=0.0581

	Descriptive Statistics (CISS data.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
Baseline CISS	143	16.68085	0.00	44.00000	9.187195
PE #1 CISS	143	11.46099	0.00	32.00000	7.849038
PE #2 CISS	142	8.60284	0.00	35.00000	7.515583
PE #3 CISS	112	7.70435	0.00	26.00000	6.729060
PE #4 CISS	54	6.03704	0.00	26.00000	4.859127

Figure 1. P-value matrix and descriptive statistics for all CISS values at baseline and all subsequent progress evaluations.

COVD QoL scores	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p<0.0001	p<0.0001	p<0.0001	p<0.0001
PE #1	N/A	N/A	p=0.0005	p<0.0001	p<0.0001
PE#2	N/A	N/A	N/A	p=0.2538	p=0.0021
PE#3	N/A	N/A	N/A	N/A	p=0.0367

Variable	Descriptive Statistics (COVD QoL data.sta)				
	Valid N	Mean	Minimum	Maximum	Std.Dev.
Baseline QoL	143	58.34965	3.000000	102.0000	22.59012
PE #1 QoL score	143	37.69930	2.000000	88.0000	18.89557
PE#2 QoL score	142	27.66901	0.000000	74.0000	17.39190
PE #3 QoL score	112	25.06452	0.000000	86.0000	16.55282
PE #4 QoL score	54	19.59259	1.000000	50.0000	12.39525

Figure 2. P-value matrix and descriptive statistics for all COVD QoL values at baseline and subsequent progress evaluations.

5-6cm (Figure 3) Vergence Facility (at near) data: Vergence facility did not significantly improve from baseline to PE#1, but did improve by PE #2 with some further gains thereafter. Majority of gains were achieved by PE #2. Average baseline metric (to nearest cpm) was 6cpm with end of therapy in the 13cpm range (Figure 4)

NPC data	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p<0.0001	p<0.0001	p<0.0001	p<0.0001
PE #1	N/A	N/A	p=0.0031	p<0.0001	p<0.0001
PE#2	N/A	N/A	N/A	p=0.0079	p=0.0004
PE#3	N/A	N/A	N/A	N/A	p=0.1368

Variable	Descriptive Statistics (NPC data.sta)				
	Valid N	Mean	Minimum	Maximum	Std.Dev.
BaseNPC	143	12.76761	2.000000	50.00000	7.349111
PE#1 NPC	143	8.57746	1.500000	25.00000	3.663746
PE #2 NPC	142	6.78169	1.000000	18.00000	2.565776
PE #3 NPC	112	6.02344	1.500000	14.00000	2.021401
PE #4 NPC	54	5.61333	1.000000	8.00000	1.634868

Figure 3. P-value matrix and descriptive statistics for NPC measurements at baseline and subsequent PEs.

Vergence Facility	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	P=0.0761	P=0.0014	p<0.0001	p<0.0001
PE #1	N/A	N/A	p=0.0683	p=0.0237	p=0.0158
PE#2	N/A	N/A	N/A	p=0.0982	p=0.1153
PE#3	N/A	N/A	N/A	N/A	p=0.3815

	Descriptive Statistics (VF data LD.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
BaseVF40cm	143	6.24306	0.000000	106.0000	9.885531
PE#1 VF	143	8.72917	0.000000	16.0000	4.811436
PE#2 VF	142	11.02083	1.000000	16.0000	4.094118
PE#3 VF	112	12.54472	3.000000	18.0000	3.419453
PE #4 VF	54	12.84043	2.000000	16.0000	3.437000

Figure 4. P-value matrix and descriptive statistics for Vergence Facility at near measurements at baseline and subsequent progress evaluations.

Vergence amplitudes at near data: Vergence amplitudes (Base Out Break and Base In Break) showed significantly improvement from baseline by PE #1 for base out break data, but not until PE #2 for base in break data with some further gains thereafter in both cases (Figure 5)

Base out break (BOB) at 40cm	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p<0.0001	p<0.0001	p<0.0001	p<0.0001
PE #1	N/A	N/A	p=0.0021	p<0.0001	p<0.0001
PE#2	N/A	N/A	N/A	p=0.1015	p=0.0614
PE#3	N/A	N/A	N/A	N/A	p=0.4181

Base in break (BIB) at 40cm	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p=0.0915	p=0.0413	p=0.0217	p=0.0103
PE #1	N/A	N/A	p=0.3583	p=0.0611	p=0.0241
PE#2	N/A	N/A	N/A	p=0.4282	p=0.0713
PE#3	N/A	N/A	N/A	N/A	p=0.6153

	Descriptive Statistics (BOB at 40cm data.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
BaseBOB	143	13.36364	0.00000	40.00000	9.564860
Ckpt1BOB	143	23.84507	6.00000	40.00000	9.088451
Ckpt2BOB	142	31.59859	12.00000	40.00000	7.324359
Ckpt3BOB	112	36.40625	20.00000	40.00000	4.857720
Ckpt4BOB	54	38.48101	25.00000	40.00000	2.925839

	Descriptive Statistics (BIB at 40cm data.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
BaseNFV	143	7.40972	1.00000	16.00000	2.880883
PE#1 BIB	143	10.47222	6.00000	18.00000	2.877315
PE#2 BIB	142	13.62500	6.00000	20.00000	3.010181
PE#3 BIB	112	16.07407	10.00000	22.00000	2.429198
PE#4 BIB	54	17.58537	12.00000	25.00000	2.418425

Figure 5. P-value matrix and descriptive statistics for PFV and NFV break points at near

Monocular Accommodative Facility (MAF, OD & OS) data: MAF significantly improved by PE #1 with further signficiant gains at PE #2, with majority of gains evident by PE #2. Average baseline (nearest cpm) in 5cpm range with end of therapy average in the 12cpm range (Figure 6)

MAF (OD data)	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p<0.0001	p<0.0001	p<0.0001	p<0.0001
PE #1	N/A	N/A	p<0.0001	p<0.0001	p<0.0001
PE#2	N/A	N/A	N/A	p=0.1154	p=0.0813
PE#3	N/A	N/A	N/A	N/A	p=0.4181

MAF (OS data)	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p<0.0001	p<0.0001	p<0.0001	p<0.0001
PE #1	N/A	N/A	p<0.0001	p<0.0001	p<0.0001
PE#2	N/A	N/A	N/A	p=0.1843	p=0.1113
PE#3	N/A	N/A	N/A	N/A	p=0.4881

	Descriptive Statistics (LD stats.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
Baseline MAF OD	143	4.98582	0.000000	14.00000	4.294491
PE#1 MAF OD	143	7.97872	0.000000	14.00000	3.471245
PE#2 MAF OD	142	9.94245	2.000000	16.00000	2.650594
PE#3 MAF OD	112	10.89916	7.000000	16.00000	2.176122
PE#4 MAF OD	54	11.67857	8.000000	15.00000	1.591852

	Descriptive Statistics (LD stats.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
Baseline MAF OS	143	5.29078	0.000000	14.00000	4.315320
PE#1 MAF OS	143	8.28369	1.000000	15.00000	3.450313
PE#2 MAF OS	142	10.12230	3.000000	16.00000	2.597268
PE#3 MAF OS	112	11.30833	6.000000	17.00000	1.943729
PE#4 MAF OS	54	12.18824	8.000000	18.00000	1.426736

Figure 6. P-value matrix and descriptive statistics for MAF OD and MAF OS at near measurements at baseline and subsequent progress evaluations

Stereopsis data: Stereopsis significantly improved from baseline by PE #1 with some further gains thereafter from PE #1 to PE #2 (minimal gains thereafter). Majority of gains achieved by PE #2. Average baseline metric (nearest 10 secs of arc) was 120" with end of therapy metric at PE #3 and PE #4 between 40-50" secs of arc (Figure 7)

Stereopsis (near)	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	P=0.0022	p<0.0001	p<0.0001	p<0.0001
PE #1	N/A	N/A	p=0.0359	p=0.0311	p=0.0293
PE#2	N/A	N/A	N/A	p=0.3471	p=0.2281
PE#3	N/A	N/A	N/A	N/A	p=0.7853

	Descriptive Statistics (LD stats.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
Baseline stereopsis	143	116.4583	40.00000	800.0000	170.5420
PE #1 stereopsis	143	67.2222	20.00000	800.0000	87.2457
PE #2 stereopsis	142	51.1479	20.00000	140.0000	25.6706
PE #3 stereopsis	112	47.9675	20.00000	140.0000	22.4689
PE #4 stereopsis	54	44.2391	20.00000	100.0000	14.6185

Figure 7. P-value matrix and descriptive statistics for stereopsis at near measurements at baseline and subsequent progress evaluations.

DEM (saccades) data: Significant statistical improvement in horizontal saccadic function (Type II) is evident by PE #1. Baseline average was 20th percentile with majority of gains attained by PE#3, at approximately the 65th percentile (Figure 8)

DEM-H (Type II)	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p<0.0001	p<0.0001	p<0.0001	p<0.0001
PE #1	N/A	N/A	p<0.0001	p<0.0001	p<0.0001
PE#2	N/A	N/A	N/A	p=0.0653	p<0.0001
PE#3	N/A	N/A	N/A	N/A	p=0.3963

	Descriptive Statistics (LD H-DEM stats.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
BaseDEM-H	143	25.64583	0.00000	91.00000	22.82511
PE#1 DEM-H	143	38.22917	0.00000	95.00000	24.99726
PE#2 DEM-H	142	52.48611	5.00000	98.00000	23.80926
PE#3 DEM-H	112	64.41667	12.00000	99.00000	20.89364
PE#4 DEM-H	54	70.39024	37.00000	99.00000	19.03796

Figure 8. P-value matrix and descriptive statistics for saccadic function as measured using DEM at baseline and subsequent progress evaluations

Visual Perceptual data from Test of Visual Percetual Skills (TVPS) test battery:

Global TVPS data: TVPS global score significantly improved from baseline by PE #1 with further signficiant gains thereafter up to PE #2 (some gains thereafter, but not signficiant statistically). Majority of gains achieved by PE #3. Average baseline metric was 30th percentile with 75-84th percentile being achieved by PE #3- PE #4 (Figure 9)

TVPS (Global Score)	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p<0.0001	p<0.0001	p<0.0001	p<0.0001
PE #1	N/A	N/A	p<0.0001	p<0.0001	p<0.0001
PE#2	N/A	N/A	N/A	p=0.0.013	p<0.001
PE#3	N/A	N/A	N/A	N/A	p=0.0651

	Descriptive Statistics (TVPS Global stats.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
Base Global	143	29.77083	1.00000	75.00000	19.23346
PE #1	143	46.82639	5.00000	86.00000	17.17183
PE #2	142	61.33333	25.00000	95.00000	14.72166
PE #3	112	75.25926	45.00000	98.00000	12.74874
PE #4	54	83.73171	63.00000	99.00000	9.30866

Figure 9. P-value matrix and descriptive statistics for TVPS global data measured at baseline and subsequent progress evaluations

Visual Discrimmination data: Visual disrimmination as measured by TVPS significantly improved from baseline by PE #1 with signficiant gains also seen at PE #2 and #3. Majorty of gains achieved by PE #3. Average baseline metric 20th percentile with average at graduation approximately 76-86th percentile at PE#3/PE#4 (Figure 10)

TVPS: Visual Disrimmination	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p<0.0001	p<0.0001	p<0.0001	p<0.0001
PE #1	N/A	N/A	p<0.0001	p<0.0001	p<0.0001
PE#2	N/A	N/A	N/A	p=0.0143	p<0.0001
PE#3	N/A	N/A	N/A	N/A	p=0.0643

	Descriptive Statistics (Visual Disc stats.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
Baseline	143	19.82639	1.00000	63.00000	14.04206
PE #1	143	47.26389	16.00000	75.00000	13.07107
PE #2	142	63.54861	25.00000	99.00000	11.66360
PE #3	112	76.37963	42.00000	99.00000	11.48401
PE #4	54	86.29268	55.00000	99.00000	12.57228

Figure 10. P-value matrix and descriptive statistics for TVPS Visual Disrimmination data measured at baseline and subsequent progress evaluations.

Visual Memory data: Visual memory significantly improved by PE #1 compared to baseline with some further significant gains at PE #2 and PE#3 (minimal gains thereafter). Majorty of gains achieved by PE #2 to PE #3. Average baseline metric was 29th percentile to 71-76th by PE #2-PE #3 (Figure 11)

TVPS: Visual Memory	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p<0.0001	p<0.0001	p<0.0001	p<0.0001
PE #1	N/A	N/A	p=0.0002	p<0.0001	p<0.0001
PE#2	N/A	N/A	N/A	p=0.0862	p=0.0378
PE#3	N/A	N/A	N/A	N/A	p=0.3301

	Descriptive Statistics (Visual Memory stats.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
Baseline	143	29.38889	1.00000	98.00000	23.22198
PE #1	143	59.46528	1.00000	99.00000	28.84609
PE #2	142	71.34028	5.00000	99.00000	24.75168
PE #3	112	76.41667	9.00000	99.00000	20.83586
PE #4	54	80.02439	25.00000	99.00000	18.08105

Figure 11. P-value matrix and descriptive statistics for TVPS Visual Memory data measured at baseline and subsequent progress evaluations

TOSWRF-2 reading efficiency data: TOSWRF-2 percentiles for reading efficiency significantly improved from baseline to PE #2 with further gains thereafter, with majority of gains achieved by PE #3. Average baseline metric was 20th percentile with 42nd-47th percentile being achieved by PE #3/PE #4 (Figure 12)

TOSWRF-2 data	Baseline	PE #1	PE #2	PE #3	PE #4
Baseline	N/A	p=0.2221	p=0.0321	p=0.0252	p=0.0006
PE #1	N/A	N/A	p=0.0809	p=0.0061	p=0.0003
PE#2	N/A	N/A	N/A	p=0.2725	p=0.0354
PE#3	N/A	N/A	N/A	N/A	p=0.5471

	Descriptive Statistics (LDstats.sta)				
Variable	Valid N	Mean	Minimum	Maximum	Std.Dev.
BaseTOSWRF	143	20.31144	1.000000	87.00000	20.55062
PE #1 TOSWRF	143	29.56190	5.000000	94.00000	26.13755
PE #2 TOSWRF	142	36.75941	15.000000	99.00000	27.03621
PE #3 TOSWRF	112	41.73247	18.000000	96.00000	26.61944
PE #4 TOSWRF	54	47.22500	20.000000	99.00000	24.89862

Figure 12. P-value matrix and descriptive statistics for TOSWRF-2 reading efficiency data measured at baseline and subsequent progress evaluations

Relationship between TOSWRF-2 reading efficiency data and DEM Type II data at baseline:

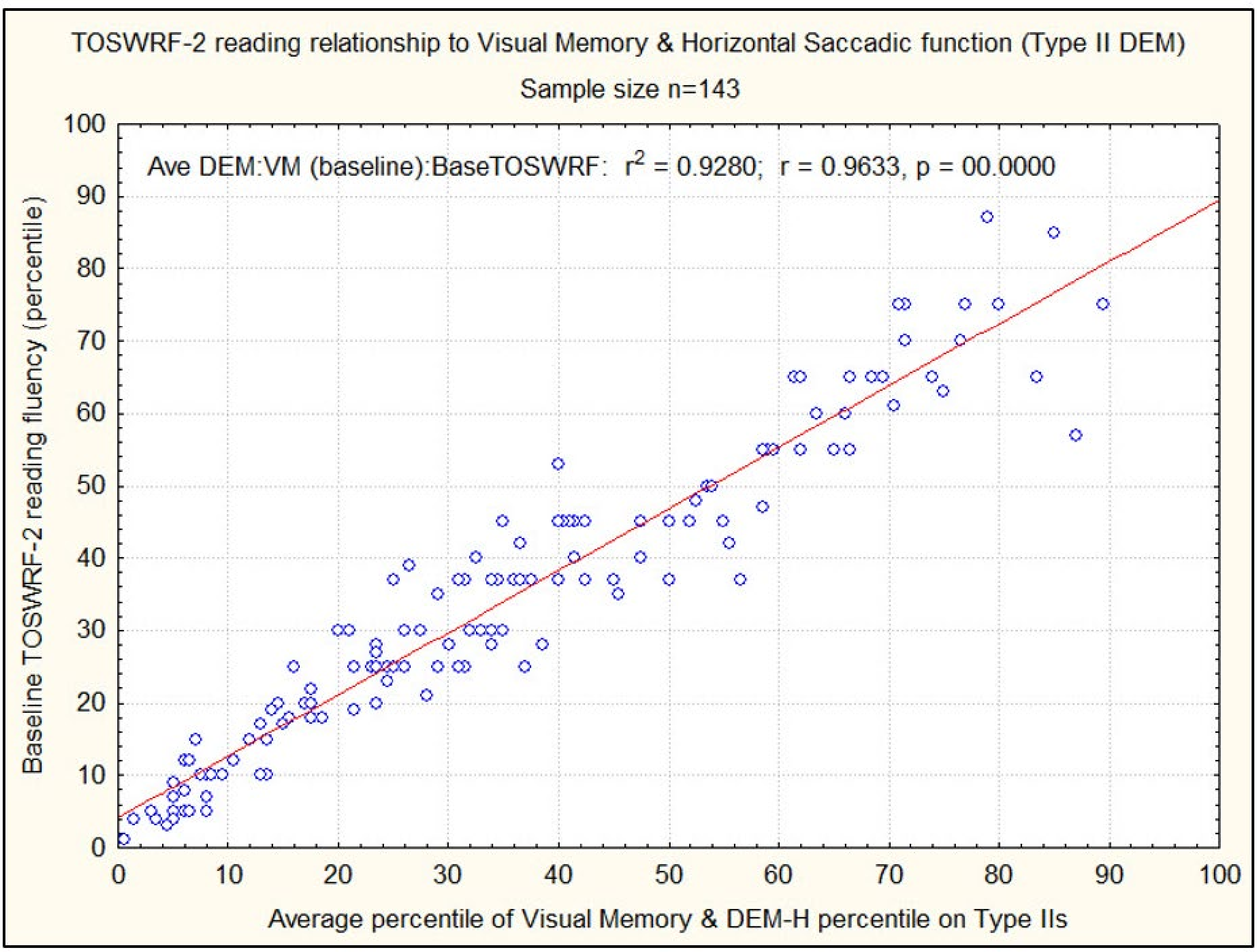


Figure 13. TOSWRF-2 findings at baseline (y-axis) graphed against average percentile of VM and DEM-H in Type II (Oculomotor Type) cases at baseline (x-axis) prior to OBVT. Of note, the co-efficient of determination (r-squared value) is signficiant ($p<0.001$). For comparison, when DEM alone or VM alone are plotted against TOSWRF-2 reading efficiency scores, co-efficient of determination drops to 0.55 and 0.32 respectively. Therefore, baseline data appears to show that both visual memory and saccadic eye movements are required for efficienct reading as shown on TOSWRF-2 testing within this age cohort.

DISCUSSION

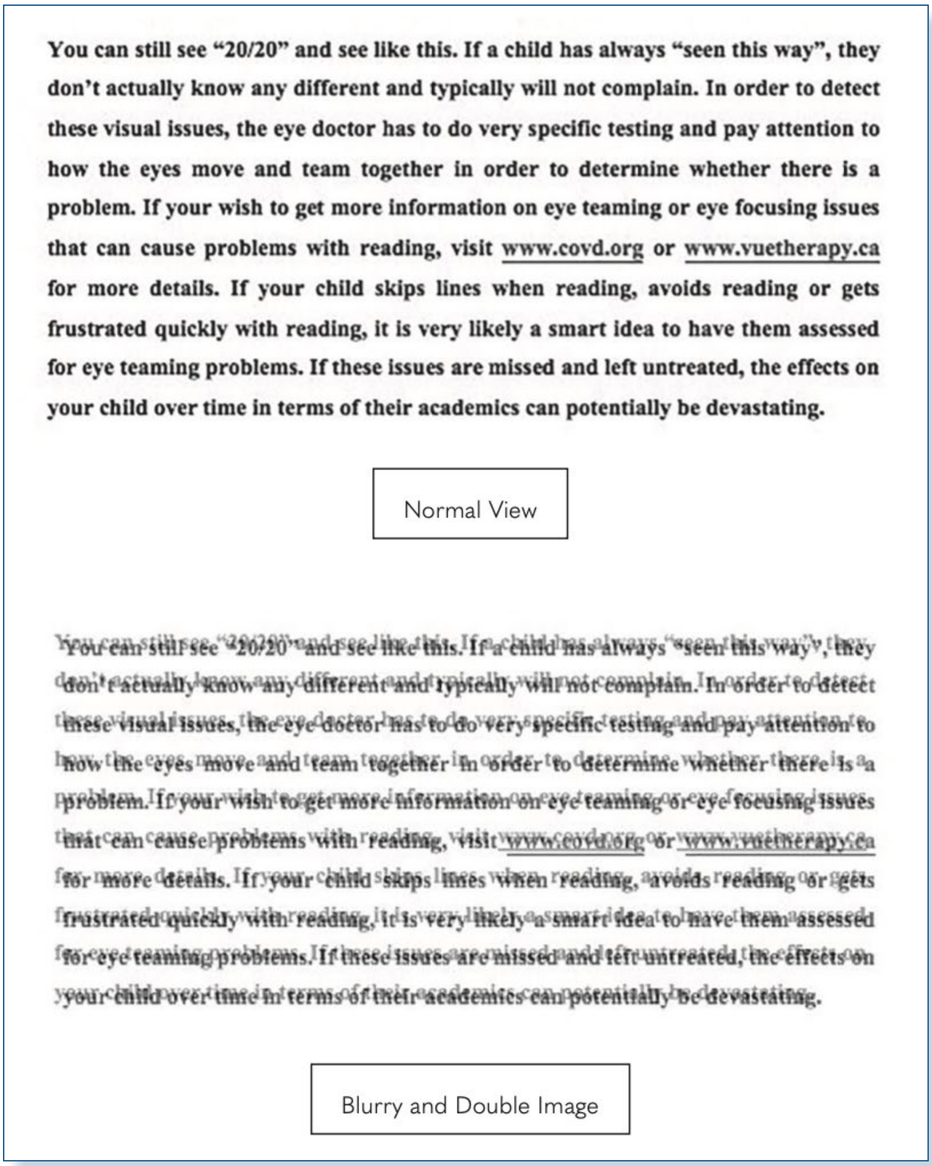
This study sought to investigate whether dynamic visual skills, visual processing, and/or reading fluency improved in children diagnosed with visual skills deficiencies (VSD) and treated with an office based vision therapy (OBVT) program. Although the study was a restrospective review of patient files, results were found to be consistent with previously reported findings,[1,3,8,14-16,23] and should be considered in future study designs. Specifically, this study found a high frequency of VSD and VIP deficits in children (age 6-18 years) with a dyseidetic reading disorder measured using the DST suggesting a relationship may exist between visual skills, visual processing and reading efficency. In addition, results found reading ability, as measured using the TOWSRF-2 reading efficiency test battery, as well as several visual processing indexes, improved while being treated with an OBVT program, supported by home re-enforcement; however, it is unclear whether additional metrics (i.e. concurrent reading program at school) also contributed to the overall finding. While most metrics such as OMD and VIP changed by the first progress evaluation (PE), reading outcome measures and vergence facility did not show gains until the second PE assessment (i.e. after 20 sessions). The fact that improvements in reading efficiency were seen mid-way through the vision therapy program is interesting, especially since vergence facility also appeared to follow the same time course.

These results were similarly reported by Quaid & Simpson (2013), who demonstrated vergence facility testing at near was the strongest dynamic visual skill measurement correlated to reading performance.[1] Therefore, the results presented in this paper taken with prior research,[1] suggests that in dyseidetic reading difficulty cases, reading fluency may be correlated with vergence facility, and also appears to improve in parallel with vergence facility outcome measures. This finding suggests that vergence function and reading scores may be associated, as seen in studies by Dodick *et al.*,[2] Husseindeen *et al.*[12] and Scheiman *et al.*[18] More specifically, results from this study showed that in addition to vergence facility, base-in prism break points also did not to improve until PE #2; a pattern not yet reported in the literature with base-out prism data and warrants further investigation.

In addition to the correlation between vergence facilty and reading effiency in children,[1] it has also been reported that visual memory may be predictive of reading and math performance.[5,6] Applying these connections, it can assumed that if a word appears different due to visual fluctuations (i.e., diplopia or intermittent blur), visual recall will be challenging since there is no consistency in visual and an almost "overly phonetic" pattern of spelling, i.e., "fucher" for FUTURE or "stashun" for STATION will be depicted (Figure 14). Therefore, if a child cannot recall what a word *looks like* and proper phonemic awareness is present, the educational default will be to spell the word based on how it sounds. This results in a noticeable lack of reading fluency due to poor sight word or rapid "jail word" recognition, potentially leading to a stunted and laboured reading pattern[26,29] due to failure of the visual component of the orthographic mapping process.[20]

This study also explored whether commonly reported symptoms using the COVD QoL and CISS questionnaires were associated with abnormal binocular findings (Figures 3-7).

When comparing symptoms associated with binocular vison dysfunction to data-base findings, it was found commonly reported symptoms such as "words sometimes move on the page when I try to read"; "words come in and out of focus when I am trying to read"; "the words look funny when I am trying to read"; "sometimes I think the word is written twice on the page"; "I loose my place a lot when I read and have to use my finger to keep my spot" were recorded in patient files who also had a receded NPC and/or reduced accommdative or vergence facilty. This is likely because children have difficulty understanding what is meant by "normal vision" but appreciated the clarity and comfort in vision when lenses and therapy were introduced. Similar to the findings in this study, the Convergence Insufficiency (CI) Treatment Trial (CITT)[31] reported symptomatic


You can still see "20/20" and see like this. If a child has always "seen this way", they don't actually know any different and typically will not complain. In order to detect these visual issues, the eye doctor has to do very specific testing and pay attention to how the eyes move and team together in order to determine whether there is a problem. If your wish to get more information on eye teaming or eye focusing issues that can cause problems with reading, visit www.covd.org or www.vuetherapy.ca for more details. If your child skips lines when reading, avoids reading or gets frustrated quickly with reading, it is very likely a smart idea to have them assessed for eye teaming problems. If these issues are missed and left untreated, the effects on your child over time in terms of their academics can potentially be devastating.

Normal View

You can still see "20/20" and see like this. If a child has always "seen this way", they don't actually know any different and typically will not complain. In order to detect these visual issues, the eye doctor has to do very specific testing and pay attention to how the eyes move and team together in order to determine whether there is a problem. If your wish to get more information on eye teaming or eye focusing issues that can cause problems with reading, visit www.covd.org or www.vuetherapy.ca for more details. If your child skips lines when reading, avoids reading or gets frustrated quickly with reading, it is very likely a smart idea to have them assessed for eye teaming problems. If these issues are missed and left untreated, the effects on your child over time in terms of their academics can potentially be devastating.

Blurry and Double Image

Figure 14. Comparing single, clear vision to what a child woudlsee if vergences and accommodation were a problem, causing double vision and blurred vision. This perception of print, which is purely a visual phenomenon will affect orthographic mapping by significantly ipauring a child's ability to "recall what has been seen. Although phonetic awareness and teaching insutrction are also vital, a child's abilty to see clearly and consistently is a key aspect to devoping visual memory, which is a requirement for sight word development to occur. The child will often prefer larger font despite attaining "20/20"acuity due to the "crowding effect" of smaller print.

children with CI can be successfully treated with office-based vision therapy (OBVT) re-enforced by home therapy. Several other studies such as those by Dodick *et al.* in 2016[2] and Scheiman et al. in 2011[18] also report improvements in accommodative function and reading outcomes with OBVT.[10,12] It should be noted, however, that while the above mentioned studies including this one, showed gains in reading performance following an OBVT program, it is unclear how much of the gains were due to a placebo effect or other factors such as concurrent reading program at school. While it can be speculated that reading performance improves following an OBVT program as noted in this study, a prospective randomized control trial would need to be carried out to confirm results.

Similarly, other research has shown that reading based outcomes as measured by the Wechsler Indivisual Achievement Test (WIAT-II) and Grey Oral Reading Test (GORT) methods reveal signficant gains in performace in 57% of the sample size by 16 sessions, with and a further 25% show signficiant gains by 24 sessions,[18] suggesting the TOSWRF-2 may require more sessions to show gains by virtue of how it is administered (i.e. TOSWRF-2 uses crowded lines of letters with no gaps, therefore likely requiring better figure-ground and visual discrimination skills). The greatest gains seen in the study by Scheiman et al. in 2018[18] was attained using WIAT-II test in terms of reading comprehension subtest. Of particular interest as seen in this study, Scheiman et al. found that the children with more significant degrees of convergence insufficiency and the lowest TOSWRF-2 scores had more significant gains in therapy, and concluded that improvements in reading comprehension and reading speed were seen to a greater degree in a children who were poor readers with more severe convergence problems following therapy. Although the limitation to this study was the lack of a control group, the conclusion is in agreement with the data presented in this paper. Specifically, the TOSWRF-2 reading level in the cohort examined in the research presented here at baseline was in the 20th percentile, and the overall baseline convergence was almost 13cm, with horizontal saccades being in the 25th percentile at baseline. This data indicates that the "average" child at baseline in the current study could quite reasonably be classified as having "significant VSD concerns". Therefore, it appears that the results in this study are in agreement with both the study by Scheiman[18] when several factors are taken into account. Of all factors discussed however, ensuring that primarily dyseidetic cases, and not disphonetic cases are used, and ensuring appropriate diagnosis from a VSD aspect, appear to confer the maximum benefit from OBVT. In addition to DST testing, tests such as the Test of Word Reading Efficiency (TOWRE) and the Weschler Individual Achievement (WIAT) Pseudoword Decoding Test could also be used to further clarify the underlying etiology.

The involvement of vision in the reading acquisition process cannot be understated. Visual skills are required in conjuction with several other sensory areas to set the foundation for overall reading skills to emerge. Although the orthographic mapping process also requires important factors outside of vision such as intact phonological awareness, proper hearing ability, and proper instruction strategies, consistent visual input of what is seen on the page is vital for success in the literacy acquisition phase. Without appropriate oculomotor and binocular integration skills, it is a reasonable assertion that the "automaticity of sight word recognition" required for fluent reading ability will be difficult, if not impossible to attain.[29,40] Symptoms such as intermittent blurred vision, double vision, tracking issues, and as a result reduced visual memory, will all lead to significant challenges when reading. Left untreated, VSD issues would logically lead to persistent dyseidetic reading issues, despite the administration of more traditional interventions such as tutoring, speech language pathology (SLP) intervention in terms of phonological training, or technology specific interventions such as "Fast-Forward" or "Empower" programs or similar computer screen based (i.e. text to talk) interventions. Outcome data presented in this study suggests that OBVT is a critical component in treating children with persistent dyseidetic based reading issues when significant VSD issues are formally diagnosed. This conclusion is in agreement with several other studies conclusing that VSD issues should be ruled out or treated in children with poor reading performance.[1-3,8,11,12,15,16,18,23,30,39]

Limitations of the Study

Due to the retrospective nature of this study (data gathered from direct patient examinations), participants/patients were not masked and clinician bias must be considered when reviewing the results. Similarly, although the same clinician did examine the patient at baseline and during the PE exam, different clinicians were involved in the overall treatment of the patient (three total) and therefore inter-clinician variability must also be taken into account when reviewing data. Although data from this study does suggest that OBVT may be effective in improving areas of VSD and 490 VIP, the limitations of the study design cannot confirm this association. To confirm the results of this study, a future study should be a prospective, double-blind, randomised trial with similar subject recruitment criteria and treatment approaches.

CONCLUSION

Data presented in this paper confirms that treating appropriately diagnosed visual skill deficiencies (VSD) in children with dyseidetic reading problems with at least 20 office based vision therapy (OBVT) sessions improves reading fluency and efficiency as measured using TOWSRF-2 testing. More specifically, OBVT was found to improve several visual processing skills, in particular visual memory and visual discrimination ability, in addition to improving saccadic function, accommodation and vergence facility. Vergence facilty in particular, in line with prior research1 highlighting significant association, appears to improve in parallel with gains in reading fluency. This finding highlights the need to detect and treat VSD issues in children with dyseidetic reading difficulties, in particular those that appear to have persistent sight word acquisition and retention difficulites despite traditional interventions being undertaken.

ACKNOWLEDGEMENTS

This research is supported by the Government of Canada Scientific Research and Experimental Development (SR&ED) Grant and the College of Optometrists in Vision Development Research Grant.

We would also like to thank Dr. Heather Mackenzie, OD, FCOVD (HM) for help in collecting data on patients during clinic time.

DISCLOSURE

The authors report no conflicts of interest and have no proprietary interest in any of the materials mentioned in this article.

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