1040-5488/17/9401-0101/0 VOL. 94, NO. 1, PP. 101–107
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Vision Therapy for Binocular Dysfunction Post Brain Injury

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ABSTRACT

Purpose. To prospectively evaluate the effectiveness of home-based computer vergence therapy for the treatment of binocular vision disorders in adults at least 3 months after an acquired brain injury.

Methods. Eligibility criteria included presence of binocular dysfunction characterized by receded near point of convergence (≥6 cm break), insufficient positive fusional vergence at near (failing Sheard's criterion or <15Δ blur or break), insufficient negative fusional vergence at near (<12Δ blur or break), and/or reduced vergence facility at near (<15 cycles per minute with 12ΔBO/3ΔBI). Participants were prescribed 12 weeks of home-based computer vergence therapy. Phoria (cover test), negative fusional vergence, positive fusional vergence, near point of convergence, vergence facility, and symptoms (convergence insufficiency symptom survey [CISS]) were assessed at baseline and after 4, 8, and 12 weeks of prescribed therapy. ANOVA was used to evaluate change in each measure. Percentage successful was also determined.

Results. Nineteen participants were enrolled (mean age 45.4 ± 12.9 years); six participants were lost to follow-up. Baseline findings were orthophoria at distance, 7.2Δ exophoria at near, near point of convergence break = 17.5 cm, near point of convergence recovery = 21.8 cm, negative fusional vergence = 12.3Δ, positive fusional vergence blur = 8.4Δ, vergence facility = 3.9 cycles per minute, and CISS = 32.1. ANOVA showed a statistically significant improvement for near point of convergence break ($p = 0.002$) and recovery ($p < 0.001$), positive fusional vergence blur ($p < 0.0001$), break ($p < 0.0001$), and recovery ($p < 0.0001$), negative fusional vergence blur ($p = 0.037$), break ($p = 0.003$), and recovery ($p = 0.006$), vergence facility ($p < 0.0001$), and CISS ($p = 0.0001$). The percentage of patients who were classified as ''successful'' or ''improved'' was 69% for near point of convergence (<6 cm or decrease of ≥4 cm), 77% for positive fusional vergence (>15Δ and passing Sheard's criterion or increase of ≥10Δ), 77% for negative fusional vergence (≥12Δ or increase of ≥6Δ), 62% for positive fusional vergence and near point of convergence composite, and 92% for vergence facility (15 cycles per minute or increase of 3 cycles per minute).

Conclusions. The majority of participants who completed the study experienced meaningful improvements in signs and symptoms.

(Optom Vis Sci 2017;94:101–107)

Key Words: vision therapy, binocular vision dysfunction, brain injury, adults, orthoptics

The Brain Injury Association of America has reported that approximately 1.4 million Americans are known to suffer from a traumatic brain injury (TBI) event every year. The number of individuals who have a qualifying TBI event and do not seek care is not known. Falls account for the largest percentage of TBI (28%), whereas motor vehicle accidents are second (20%).[1] In 1999, the Centers for Disease Control (CDC) reported that approximately 3.17 million Americans who have sustained a TBI have deficits in completing activities of daily living.[2] Brain injury is also frequently associated with vergence dysfunction.[3]

In a review of 220 medical records, Ciuffreda et al. reported signs and symptoms of 160 mild TBI patients (mean age 44.9 years) and 60 cerebrovascular accident patients (mean age 61.2 years).[4] Visual symptoms were prevalent in both groups. In TBI, eyestrain with near vision tasks (52%), increased light sensitivity (50%), headaches with near vision (44%), and near vision blur (44%) were the most common visual symptoms. In the cerebrovascular accident subgroup, near vision blur (40%), eyestrain with near vision tasks (38.3%), loss of place while reading (33.3%), and distance vision blur (31.7%) were the most common visual symptoms. Deficits of vergence were present in 56% of the TBI group and 37% of the cerebrovascular accident group. Convergence insufficiency (CI) was the single most common

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oculomotor dysfunction found in this review, being seen in approximately 40% of those with brain injury. In contrast, the reported prevalence of convergence insufficiency in a standard, non-presbyopic clinical population was 4%.[5,6] Deficiency in accommodation was present in 41% of TBI patients and 12.5% of cerebrovascular accident patients, with accommodative insufficiency and accommodative infacility being the most common types, respectively. Strabismus was present in 26% of TBI with greater frequency at near, whereas strabismus was present in 37% of cerebrovascular accident with greater frequency at distance. A similar number of TBI and cerebrovascular accident patients were found to have constant versus intermittent and unilateral versus alternating strabismus.

Cohen reported finding convergence insufficiency in 42% of brain injured patients at 3 years' follow-up. CI was found to have statistically significant associations with the presence of cognitive disturbances and difficulty finding work in the open market.[7] Lepore conducted a retrospective review of 60 brain injury patients with posttraumatic ophthalmoplegia and found trochlear nerve palsies to be the most common nuclear or infranuclear cause for traumatic diplopia, whereas convergence insufficiency was the most common cause of supranuclear traumatic diplopia.[8] Alvarez et al. reported on the prevalence of convergence insufficiency in the civilian TBI population (n = 557) with and without simultaneous visual dysfunctions, such as oculomotor dysfunction, cranial nerve palsies, visual field defects, and photophobia. Isolated CI in the TBI sample was reported to occur in 9%, whereas the overall prevalence of CI was 23%.[9]

Post trauma vision syndrome has been used to describe the constellation of signs and symptoms that often accompany a brain injury. Signs include exotropia, accommodative dysfunction, convergence insufficiency, low blink rate, spatial disorientation, poor fixations and pursuits, and unstable ambient vision (magnocellular mediated vision). Symptoms of Post trauma vision syndrome include diplopia, stable objects appearing to move, poor concentration, poor attention, staring, poor visual memory, photophobia, asthenopia, poor balance, poor coordination, and poor posture.[10,11]

In populations of non-TBI patients, randomized clinical trials have recently shown the effectiveness of treatment for convergence insufficiency, one common binocular dysfunction found in brain injured populations.[12–15] The Convergence Insufficiency Treatment Trial (CITT) group found that vergence/accommodative therapy is effective in treating symptomatic convergence insufficiency in children age 9 to 17.[12,14] Additionally, computer-based vergence/accommodative therapy was shown to significantly improve both near point of convergence and positive fusional vergence at near when compared to placebo therapy.[14] The effect of treatment on signs and symptoms of CI were maintained at least 1 year after discontinuation of treatment.[16] Improvement of signs of CI with office-based and computer-based vergence/accommodative therapy was more rapid than improvement in symptoms.[17] Changes in vergence function, functional magnetic resonance imaging scans, and reading have been reported in adults with TBI suggesting the presence of neuroplasticity.[18–20]

There is limited prospective clinical research regarding treatment of binocular dysfunction in the brain injury population. The purpose of this study was to prospectively evaluate the effectiveness of home-based computer vergence therapy in improving signs and symptoms of binocular dysfunction in adults, ages 18 to 85, at least 3 months post brain injury.

METHODS

Participants between the ages of 18 and 85 with a history of documented brain injury at least 3 months before were recruited. The research followed the tenets of the Declaration of Helsinki. The research was approved by the institutional review board and written informed consent was obtained from the participating participants after an explanation of the study.

Brain injury was defined as an insult to the brain caused by an external physical force, cerebrovascular accident, or toxin (i.e. not of degenerative or congenital nature). Because this was a study of the effectiveness of therapy in those with brain injury and it was unknown whether the effectiveness of therapy would differ according to the cause of the injury, inclusion was not limited to those with a particular type of brain injury.

Inclusion criteria also included at least 20/25 best-corrected visual acuity at distance (20 feet equivalent) and near (40 cm) and the presence of convergence insufficiency, accommodative insufficiency, and/or fusional vergence dysfunction. Convergence insufficiency was defined as a condition consisting of exophoria at near that was 4 prism diopters greater than the phoria at distance, receded near point of convergence of ≥6 cm break, and insufficient positive fusional vergence (i.e. failing Sheard's criterion or minimum normative positive fusional vergence of 15 base-out to blur, or break if no blur finding), as defined in the CITT study.[14] Fusional vergence dysfunction was defined as a condition consisting of insufficient positive fusional vergence at near (i.e. failing Sheard's criterion or minimum normative positive fusional vergence of less than 15 base-out blur or break if no blur finding), insufficient negative fusional vergence at near (less than 12 base-in to blur or break), or insufficient vergence facility at near (<15 cycles per minute using a 12 base-out/3 base-in split prism). For non-presbyopic participants, accommodative insufficiency was defined as having amplitude of accommodation 2 or more diopters (D) below the minimum expected for the subject's age using the formula 15 D − 0.25 (age in years).

Additional inclusion criteria included having an eye examination with refraction in the last 3 months (to ensure known ocular health status and best-corrected visual acuity for study measures), presence of 500″ random dot stereopsis on Randot stereoacuity testing, willingness to wear glasses or contact lenses to correct refractive error if necessary, and willingness to discontinue wearing a plus-add bifocal (pre-presbyopes only, if applicable). Access to a personal computer with an internet connection was required to enable monitoring of therapy activity via a secure database. No minimum Convergence Insufficiency Symptom Survey (CISS) score was required for eligibility to allow participants with low CISS scores due to avoidance of near work to participate in the study.

Exclusion criteria included constant strabismus, pregnancy, history of neurological disease (e.g. multiple sclerosis, Parkinson's disease), developmental disability, or learning disability that may interfere with performing therapy (at investigator discretion).

Subject history collected included date of birth, date of brain injury, and type of brain injury. Habitual spectacle correction was checked by lensometry, if applicable.

Testing procedures followed the CITT protocol[14,21] with the exception that presbyopic patients were instructed to look through their bifocal which put the subject in a down gaze position. The CISS[22,23] was used to assess symptom level. The CISS was administered to all participants before performing any other testing and again at the end of the testing. The average CISS from the two test administrations was used in all analyses. Cover testing was performed with a 20/30 letter isolated at distance and near. The near point of convergence was assessed using the Astron International (ACR/21) Accommodative Rule with a single column of letters of 20/30 Snellen equivalent at 40 cm as a target according to the procedure detailed in the CITT.[21] Near point of convergence break and recovery was measured three times, with a 10-second break in between each measure, and the mean was used for analysis. negative fusional vergence and positive fusional vergence were measured with a horizontal prism bar (Gulden B-16 horizontal prism bar; Gulden Ophthalmics, Elkins Park, PA) and a hand-held fixation target (Gulden Fixation Stick #15302) with a single column of letters of 20/30 Snellen equivalent according to the procedure detailed in the CITT. Blur, break, and recovery were measured three times, with a 30-second break in between, and the mean of each was used for analysis. Because only one subject who completed therapy was under 30, accommodation testing procedures are not described here.

Vergence facility was assessed using a 12Δ base-out/3Δ base-in split prism while the subject viewed a vertical row of 20/30 Snellen equivalent letters (Gulden Fixation Stick #15302) at a test distance of 40 cm. Vergence facility was recorded in cycles per minute to the closest half cycle.[21]

The HTS computer software was demonstrated and provided to all eligible participants. Each subject was instructed to perform five therapy sessions each week. Follow-up visits were scheduled every 4 weeks throughout the subject's enrollment in the study. Tests at each follow-up visit included CISS, visual acuity, cover testing, near point of convergence, negative fusional vergence, positive fusional vergence, and vergence facility. At each visit, compliance was encouraged and any questions or concerns were addressed.

Progress in between follow-up visits was monitored via the HTS tools performance review. This provided a record of date and time of each therapy session completed, amount of time spent on therapy, and level achieved for a given task. Number of sessions completed and level achieved in the HTS program (base-in/base-out vergence, autoslide, jump ductions, or program completed) were recorded as indicators of compliance. Participants were classified as ''successful'' or ''improved'' based upon the criteria used in the CITT and normative values for clinical signs.[14,24] Specifically, participants were classified as ''successful'' on each outcome measure according to the following criteria: near point of convergence less than 6 cm, normal positive fusional vergence (i.e. blur/break greater than 15 and passing Sheard's criterion), normal negative fusional vergence (12Δ or greater), and normal vergence facility (≥15 cycles per minute). Participants were not classified as successful based on CISS score because a symptomatic score was not required for eligibility and the best cut points for those with TBI and those with vergence dysfunction other than CI are not known. Each subject was classified as ''improved'' for each clinical sign based upon the following criteria: a decrease in near point of convergence ≥4 cm, an increase in positive fusional vergence of ≥10 prism diopters, an increase in negative fusional vergence of 6Δ or greater, or an increase in vergence facility of 3 cycles per minute or more.

This study was designed as a pilot study with a goal of collecting baseline data to estimate the need for and sample size of a larger clinical trial. All data analyses were performed using the SPSS 17.0 software (IBM Corporation, Somers, NY). A one group by three time period repeated measures analysis of variance (ANOVA) was used to detect change in clinical measures between study visits. Unless specifically stated otherwise, an α-level of 0.05 was used.

RESULTS

Nineteen participants enrolled in the study with 13 of these completing the study. Three participants missed the 4-week follow-up, five missed the 8-week follow-up, and six missed the 12-week follow-up. The mean age was 45.2 years (±12.5). Fifteen of the 19 participants suffered from a TBI, most commonly vehicle-related accidents (n = 11). Three of the remaining participants suffered from cerebrovascular accidents and one suffered from organic brain syndrome via a venomous snake bite. The mean amount of time passed from date of injury to date of baseline study visit was 2.2 years (excluding two outlying values that were 14 and 15.5 years since injury, respectively). Twelve were male and seven were female. Sixteen participants were white, two were African American, and one was of Middle Eastern descent. One subject's spectacles included 4Δ base-in prism and values for clinical measures were adjusted accordingly. No participants were excluded due to inability to understand therapy and requirements for completion of therapy.

The baseline clinical profile of participants who completed 12 weeks of therapy (n = 13) is compared to that of participants lost to follow-up (n = 6) in Table 1. Those who completed the study had more severe signs of binocular dysfunction, were more symptomatic, had a longer time since brain injury, and were slightly younger than those who were lost to follow-up. Clinical characteristics at baseline and outcome are shown in Tables 2–4. At baseline, the mean phoria was orthophoria at distance and 7.2Δ exophoria at near. Mean negative fusional vergence value at 40 cm was 12.3Δ to blur and 10.3Δ to recovery. The mean

TABLE 1.
Clinical measures—completed versus lost to follow-up

	Completed (n = 13)	Lost to follow-up (n = 6)
Age (yrs)	42.3 (13.1)	46.5 (12.6)
Time since (yrs)	4.2	3.4
Near phoria (Δ)	−9.3 (3.9)	−6.2 (5.3)
NFV (Δ)	13.3 (4.4)	11.8 (4.3)
PFV (Δ)	5.4 (3.8)	9.8 (6.1)
NPC break (cm)	21.0 (13.0)	15.9 (9.1)
VF (cpm)	2.9 (4.1)	4.3 (4.6)
CISS	41.1 (9.4)	28.6 (13.0)

Δ, prism diopter; NFV, negative fusional vergence; PFV, positive fusional vergence; NPC, near point of convergence; cm, centimeter; VF, vergence facility; cpm, cycles per minute; CISS, Convergence Insufficiency Symptom Survey score.

TABLE 2.
Findings at baseline and outcome

	Baseline					
Patient	Phoria (Δ, distance/near)	NFV (Δ)	PFV (Δ)	NPC (cm, break/recovery)	VF (cpm)	CISS score
1	0/8XP	x/15/13	x/11/8	7/10	0	23.5
2	0/8XP	x/12/9	x/14/12	31/33	10	24
3	4EP/8EP	x/5/2	10/14/12	30/37	6	23.5
4	0/8XP	x/17/14	12/16/13	8/10	10	20
5	0/6XP	x/15/12	3/7/5	6/9	3	14
6	0/12XP	x/19/17	4/5/3	12/15	3	10
7	0/8XP	x/11/8	6/8/5	24/30	0	50
8	0/4EP	x/12/10	25/28/23	19/32	14	20.5
9	0/10XP	x/16/13	12/18/15	11/16	3	46.5
10	0/12XP	9/16/13	11/19/11	9/13	5.5	38
11	0/4XP	x/10/6	9/15/11	6/7	6	31
12	2XP/12XP	x/20/16	x/3/1	44/49	0	30
13	0/14XP	x/17/15	8/14/10	13/16	10	45
14	0/6XP	9/11/7	2/6/4	22/27	0.5	50.5
15	0/6XP	x/9/4	x/6/3	14/18	0.5	22
16	0/12XP	x/12/9	x/9/7	16/21	0.5	31
17	0/0	7/10/7	x/12/11	9/13	0.5	33
18	0/6XP	x/7/5	x/1/−2	27/30	0.5	46.5
19	0/8XP	12/15/13	2/4/2	25/27	0.5	48

Δ, prism diopter; NFV, negative fusional vergence; PFV, positive fusional vergence; NPC, near point of convergence; cm, centimeter; VF, vergence facility; cpm, cycles per minute; CISS, Convergence Insufficiency Symptom Survey; XP, exophoria; EP, esophoria.

positive fusional vergence value at 40 cm was 8.4Δ to blur and 8.8Δ to recovery. The mean near point of convergence break was 17.5 cm and recovery was 21.8 cm. The mean vergence facility (12Δ base-out/3Δ base-in) at 40 cm was 3.9 cycles per minute. The mean CISS score at baseline was 32.1 out of a maximum score of 60. The most commonly reported symptoms were slow reading, difficulty

TABLE 3.
Findings at outcome

	Outcome							
Patient	Phoria (Δ, distance/near)	NFV (Δ)	PFV (Δ)	NPC (cm, break/recovery)	VF (cpm)	CISS score	Sessions completed*	HTS level reached†
1	0/8XP	x/15/13	x/20/15	4/9	20	26.5	61	AS
2	0/8XP	x/17/15	x/24/20	5/8	15	16	57	JD
3	2EP/6EP	x/28/21	x/32/25	6/10	18	9.5	71	JD
4	0/10XP	16/17/14	x/25/20	6/10	20	4.5	22	JD
5	0/6XP	x/13/11	17/19/16	7/11	9	16.5	19	BI/BO
6	2XP/12XP	x/23/15	x/35/30	4/7	19	3.5	76	C
7	0/8XP	6/9/5	4/8/5	32/34	0.5	45.5	40	BI/BO
8	0/8EP	x/11/8	11/30/22	16/21	18.5	23	61	AS
9	0/8XP	12/18/16	14/20/17	5/8	18	34	47	JD
10	2XP/16XP	20/25/20	28/37/27	4/7	15	14.5	55	C
11	—	—	—	—	—	—	5	BI/BO
12	—	—	—	—	—	—	0	—
13	—	—	—	—	—	—	2	BI/BO
14	—	—	—	—	—	—	6	BI/BO
15	0/8XP	x/30/25	x/35/30	4/6	13	22	48	C
16	—	—	—	—	—	—	30	BI/BO
17	0/0	8/13/9	x/25/18	9/12	15.5	27	88	JD
18	0/6XP	13/15/12	x/10/8	21/25	6.5	43	54	JD
19	—	—	—	—	—	—	23	BI/BO

*Total number of therapy sessions completed.

†Highest level of the computer program attained by subject.

Δ, prism diopter; NFV, negative fusional vergence; PFV, positive fusional vergence; NPC, near point of convergence; cm, centimeter; VF, vergence facility; cpm, cycles per minute; CISS, Convergence Insufficiency Symptom Survey; XP, exophoria; AS, autoslide vergence; JD, jump ductions; EP, esophoria; BI/BO, Base-In/Base-Out; C, completed vergence therapy.

TABLE 4.

Change in binocular vision findings and symptoms from baseline to outcome

	Baseline	4 wks	8 wks	12 wks	
	Mean (SD) (N = 19)	Mean (SD) (N = 16)	Mean (SD) (N = 14)	Mean (SD) (N = 13)	p-value*
Distance phoria (Δ)	−0.1 (1.0)	0 (0.7)	0 (0.8)	−0.2 (1.0)	0.40
Near phoria (Δ)	−7.2 (5.0)	−7.1 (5.9)	−5.9 (6.4)	−5.8 (6.8)	0.50
NFV blur (Δ)	12.3 (4.2)	15.4 (6.9)	14.4 (3.7)	16.8 (6.8)	0.037
NFV break (Δ)	13.0 (3.9)	17.3 (6.6)	15.5 (3.8)	18.2 (6.5)	0.003
NFV recovery (Δ)	10.3 (4.1)	13.5 (5.1)	12.0 (3.3)	14.3 (5.5)	0.006
PFV blur (Δ)	8.4 (5.8)	16.1 (8.9)	17.2 (7.9)	21.3 (9.8)	<0.0001
PFV break (Δ)	11.6 (6.8)	18.3 (8.3)	20.8 (9.0)	24.3 (9.2)	<0.0001
PFV recovery (Δ)	8.8 (6.2)	13.7 (7.3)	15.2 (7.3)	19.2 (7.7)	<0.0001
NPC break (cm)	17.5 (10.4)	10.9 (7.3)	10.8 (7.4)	9.4 (8.5)	0.002
NPC recovery (cm)	21.8 (11.4)	14.6 (7.7)	14.6 (8.5)	12.9 (8.6)	<0.001
Vergence facility (cpm)	3.9 (4.4)	9.1 (4.8)	11.8 (6.6)	14.5 (5.9)	<0.0001
CISS score	32.1 (13.2)	25.6 (14.5)	22.8 (13.1)	22.5 (13.7)	0.0001

*Repeated measures ANOVA comparing mean at weeks 0, 4, 8, and 12.

SD, standard deviation; Δ, prism diopter; NFV, negative fusional vergence; PFV, positive fusional vergence; NPC, near point of convergence; cm, centimeter; cpm, cycles per minute; CISS, Convergence Insufficiency Symptom Survey.

concentrating while reading, having to re-read lines of text, trouble remembering what was read, and frequent loss of place.

Clinical Findings Post Vision Therapy

Participants completed an average of 53.8 sessions (range 19–88) of home-based therapy with most participants reaching the jump duction procedure or completing the program by 12 weeks (two were still on the base-in/base-out procedure and 2 were on autoslide after 12 weeks). At the 12-week outcome visit, the 13 participants who completed the study showed a mean phoria of orthophoria at distance and 5.8Δ exophoria at near. The mean negative fusional vergence value at 40 cm was 16.8Δ to blur and 14.3Δ to recovery. The mean positive fusional vergence value at 40 cm was 21.3Δ to blur (or break if no blur) and 19.2Δ to recovery. The mean near point of convergence break was 9.4 cm and recovery was 12.9 cm. The mean vergence facility (12Δ base-out/3Δ base-in) value at 40 cm was 14.5 cycles per minute. The mean CISS score after vision therapy was 22.5 out of a maximum score of 60.

Analyses were performed to identify whether a significant change occurred from baseline to week 12 (Table 4). Repeated measures ANOVA for negative fusional vergence showed statistical significance for improvement (increase) in base-in to blur ($p = 0.037$), break ($p = 0.003$), and recovery ($p = 0.006$) from baseline to outcome. Post hoc analysis using Tukey adjusted p-values for negative fusional vergence blur showed a significant difference between baseline and week 12 ($p = 0.032$), but not between any of the other visit to visit comparisons ($p \geq 0.13$). Post hoc analysis for negative fusional vergence break showed a significant difference between baseline and the week 4 visit ($p = 0.015$) and between baseline and week 12 ($p = 0.004$), but not between any of the other visit to visit comparisons ($p \geq 0.27$). Post hoc analysis for negative fusional vergence recovery showed a significant difference between baseline and week 4 ($p = 0.035$) and between baseline and week 12 ($p = 0.007$), but not between any of the other visit to visit comparisons ($p \geq 0.27$). Repeated measures ANOVA for positive fusional vergence showed statistical significance for improvement (increase) in positive fusional vergence blur ($p < 0.0001$), break ($p < 0.0001$), and recovery ($p < 0.0001$) from baseline to outcome. Post hoc analysis using Tukey adjusted p-values for positive fusional vergence blur showed a significant difference between baseline and week 4 ($p = 0.006$), baseline and week 8 ($p = 0.003$), and baseline and week 12 ($p < 0.0001$), but not between any of the other visit to visit comparisons ($p \geq 0.18$). Post hoc analysis for positive fusional vergence break showed a significant difference between baseline and week 4 ($p = 0.004$), baseline and week 8 ($p < 0.001$), and baseline and week 12 ($p < 0.0001$), but not between any of the other visit to visit comparisons ($p \geq 0.06$). Post hoc analysis for positive fusional vergence recovery showed a significant difference between baseline and week 4 ($p = 0.026$), baseline and week 8 ($p = 0.004$), baseline and week 12 ($p < 0.0001$), and between week 4 and week 12 ($p = 0.043$).

Near point of convergence break ($p = 0.002$) and recovery ($p < 0.001$) showed statistically significant improvements (decreases) from baseline to outcome. Post hoc analysis using Tukey adjusted p-values for near point of convergence break showed a significant difference between baseline and week 4 ($p = 0.009$), baseline and week 8 ($p = 0.011$), and baseline and week 12 ($p = 0.004$), but not between any of the other visit to visit comparisons ($p \geq 0.95$). Post hoc analysis for near point of convergence recovery also showed a significant difference between baseline and week 4 ($p = 0.003$), baseline and week 8 ($p = 0.004$), and baseline and week 12 ($p < 0.001$), but not between any of the other visit to visit comparisons ($p \geq 0.91$).

Repeated measures ANOVA showed overall statistical significance for improvement (increase) in vergence facility from baseline to outcome ($p < 0.0001$). Post hoc analysis using Tukey adjusted p-values showed a significant difference between baseline and week 4 ($p < 0.001$), baseline and week 8 ($p < 0.0001$), baseline and week 12 ($p < 0.0001$), and between week 4 and week 12 ($p = 0.001$), but not between the other visit to visit comparisons ($p \geq 0.19$).

CISS score improved (decreased) significantly from baseline to outcome ($p = 0.0001$). Post hoc analysis using Tukey adjusted p-values showed a significant difference between baseline and week 4 ($p = 0.007$), baseline and week 8 ($p < 0.001$), and baseline and week 12 ($p = 0.001$), but not between any of the other visit to visit comparisons ($p \geq 0.50$).

TABLE 5.
Percentage successful and improved

Variable	% Successful	% Successful or improved
Near point of convergence	46%	69%
Positive fusional vergence	69%	77%
Negative fusional vergence	77%	77%
Vergence facility	69%	92%
Near point of convergence and positive fusional vergence composite	54%	62%

The percentage of participants (among those who completed the final outcome visit) who were classified as ''successful'' or improved in both near point of convergence and positive fusional vergence and for each measure is shown in Table 5.

DISCUSSION

In this study, participants with binocular dysfunction secondary to brain injury showed significant improvements in near point of convergence (break and recovery), negative fusional vergence (blur, break, and recovery), positive fusional vergence (blur, break, and recovery), vergence facility, and reduced symptoms after a 12-week program of home-based computer therapy. The majority of the participants suffered from brain injury due to TBI. Participants were generally compliant with therapy. Although differences in methodology (retrospective analysis, case analysis, success criteria, type of therapy) prevent direct comparison, these findings support those of previous studies that have reported improvements with therapy post brain injury; this suggests the presence of neuroplasticity.[4,18–20,25] Due to the time elapsed since the injury, ranging from months to many years (4.2 years on average for those who completed the study), it is unlikely that the improvements occurred spontaneously.

A significant improvement (decrease) in CISS was found with the mean score decreasing from 32.1 (±13.2) at baseline to 22.5 (±13.7) at outcome.[22]

The mean improvement of vergence facility from the baseline visit to the outcome visit outpaced the other outcome measures. One factor contributing to this disparity may be the fact that as a group, the mean positive fusional vergence at baseline was less than the 12Δ base-out required to complete one cycle of vergence facility and nine participants had vergence facility measuring less than 1 cycles per minute at baseline. At the 4-week follow-up visit, the mean positive fusional vergence of the group had increased to greater than 15Δ and only one subject could not complete at least 1 cycles per minute. Nevertheless, Melville and Firth suggest that fusional vergence ranges and vergence facility shed light on different aspects of the vergence system (slow fusional vergence system versus fast fusional vergence system, respectively).[26] McDaniel and Fogt confirmed the lack of correlation between positive fusional vergence and vergence facility.[27]

Limitations of the current study include a small sample size, lack of masking, and the lack of a placebo control group. It is possible that participation in a prescribed therapy program had a positive effect on a subject's perception of the condition (i.e. symptoms).[28] A masked, placebo-controlled study is needed to confirm the effect of treatment on symptoms. Further research is also needed to compare the effectiveness of various types of convergence insufficiency therapy, such as in-office and home-based treatments. Home-based delivery of therapy is commonly practiced and has been shown to provide some positive effects on signs.[14] Furthermore, home-based therapy provides access to treatment on a flexible schedule at home when mobility and transportation may be an obstacle. However, office-based vergence/accommodative therapy has been shown to be significantly more effective in treating convergence insufficiency in children without TBI.[14] Participants were required to have access to the internet which allowed closer follow-up, but could present an issue to a patient who does not have internet access. Although the time allotted to complete each procedure could be adjusted when needed (e.g. for participants who fatigued quickly), a potential limitation was use of the fixed HTS goals; individualized goals may result in better overall success in this population. In addition, there was a high loss to follow-up, and it is not known whether those who were unsuccessful in the present study would have benefited from a different mode of therapy. It is not known whether greater improvements would have been found with an increased duration or frequency of home-based therapy sessions or with office-based therapy.

Twelve weeks of home-based computer therapy resulted in meaningful improvements in signs and symptoms for adults with binocular vision dysfunction post brain injury who were compliant with the therapy program. Due to the high prevalence of brain injury, the high frequency of associated binocular dysfunction, and the impact of binocular dysfunction on the quality and functioning of daily activities, a randomized, placebo-controlled clinical trial is needed to provide the information necessary regarding the best treatment for common binocular vision conditions post brain injury to assist in the remediation of visual function.

ACKNOWLEDGMENT

This research was supported by a Beta Sigma Kappa Optometric Honor Society grant.

Received January 16, 2016; accepted June 3, 2016.

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