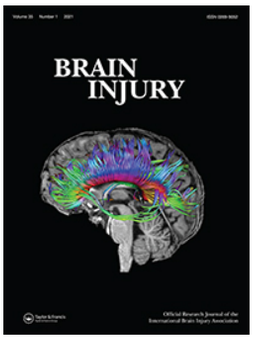

Brain Injury

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ibij20

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To cite this article: J. Johansson, M. Berthold Lindstedt & K. Borg (2021) Vision therapy as part of neurorehabilitation after acquired brain injury – a clinical study in an outpatient setting, Brain Injury, 35:1, 82-89, DOI: 10.1080/02699052.2020.1858495

To link to this article: https://doi.org/10.1080/02699052.2020.1858495

Published online: 09 Dec 2020.

BRAIN INJURY
2021, VOL. 35, NO. 1, 82–89
https://doi.org/10.1080/02699052.2020.1858495

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Vision therapy as part of neurorehabilitation after acquired brain injury – a clinical study in an outpatient setting

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ABSTRACT

Introduction: Oculomotor (OM) functions may be affected by acquired brain injury (ABI). The ability to benefit from rehabilitation or to perform daily activities may be affected by OM dysfunctions and associated symptoms. The purpose of this study was to investigate the effects of vision therapy (VT) as part of neurorehabilitation after ABI.

Materials and Methods: The study included two groups of outpatients (median 49.5–52.0 years, range 27–67) admitted to neurorehabilitation due to moderate to severe ABI. One group received VT while the other group served as controls to monitor the course of OM dysfunctions without VT.

Results: The intervention group showed significant improvements in convergence ($Z = 2.26$, $p = .02$), vergence facility ($Z = -2.16$, $p = .03$) and vergence reserves ($Z = -2.44$, $p < .01$ and $t = -4.47$, $DF = 15$, $p < .01$) along with a significant reduction in vision-related symptoms ($Z = 2.97$, $p < .01$).

Discussion: We conclude that OM issues were frequent and that targeted VT, as part of neurorehabilitation, can be an efficient treatment resulting in improved functions and reduced symptoms. Further study will be required to understand how improved functions link to performance and satisfaction with everyday activities.

ARTICLE HISTORY
Received 14 May 2020
Revised 9 October 2020
Accepted 29 November 2020

KEYWORDS
Acquired brain injury; vision therapy; rehabilitation interventions; visual impairment

Introduction

Vision can be viewed as a primary sense in many respects due to its strong integration in continuous information gathering, communication, orientation and ambulation. It involves extensive networks of the brain (1) that may be affected by acquired brain injury (ABI) through focal or diffuse lesions. Subsequent visual dysfunctions and associated symptoms (2–7) may affect the patient's ability to benefit fully from rehabilitation or to perform daily activities (8–13). A growing body of literature, including a conceptual model suggested by the American Congress of Rehabilitation Medicine's (ACRM's) Vision Task Force, raises the importance of including assessment and intervention of visual dysfunctions as part of neurorehabilitation (14–21).

Efficient visual function essentially depends on visual acuity (resolution of detail), visual field (visual overview), and also oculomotor functions. Oculomotor functions are crucial in the acquisition of visual information both in terms of detail and overview; pointing the two eyes, the gaze, toward visual targets allow visual images to be projected onto the central retina where resolution of detail is the highest. Moving the gaze also expands the functional visual field which may be of particular relevance in the event of visual field defects. Motor coordination of the eyes, eye teaming, is essential for maintaining clear, single and comfortable vision at near and far and enables depth perception among other two-eyed advantages.

The symptoms of oculomotor dysfunctions may include eye strain, blurred or double vision, photophobia, abnormal fatigue, headaches, difficulties with near work such as reading, dizziness, abnormal postural adaptation and pain in or around the eyes (American Optometric Association, AOA.org). It has been demonstrated that vision therapy (VT) can be an effective treatment for visuomotor issues such as eye movement disorders, eye teaming issues, focusing problems and visual-motor integration (22–24). VT consists of neurosensory and neuromuscular activities that are individually prescribed and monitored and intended to rehabilitate and enhance visual skills and processing (AOA.org). A VT program is based on the results of a thorough vision examination and considers the results of clinical tests and the patient's signs and symptoms. VT may include the use of lenses, prisms, filters, computer programs and free-space techniques. The activities may be performed in-office and/or at home but require supervision and monitoring. Reviews of current research have found promising results regarding interventions for visuomotor dysfunctions after ABI, however, there has also been identified a need for additional research that quantifies the functional outcomes (25–27).

The purpose of this study was to investigate the effects of VT as part of neurorehabilitation after acquired brain injury. Two groups of outpatients from the same clinic but from geographically separated units were included. One group received VT for their oculomotor dysfunctions while the other group served as controls in order to monitor the course of oculomotor dysfunctions without VT.

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Materials and methods

The study was carried out as an analytical interventional study in an outpatient setting. The patients were recruited from a regional rehabilitation clinic consisting of two units with separate catchment areas; north and south part of the region. The patients had been referred from caregivers in the region for evaluation of rehabilitation needs. Irrespective of catchment area all admitted patients had to pass the same diagnostic criteria and a common structured assessment. To qualify for a rehabilitation program, the patient had to be medically stable and in need of rehabilitation based on the assessment program. The assessment included medical, cognitive and psychological status as well as activity/occupational limitations. Based on this assessment an individual rehabilitation program was formed with a mean duration of eight weeks with three to four days per week spent in the clinic.

Inclusion criteria were (1) adult patients aged 18–65 years who had suffered a moderate to severe acquired brain injury in adulthood and (2) persistent disability corresponding to grade 4–7 on the Glasgow Outcome Scale Extended (GOSE). The main diagnoses included stroke, traumatic brain injury (TBI), sub-arachnoid haemorrhage (SAH), infection, tumour and hypoxia. Exclusion criteria were cognitive disabilities not related to the current brain injury, ongoing drug abuse, or extensive aphasia.

Patients admitted to the south unit were assigned to the intervention group that received VT in addition to customary neurorehabilitation (Figure 1). Patients admitted to the north unit served as controls and received customary rehabilitation but no VT.

The patients were invited to participate in the study upon admittance to the rehabilitation program. Verbal and written information about the study were provided and the patient was asked to give written consent if accepting to participate. The study adhered to the tenets of the Declaration of Helsinki and was approved by the regional ethics board.

Statistical power was calculated based on preliminary observations using the program G*Power (www.psychologie.hhu.de). The calculation was based on four of the oculomotor outcome variables and indicated a sample size of 17–24 to achieve a statistical power of 0.80 (1-β). To account for drop-outs and difficulty to predict dispersion in collected data it was decided to aim for 40 patients in each group. Analysis of results was performed with IBM SPSS Statistics 26 and Originlab Origin 2017. Distribution-tests were performed with Chi-square or Fisher Exact and for pairwise analysis the Wilcoxon signed rank or Student's t-test were applied. The Mann-Whitney U test was used for non-pairwise tests.

The visual examination was performed by a licensed optometrist and it took place at the clinic within 1–2 weeks of admittance and discharge respectively. The duration of an examination was maximum one hour and included; estimation of symptoms at near work using the Convergence Insufficiency Symptom Survey (CISS) (28), visual acuity, refractive error, accommodation, stereovision (TNO), eye motility, and eye teaming (cover test, near point of convergence, vergence facility, vergence reserves) (Table 1). Near point of accommodation (push-up) was measured (average of three repeated measures) with an R.A.F. near point rule (Haag-Streit, UK) using the fourth line on the near chart target. Accommodative facility was measured with a spherical flipper ± 2 diopters during one minute using the numbers on the back of a Lang fixation stick as target (test distance 30 cm). Near point of convergence (pushup) was measured (average of three repeated measures) with the R.A.F. rule using the convergence fixation target. The primary judgment for break was subjective reporting of diplopia, however the examiner also observed for eye deviation. In the event of no subjective diplopia the point of eye turn was noted. Vergence facility was measured with a Vergence Facility Prism (12D Base-Out/3D Base-In) during one minute using a symbol on the Lang fixation stick as target (test distance 40 cm). A cover test was performed to detect and measure heterotropia followed by an alternating prism cover test (prism bar) to measure heterophoria. Vergence reserves, divergent and convergent, were measured with prism bar step vergence using a symbol on the Lang fixation stick as near target and a small fixation light as

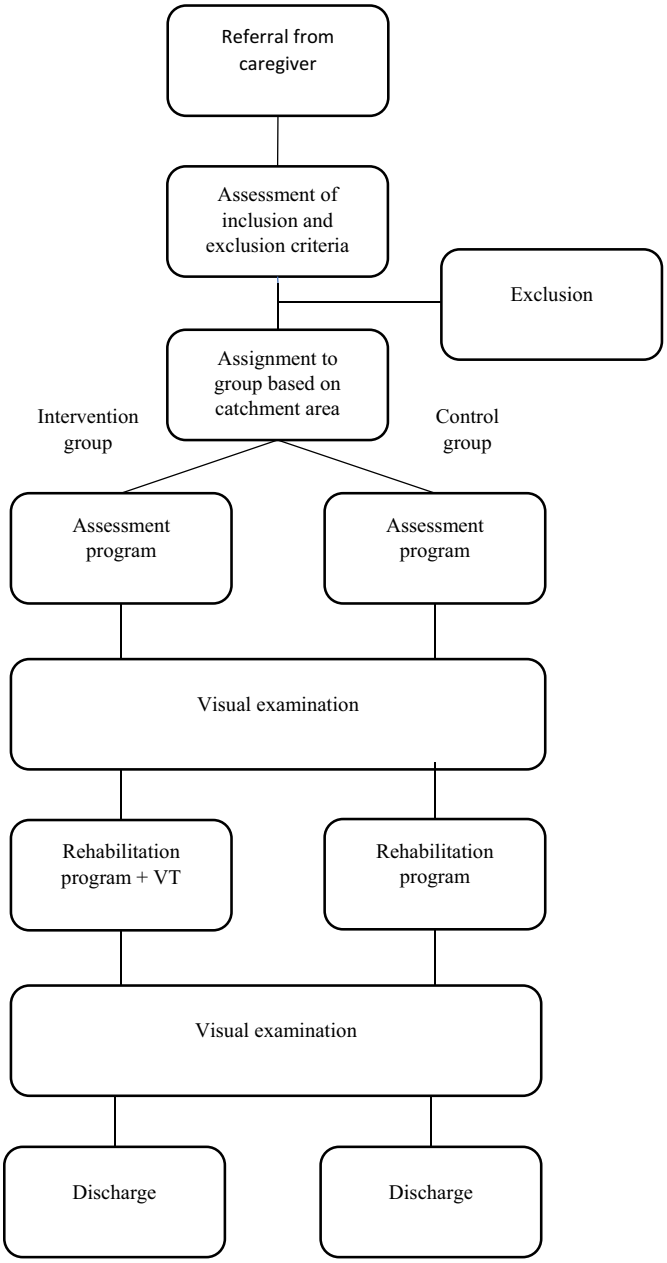

Figure 1. Flowchart showing the study procedure.

Table 1. A summary of the visual functions, how an impairment may manifest itself and the associated typical symptoms.

Visual function	Type of impairment	Criteria	Typical symptoms
Visual acuity	Uncorrected refractive error, amblyopia, or a lesion along visual pathways	Visual acuity less than decimal 1.0	Constant blurred vision or fluctuating clarity at distance viewing
Visual field	Partial or complete loss of peripheral vision due to lesions along the visual pathways	As diagnosed at the ophthalmologist's office, mainly via Humphrey Visual Field Analyzer	Difficulties with visual overview and ambulation. Indirect effects on the efficiency of oculomotor functions (gaze and eye teaming)
Gaze *Conjugate (version) eye movements, both eyes move in the same direction*	Impaired ability to track moving objects smoothly (pursuit), to move one's eyes rapidly from one object to another (saccades), or to maintain one's eyes on an object (fixation)	Clinical assessment	Reading-related issues; slow, loss of place, mis-readings. Dizziness or disequilibrium.
Eye teaming:			
Eye alignment	Strabism or decompensating heterophoria	Clinical assessment with covertest	Constant or intermittent double vision, eye strain, headache
Convergence *Dis-conjugate (vergence) eye movements for near viewing*	Defective near point	Near point > 10 cm	Issues at near, e.g. reading; intermittent double vision, eye strain, headache.
	Infacility (reduced flexibility)	< 11 cpm with 3 pd BI/12 pd BO prism flipper (pre-presbyope, age < 40) < 7 cpm with 3 pd BI/12 pd BO prism flipper (presbyope, age ≥ 40)	Lagging clarity of vision when altering focus between near and far. Headaches and eyestrain in dynamic situations such as social interaction and meetings
Vergence reserves *Dis-conjugate motor reserves for maintaining eye alignment*	Below minimum expected amplitudes of vergence reserve width	Width at distance viewing < 19 prismdiopters (pd) At near viewing < 27 pd	Eye strain, headache, intermittently blurred or double vision, floating words, apparent movement of fixated object, straining to maintain eye contact
Focusing:			
Accommodation *Adjustment of the eye's refractive power for near viewing*	Defective amplitude (near point)	Accommodative amplitude (D) less than minimum expected according to the Hofstetter formula (15–1/4 age).	Difficulty to achieve and maintain focus at near, eye strain.
	Infacility (reduced flexibility)	<4.5 cpm with age- appropriate lens power(±1 D to ±2 D lens flipper).	Lagging clarity of vision when switching focus between near and far.

distance target. The primary judgment for break was subjective reporting of diplopia, however the examiner also observed for eye deviation. In a limited number of patients, it was difficult to judge the break point and in these cases the target was switched to a small LED light source (diameter 5 mm). The patient then wore Bagolini glasses and was instructed to report when the percept changed from four diagonal rays emitting from the light source to only two (diagonally). The criteria for subnormal visual functions were derived from the literature (29–35). Visual field defects were diagnosed at the ophthalmologist's office, mainly via Humphrey Visual Field Analyzer, prior to attending the visual examination.

In addition to the clinical examination, eye movements were recorded with eye tracking during tests of saccades (fast gaze shifts), smooth pursuit (smooth, tracking eye movements) and fixation (gaze stability). This will be presented in a separate report.

The patients in the intervention group were part of a larger descriptive cross-sectional study (in review) focusing on visual symptoms and its association with visual functions.

Both the intervention group and the controls went through the vision examination. For the control group the clinical findings were documented but no VT was initiated. In this group, the patients as well as responsible clinicians were restricted from information about the findings. After completion of study participation however, information was provided and the patient offered VT in a supervised home-based setting in case of remaining clinical signs and symptoms.

The intervention group received VT intended to specifically target the dysfunctions found. It was performed three times a week in clinic, under the supervision of an occupational therapist trained in VT. On average, four exercises for an efficient total time of 60 minutes per week, were performed. The VT program started with eye teaming exercises and then progressed with gaze-related exercises. Eye teaming exercises were only performed if it had been confirmed that the patient possessed binocular vision, i.e. benefitted from a simultaneous and unified percept from both eyes. This was confirmed with a stereovision test. The typical duration of an exercise was three times 30–60 seconds. The eye teaming exercises were performed using Brocks string, pencil push-ups, Hart charts, and Eccentric circles. Accommodative exercises were performed with spherical flippers (±1 or ±2 diopters).

Brocks string was performed with a 1-meter string and 3 beads. The patient wore reading glasses if needed. The exercise started with an explanation of the concept and a demonstration with only one bead to ensure that the patient could perceive the crossed lines due to physiologic diplopia. If the patient found it difficult to understand the concept the demonstration was supplemented with an instructional video. When starting the exercise, the position of the nearest bead was decided by finding the nearest point at which the patient could maintain single vision. The second and third beads were then positioned approximately 20 cm apart. It was emphasized to achieve correct focus on each bead before

switching focus to the next. The goal was to maintain correct focus on each bead for 10 seconds before switching and to bring the nearest bead to 10 cm from the eyes.

In the Pencil push-up exercise the patient controlled the pen and was instructed to bring it at a steady pace toward the nose from slightly below. The patient was encouraged to bring it as close as possible while maintaining single vision. Once diplopia occurred the instruction was to slowly back out again while trying to regain single vision. In the initial phase the therapist observed the eyes of the patient and provided feedback to maintain fixation on the pen if necessary. The goal was to bring the pen to 6–10 cm from the eyes while maintaining single vision.

Hart charts were used to train vergence and accommodative facility. The patient was instructed to read one line of letters on the near chart, then swiftly alter focus to the distance chart and read one line of letters, then back to the near chart and read the next line, and so on. It was emphasized that the patient should strive to achieve single clear vision as soon as possible after switching focus from one chart to the other. The overall goal was to complete the exercise in approximately one minute.

Eccentric circles were used to train positive vergence reserves at distance. The circles (outer diameter 20 cm, printed on A4-sheets) were positioned on a wall, at eye level, approximately 3 meters from the eyes of the patient. The patient was encouraged to over-converge the eyes slightly (demonstrated by the therapist) in order to perceive a third, centred, set of circles and to see the word "clear" clearly. As the therapy progressed the patient was also encouraged to try to perceive the sense of depth in the imaginary third set of circles. If the patient had difficulties over-converging the eyes voluntarily the therapist demonstrated how to use his/her own thumb as fixation support. The goal was to maintain correct focus for 10 seconds for 10 repetitions.

The methods are described further in detail elsewhere (32). All exercises were performed seated initially and further on in standing position, provided that it could be done safely with respect to postural stability.

Gaze issues were targeted with free-space saccadic, fixation and pursuit exercises. The saccadic exercises consisted of small and large amplitude tasks with distinct visual targets either at reading distance (letters on a Hart chart) or at 2-3-meter (letters on post-it notes at eye level). Initially the exercise was performed at own pace with accuracy as the priority. Further on the pace was increased stepwise and a metronome used as support to keep the pace. In the pursuit exercises the patient moved a handheld stick with a distinct visual target in a pattern at eye level. Initially it was done at own pace and further on the target was moved by the OT. To increase the challenge the background was changed from neutral to more intense patterns. For both saccadic and pursuit exercises it was emphasized that the patient's head should be stationary while moving the eyes. Visual fixation exercises were done by having the patient fixate a visual target while moving the head horizontally and vertically.

In the event of sub-optimal spectacle correction, a prescription was provided and the patient was referred to an external optician.

Results

The intervention group included 48 patients (median age 49.5 years, range 27–63) and the control group 41 patients (median age 52 years, range 18–67). No statistically significant differences were found between groups regarding age, distribution of gender or diagnosis, time since injury or persistent disability according to GOSE (Table 2).

Table 2. Demographics.

		Intervention group n = 48	Control group n = 41
Female/Male (%)		39.6%/60.4%	39.0%/61.0%
Time since injury, n (%)	0–3 months	9 (18.8%)	2 (4.9%)
	4–6 months	17 (35.4%)	15 (36.6%)
	7–12 months	10 (20.8%)	17 (41.5%)
	13–24 months	7 (14.6%)	5 (12.2%)
	> 24 months	5 (10.4%)	2 (4.9%)
GOSE, median (range)		5 (4–7)	5 (4–6)
Diagnoses, n (%)	Stroke	24 (50.0%)	27 (65.9%)
	Trauma	7 (14.6%)	3 (7.3%)
	Infection, SAH, Tumor	13 (27.1%)	8 (19.5%)
	Other†	4 (8.3%)	3 (7.3%)

†Other diagnoses: hydrocephalus, arteriovenous malformation, idiopathic intracranial hypertension.

Table 3. Findings in the vision examination.

		Intervention group n = 48	Control group n = 41
Suboptimal spectacle correction (visual acuity)		9 (18.7%)	13 (31.7%)
Suboptimal near correction (near visual acuity)		9 (18.7%)	10 (24.4%)
Visual field defects		2 (4.2%)	5 (12.2%)
Strabism, eye motility disorder		2 (4.2%)	2 (4.9%)
Eye teaming issue (only patients with binocular vision)		n = 43	n = 33
	Convergence, amplitude	15 (34.9%)	7 (21.2%)
	Convergence, facility	24 (55.8%)	20 (60.6%)
	Fusional vergence (distance), width	12 (27.9%)	18 (54.5%)
	Fusional vergence (near), width	16 (37.2%)	12 (36.4%))

The findings in the vision examination are presented in Table 3. There was a subgroup of patients (intervention group n = 5, control group n = 8) who did not possess binocular vision, that is, they did not benefit from a simultaneous and unified percept from both eyes. The reasons were acquired or congenital eye lesions, strabismus, or abnormal visual development. It was not relevant to measure or treat eye teaming for these patients. Accommodation issues were found for two patients in the intervention group and one patient in the control group.

Convergence

The near point of convergence (NPC) improved in the intervention group, from median 20 to 12 (Z = 2.26, p = .02) (Figure 2). It improved to some extent in the control group as well but not at a statistically significant level.

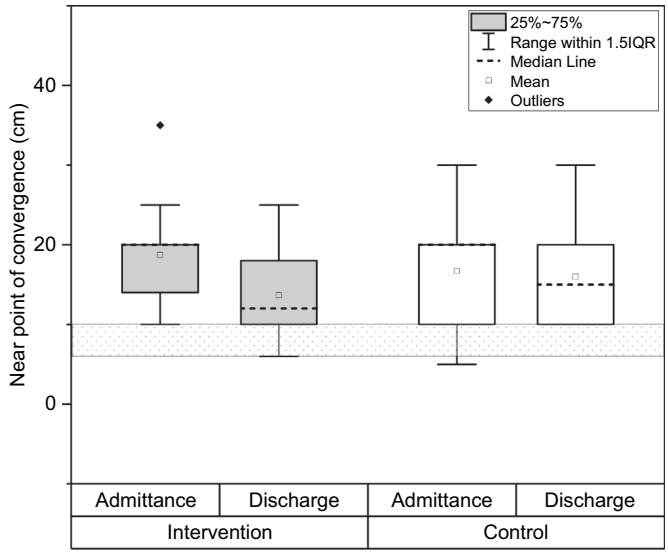

Figure 2. The NPC (cm) at admittance and discharge for the intervention and control group. A lower value is better with the aim of 6–10 cm as indicated by the greyed area.

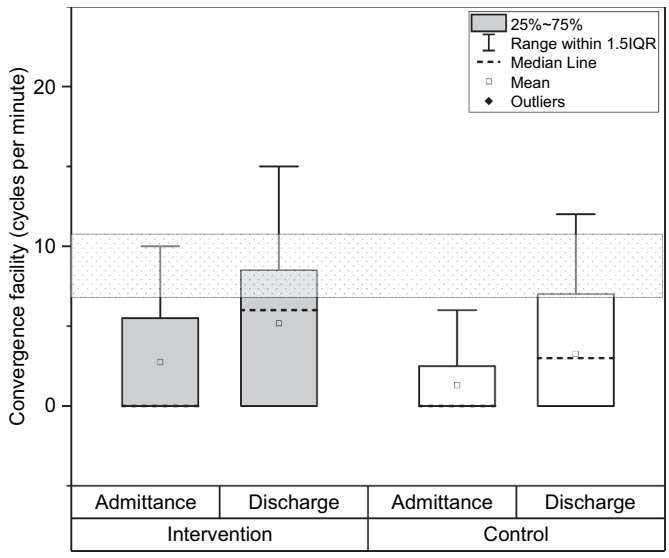

Figure 3. Convergence facility (cycles per minute, cpm) at admittance and discharge for the intervention and control group. A higher value is better with the aim of 7–11 cpm as indicated by the greyed area.

Convergence facility

Convergence facility improved in both groups (Figure 3). The change was statistically significant in the intervention group (Z = −2.16, p = .03). The truncated appearance of the boxplots reflects the fact that a number of patients performed nil cycles at admittance as well as discharge.

Vergence reserves at distance viewing

A statistically significant increase of the vergence reserves for distance viewing was found in both intervention (Z = −2.44, p < .01) and control group (Z = – 1.99, p = .04) (Figure 4). The median for the intervention group reached the target interval of vergence reserves.

Vergence reserves at near viewing

At discharge, both groups reached a level of vergence reserves for near viewing that were within or tangent to the target interval (Figure 5). In the intervention group the change was a statistically significant (t = −4.47, DF = 15, p < .01).

Accommodation

Accommodative function was measured in patients younger than 40 years; 13 patients (age 27–39 years) in the intervention group and four patients (age 18–37 years) in the control group. Two patients in the intervention group and one in the control group had receded near point of accommodation at admittance. At discharge the near point of accommodation had improved to minimum expected near point of accommodation or better in all three patients. Due to the low number of patients no further analysis was performed.

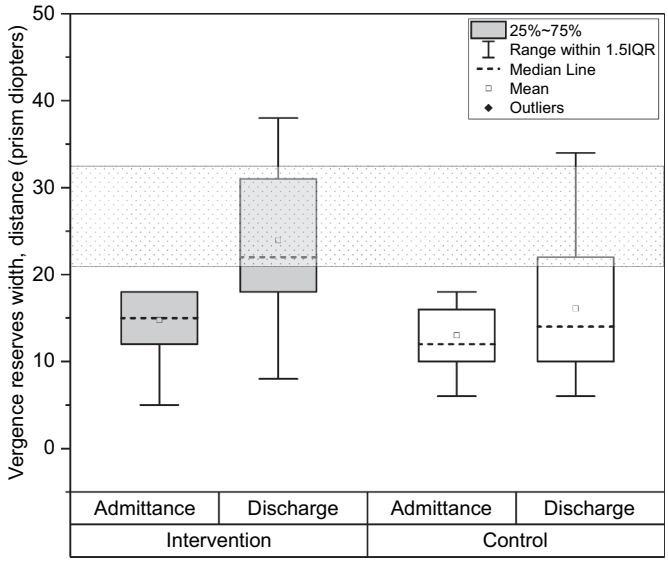

Figure 4. Fusional vergence width (prism diopters) for *distance* viewing at admittance and discharge for the intervention and control group. A higher value is better with the aim of 19 prism diopters or more as indicated by the greyed area.

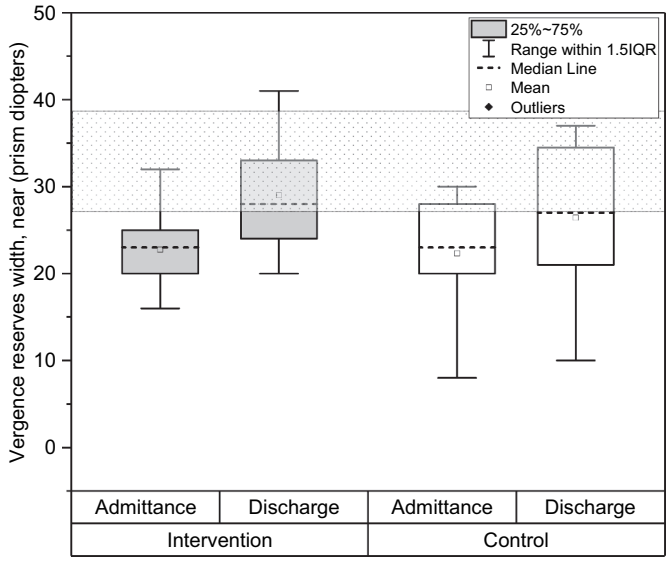

Figure 5. Fusional vergence width (prism diopters) for *near* viewing at admittance and discharge for the intervention and control group. A higher value is better with the aim of 27 prism diopters or more as indicated by the greyed area.

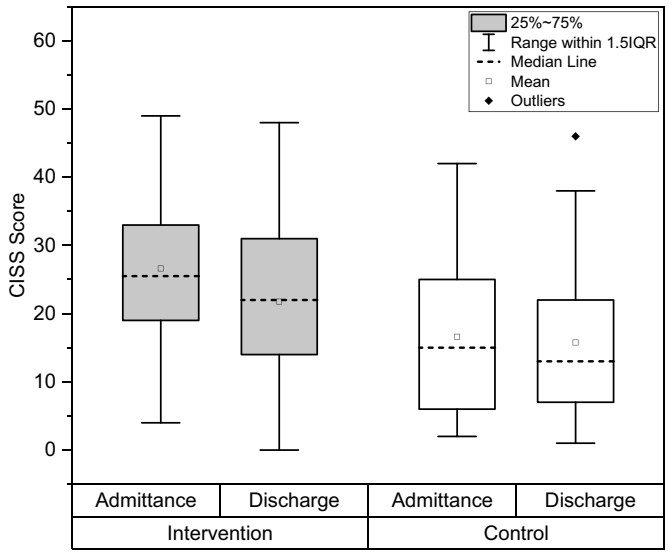

Figure 6. Visual symptoms at near work according to CISS. A lower value is better with the aim of score 21 or less.

Vision-related symptoms

Visual symptoms at near work were estimated with the CISS survey at admittance and discharge. The change in score was analyzed for those patients in the intervention group who went through VT (n = 38) and for the patients in the control group who might have benefitted from VT (n = 31) (Figure 6). In the intervention group the reduction in symptoms was statistically significant (Z = 2.97, $p < .01$). There was no statistically significant change in the control group. There was a significant difference between the groups in baseline symptom level (U = 932, Z = 3.51, $p < .01$) that can impact the interpretation of the outcome.

Discussion

The purpose of this study was to investigate the effects of VT as part of neurorehabilitation after acquired brain injury. One group received VT for their oculomotor dysfunctions while the other group served as controls in order to monitor the course of visual dysfunctions without VT. The two groups were of equal characteristics in terms of age, gender, diagnosis, time since injury and persistent disability according to GOSE.

A total of 18.7–31.7% of the patients had suboptimal spectacle correction. The reason could simply be normal change in refraction but it could also be due to a reduced ability to compensate. For example, far-sightedness (hyperopia) may not be as lightly compensated for through accommodative effort after an ABI. Furthermore, affected contrast vision, resulting from subtle visual pathway lesions (17), may mean that suboptimal spectacle correction has greater effect on visual clarity. Visual clarity is in turn an important component for optimal eye teaming. Our findings suggest that screening of visual acuity at admittance should be considered.

The prevalence of specific oculomotor dysfunctions was between 27.9% and 60.6% amongst 75.6–79.2% of the patients which is in line with previous research (3,5). The occurrence of specific oculomotor dysfunctions differs somewhat from previous literature which may be related to patient populations and criteria for defining dysfunctions. Even though differences in injury and persistent disability may occur, we consider the control of patient demographics to be a strength of this study. Given the clinical setting, the criteria for oculomotor dysfunctions were derived from the literature and balanced against our clinical experience. This means that the lower borders of the criteria were set to reflect what from our clinical experience is required for functional vision. The purpose being to balance vision-related rehabilitation efforts against other rehabilitation needs. The reported occurrence of oculomotor dysfunctions in this study would likely have been higher if choosing criteria considered optimal in an otherwise healthy population.

In the intervention group there were significant improvements in convergence, facility, vergence reserves and vision-related symptoms. This agrees with previous research performed in similar settings (22–24). Some improvement could also be found in the control group. Both the intervention and control group went through an individually customized program that included cognitive-, occupational-, and physiotherapeutic rehabilitation. The cognitive therapy includes for example Attention Process Training (APT) that contains visually demanding elements. The occupational therapy includes for example computer- and administrative activities as well as orientation and ambulation elements. We may speculate that there are indirect training effects from the exposure to customary neurorehabilitation activities. But since there was not a control group who did not receive any intervention at all we cannot conclude that this is the case.

All in all, the findings suggest that targeted VT, in a neurorehabilitation setting, can result in concrete improvements in terms of function and symptoms. A key to targeted VT is the close involvement of a vision-specialist in the process of evaluating rehabilitation needs, follow-up of progress and adjustments of the VT-program where necessary. Further study will be required to

understand how improvements in function link to performance and satisfaction with everyday activities.

There was a significant reduction in vision-related symptoms in the intervention group. There was no reduction in the control group, however in this group the symptom score was significantly lower at baseline despite a similar prevalence of oculomotor dysfunctions. The reason for this is unclear however plausible explanations may be found in differences in recovery, exposure to near work, knowledge about one's limitations, or avoidance of activities that cause symptoms. As a self-administered instrument there may be limitations in the capture of symptoms in this setting. Above all, the CISS was originally intended, and validated, to be used as an outcome measure when assessing symptoms related to convergence insufficiency with specific diagnostic criteria in a pediatric population. Still, we consider the CISS to cover relevant symptoms and administration in the form of an interview may prove beneficial in order to improve sensitivity in capturing visual symptoms.

We conclude that visual function issues appear to be frequent in this patient group and that targeted vision therapy, as part of neurorehabilitation, can be an efficient treatment resulting in improved functions and reduced symptoms. Further study will be required to understand how improved functions link to performance and satisfaction with everyday activities. The CISS was partially effective in monitoring vision-related symptoms however some adaptation of the administration may be required.

Some limitations need to be considered. The study's VT program was structured after the results of the optometrist´s examination and the symptoms described by the patients. The patient's dysfunctions in the area of visual attention and visual spatial dysfunctions were not considered in this report and could have hampered the outcome of the VT. In any case the need for stable basic visuomotor function is fundamental for all types of ABI.

Acknowledgments

We wish to thank the clinical and administrative staff at the rehabilitation clinic for their support.

Funding

No specific funding to declare

Availability of data and materials

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

1. Van Essen DC, Anderson CH, Felleman DJ. Information processing in the primate visual system: an integrated systems perspective. Science. 1992;255(5043):419–23.
2. Armstrong RA.Visual problems associated with traumatic brain injury. Clin Exp Optom. 2018;101(6):716–26. doi:10.1111/cxo.12670.
3. Ciuffreda KJ, Kapoor N, Rutner D, Suchoff IB, Han ME, Craig S. Occurrence of oculomotor dysfunctions in acquired brain injury: a retrospective analysis. Optometry. 2007;78(4):155–61. doi:10.1016/j.optm.2006.11.011.
4. Greenwald BD, Kapoor N, Singh AD.Visual impairments in the first year after traumatic brain injury. Brain Inj. 2012;26(11):1338–59. doi:10.3109/02699052.2012.706356.
5. Rowe FJ, Group V.Vision In Stroke cohort: profile overview of visual impairment. Brain Behav. 2017;7(11):e00771. doi:10.1002/brb3.771.
6. Ghannam ASB, Subramanian PS.Neuro-ophthalmic manifestations of cerebrovascular accidents. Curr Opin Ophthalmol. 2017;28(6):564–72. doi:10.1097/ICU.0000000000000414.
7. Jacobs SM, Van Stavern GP.Neuro-ophthalmic deficits after head trauma. Curr Neurol Neurosci Rep. 2013;13(11):389. doi:10.1007/s11910-013-0389-5.
8. Jones SA, Shinton RA.Improving outcome in stroke patients with visual problems. Age Ageing. 2006;35(6):560–65. doi:10.1093/ageing/afl074.
9. Rowe FJ.Stroke survivors' views and experiences on impact of visual impairment. Brain Behav. 2017;7(9):e00778. doi:10.1002/brb3.778.
10. Schow T, Teasdale TW, Quas KJ, Rasmussen MA.Problems with balance and binocular visual dysfunction are associated with post-stroke fatigue. Top Stroke Rehabil. 2017;24(1):41–49. doi:10.1080/10749357.2016.1188475.
11. Singh T, Perry CM, Fritz SL, Fridriksson J, Herter TM.Eye Movements Interfere With Limb Motor Control in Stroke Survivors. Neurorehabil Neural Repair. 2018;32(8):724–34. doi:10.1177/1545968318790016.
12. Wagener SG, Kreiger R.Participation and quality of life for persons with oculomotor impairments after acquired brain injury. Br J Occup Ther. 2019;82(8):475–84. doi:10.1177/0308022619827262.
13. Sand KM, Midelfart A, Thomassen L, Melms A, Wilhelm H, Hoff JM. Visual impairment in stroke patients–a review. Acta Neurol Scand Supp. 2013;196:52–56.
14. Berthold-Lindstedt M, Ygge J, Borg K.Visual dysfunction is underestimated in patients with acquired brain injury. J Rehabil Med. 2017;49(4):327–32. doi:10.2340/16501977-2218.
15. Clenet MF. The importance of studying vision after a stroke. Revue Francophone d'Orthoptie. 2011;4(4):171–73.
16. Cohen AH, Rein LD. The effect of head trauma on the visual system: the doctor of optometry as a member of the rehabilitation team. J Am Optom Assoc. 1992;63(8):530–36.
17. Kerkhoff G.Neurovisual rehabilitation: recent developments and future directions. J Neurol Neurosurg Psychiatry. 2000;68(6):691–706. doi:10.1136/jnnp.68.6.691.
18. Khan S, Leung E, Jay WM.Stroke and visual rehabilitation. Top Stroke Rehabil. 2008;15(1):27–36. doi:10.1310/tsr1501-27.
19. Ripley DL, Politzer T, Berryman A, Rasavage K, Weintraub A.The vision clinic: an interdisciplinary method for assessment and treatment of visual problems after traumatic brain injury. Neurorehabilitation. 2010;27(3):231–35. doi:10.3233/NRE-2010-0602.
20. Roberts PS, Rizzo JR, Hreha K, Wertheimer J, Kaldenberg J, Hironaka D, Riggs R, Colenbrander A. A conceptual model for vision rehabilitation. J Rehabil Res Dev. 2016;53(6):693–703. doi:10.1682/JRRD.2015.06.0113.
21. Warren M.A hierarchical model for evaluation and treatment of visual perceptual dysfunction in adult acquired brain injury, Part 1. Am J Occup Ther. 1993;47(1):42–54. doi:10.5014/ajot.47.1.42.
22. Smaakjaer P, Todten ST, Rasmussen RS.Therapist-assisted vision therapy improves outcome for stroke patients with homonymous hemianopia alone or combined with oculomotor dysfunction. Neurol Res. 2018;40(9):752–57. doi:10.1080/01616412.2018.1475321.
23. Schow T, Harris P, Teasdale TW, Rasmussen MA.Evaluation of a four month rehabilitation program for stroke patients with balance problems and binocular visual dysfunction. Neurorehabilitation. 2016;38(4):331–41. doi:10.3233/NRE-161324.
24. Watabe T, Suzuki H, Abe M, Sasaki S, Nagashima J, Kawate N. Systematic review of visual rehabilitation interventions for oculomotor deficits in patients with brain injury. Brain Inj. 2019;33(13–14):1592–96. doi:10.1080/02699052.2019.1658225.

25. Riggs RV, Andrews K, Roberts P, Gilewski M.Visual deficit interventions in adult stroke and brain injury: a systematic review. Am J Phys Med Rehabil. 2007;86(10):853–60. doi:10.1097/PHM.0b013e318151f907.
26. Pollock A, Hazelton C, Henderson CA, Angilley J, Dhillon B, Langhorne P, Livingstone K, Munro FA, Orr H, Rowe FJ, et al. Interventions for disorders of eye movement in patients with stroke. Cochrane Database Syst Rev 2011;5:CD008389.
27. Simpson-Jones ME, Hunt AW.Vision rehabilitation interventions following mild traumatic brain injury: a scoping review. Disabil Rehabil. 2018;41(18):2206–22. doi:10.1080/09638288.2018.1460407.
28. Rouse MW, Borsting EJ, Mitchell GL, Scheiman M, Cotter SA, Cooper J, Kulp MT, London R, Wensveen J. Validity and reliability of the revised convergence insufficiency symptom survey in adults. Ophthalmic Physiol Opt. 2004;24(5):384–90.doi:10.1111/j.1475-1313.2004.00202.x.
29. Pellizzer S, Siderov J.Assessment of vergence facility in a sample of older adults with presbyopia. Optom Vis Sci. 1998;75(11):817–21. doi:10.1097/00006324-199811000-00023.
30. Momeni-Moghaddam H, Goss DA, Dehvari A.Vergence facility with stereoscopic and nonstereoscopic targets. Optom Vis Sci. 2014;91(5):522–27. doi:10.1097/OPX.0000000000000227.
31. Gall R, Wick B, Bedell H.Vergence facility: establishing clinical utility. Optom Vis Sci. 1998;75(10):731–42. doi:10.1097/00006324-199810000-00018.
32. Scheiman M, Wick B. Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders. 4th ed ed. PA, USA: Lippincott Williams & Wilkins; 2014.
33. Yekta A, Khabazkhoob M, Hashemi H, Ostadimoghaddam H, Ghasemi-Moghaddam S, Heravian J, Doostdar A, Nabovati P. Binocular and accommodative characteristics in a normal population. Strabismus. 2017;25(1):5–11.doi:10.1080/09273972.2016.1276937.
34. Antona B, Barrio A, Barra F, Gonzalez E, Sanchez I.Repeatability and agreement in the measurement of horizontal fusional vergences. Ophthalmic Physiol Opt. 2008;28(5):475–91. doi:10.1111/j.1475-1313.2008.00583.x.
35. Goss DA, Becker E.Comparison of near fusional vergence ranges with rotary prisms and with prism bars. Optometry. 2011;82(2):104–07. doi:10.1016/j.optm.2010.09.011.