BMJ Open

Longitudinal changes in oculomotor function in young adults with mild traumatic brain injury in Sweden: an exploratory prospective observational study

Giedre Matuseviciene,[1] Jan Johansson,[2] Marika Möller,[1] Alison K. Godbolt,[1] Tony Pansell,[2] Catharina Nygren Deboussard[1]

Check for updates

[1]Division of Rehabilitation Medicine, Department of Clinical Sciences, Danderyd Hospital, Karolinska Institutet, Stockholm, Sweden
[2]Department of Clinical Neuroscience, Eye and Vision, Karolinska Institutet, Stockholm, Sweden

Correspondence to
Dr Giedre Matuseviciene;
giedre.matuseviciene@sll.se

ABSTRACT

Objectives To assess (1) whether visual disturbances can be demonstrated with objective measures more often in patients with mild traumatic brain injury (mTBI) than in orthopaedic controls and non-injured controls, (2) whether such objectively demonstrated disturbances change over time and (3) whether self-reported visual symptoms after mTBI correlate with objectively measurable changes in visuomotor performance.

Design A prospective, controlled, observational study, with assessments planned 7–10 and 75–100 days after injury.

Setting Emergency department of a general hospital in Sweden.

Participants 15 patients with mTBI, 15 patients with minor orthopaedic injury, 15 non-injured controls, aged 18–40 years.

Outcome measures Visual examination, including assessment of visual acuity, accommodation, eye alignment, saccades and stereoacuity. Symptom assessment using Convergence Insufficiency Symptoms Survey (CISS) and Rivermead PostConcussion Symptoms Questionnaire.

Results Assessments were performed 4–13 and 81–322 days after injury (extended time frames for logistical reasons). No statistically significant difference was found between the mTBI and control groups regarding saccade performance and stereoacuity at any time point. The accommodative amplitude was significantly lower in the mTBI group compared with non-injured controls at baseline. 6 out of 13 patients with mTBI had accommodative insufficiency at follow-up. Near point of convergence in the mTBI group was receded at baseline and improved statistically significantly at follow-up. At baseline, patients with mTBI had significantly higher CISS score than orthopaedic and non-injured controls. For patients with mTBI, the CISS score correlated with fusional vergence.

Conclusion There were some transient measurable visual changes regarding convergence in patients with mTBI during the subacute period after the injury. Our findings of persistence of accommodative insufficiency in a considerable proportion of patients with mTBI suggest

Strengths and limitations of this study

► Prospective longitudinal design with measurement at two time points.
► Strict inclusion criteria for mild traumatic brain injury (mTBI) according to American Congress of Rehabilitation Medicine.
► Inclusion of both an uninjured control group and a group with minor orthopaedic injuries without trauma to the head, to control for non-specific effects of injury such as pain and distress.
► Study methods include several easily replicable optometric measurements.
► The generalisability of this study is limited because the sample of patients with mTBI was small in size and restricted in age range.

that this visual function should not be overlooked in clinical assessment.

INTRODUCTION

There is a need for objective methods to assess and monitor recovery after mild traumatic brain injury (mTBI) as a base for developing evidence-based clinical follow-up guidelines. Changes affecting accommodation and eye alignment have been highlighted recently as possible measurable correlates of symptoms related to mTBI.[1–4] A recent systematic review of oculomotor-based vision assessment to monitor changes after mTBI found preliminary but promising evidence.[5] Although measurement of oculomotor functions appears useful in detecting changes after mTBI, the current evidence does not have sufficient strength to inform clinical guidelines.

Traumatic impact to the head, as in mTBI, may affect vision-related networks that are

widely spread throughout the brain,[1 6] and thus result in visual disturbances. Various visual impairments with a prevalence up to 70% have been found in patients with long-lasting problems after mTBI.[4 7 8] However, these studies have limitations such as retrospective design, selection bias, heterogeneity regarding severity of injury and lack of appropriate control groups. Prospective studies with early assessment and follow-up of vision-related oculomotor changes after mTBI are scarce.[9 10]

The ability to appropriately alter focus, align the eyes and make gaze changes can be measured, and has been highlighted in several recent studies on mTBI.[11–14] Convergence is a nasalward eye movement for near vision.[15] Insufficient convergence is one of the most frequently described oculomotor changes after head injury.[16] Symptoms after mTBI, both direct visual symptoms (double vision, blurred vision) and indirect symptoms (increased effort at near work), might be attributed to impaired convergence. Convergence insufficiency (CI) was found in 42%–48% of patients with mTBI in retrospective studies,[4 7] and controlled studies of military personnel who have suffered blast-induced mTBI have shown a significant difference in near point of convergence (NPC).[3 7]

Fusional vergence aligns the two eyes and thereby provides for clear single vision. Impaired fusional vergence causes unstable binocular vision, which may present as losing one's place when reading or blurred, or even double vision. Fusional vergence disorders may occur in about 3%–6% of a population with vision-based symptoms who are otherwise healthy[17 18] but may be significantly more frequent in patients with TBI.[19]

Accommodation provides a clear optical image of an object at different distances through the altering of refractive power in the crystalline lens. Symptoms of accommodative disorders include blurred vision and impaired flexibility to alter focus between near and far. A physiological deterioration of accommodative ability, presbyopia is expected with age. The current study therefore included prepresbyopic subjects of age 40 or younger. In an otherwise healthy prepresbyopic population, accommodative changes may be present in up to about 10% of individuals with vision complaints.[18 20] Significantly more prevalent accommodative disorders have been found in patients with mTBI in the subacute stage[3] and at a later stage as part of persisting issues.[21 22]

Saccades are rapid eye movements that can direct the gaze to areas of interest in the visual field. Through purposeful and accurate saccades executed in quick succession, the environment can be scanned and functional visual field is increased. Thus, an efficient saccadic performance is an important base for efficient and safe interaction with the environment and for detailed work such as reading.[23] The initiation and programming of saccades involves cognitive functions that are subserved by complex neuronal networks involving different parts of the brain. Parameters of saccades, such as latency and accuracy, have been shown to be affected after mTBI.[2 9 10 24]

In this study, we aim to assess oculomotor and visual changes after mTBI prospectively, and compare these to a control group unexposed to head injury but with minor orthopaedic injury and to a non-injured control group. The orthopaedic group allows evaluation of brain injury-specific effects by controlling for non-specific effects of pain and distress after trauma.

The study objectives are to assess: (1) whether visual disturbances can be demonstrated with objective measures more often in patients with mTBI than in orthopaedic controls and non-injured controls, (2) whether such objectively demonstrated disturbances change over time and (3) whether self-reported visual symptoms after mTBI correlate with objectively measurable changes in visuomotor performance.

METHODS

This is a prospective controlled observational study on visual disturbances after mTBI, with two control groups, defined below. This article is the first report from this study. The setting was an emergency department (ED) of a large general hospital serving the Northeast of Stockholm.

A power calculation was conducted: with an expected incidence of visual disturbances in 70% in the mTBI group[4 7 8] and 10% in the control group,[18 20] 10 persons per group were needed to detect visual disturbances with 80% power at alpha 0.05. With an expected drop-out rate of 30%, 15 persons were judged necessary in each group.

Inclusion criteria

For all study participants, age between 18 and 40 years was a necessary criterion for inclusion. Other criteria for each of the three groups were as follows:

1. mTBI group:
   a. Presented to the ED after acute blunt head trauma.
   b. Met diagnostic criteria for mTBI according to American Congress of Rehabilitation Medicine[25]: mTBI is an acute brain injury resulting from mechanical energy to the head from external physical forces. Operational criteria for clinical identification included: (1) one or more of the following: confusion or disorientation, loss of consciousness for 30 min or less, post-traumatic amnesia for less than 24 hours, and/or other transient neurological abnormalities such as focal signs, seizure and intracranial lesion not requiring surgery and (2) Glasgow Coma Scale (GCS)[26] score of 13–15 after 30 min postinjury or later on presentation for healthcare. These manifestations must not be due to drugs, alcohol, medications, caused by other injuries or treatment for other injuries (eg, systemic injuries, facial injuries or intubation), caused by other problems (eg, psychological trauma, language barrier or coexisting medical conditions) or caused by penetrating craniocerebral injury.

c. CT of the brain performed on the basis of clinical need, as assessed by the ED doctor.

2. Orthopaedic control group:
   a. Presented to the ED after minor trauma to the extremities without head trauma.
   b. Did not require surgery.

3. Non-injured control group:
   a. Individuals who had not suffered traumatic injury and who answered an advert recruiting to the study.

Exclusion criteria (any of the following)

a. Indication for neurosurgery;
b. Previous moderate or severe TBI;
c. Any head injury in the previous year requiring medical attention;
d. Presence of any contraindication for MRI;
e. Progressive neurological disease or other medical conditions with expected short survival;
f. Severe visual impairment or manifest strabismus;
g. Need for help in activities of daily living before the current injury;
h. Intoxication with alcohol at the time of the injury;
i. Not fluent in Swedish.

For demographic information, see table 1.

Data collection

Subject recruitment was conducted between January 2015 and January 2016 and was stopped when a total of 15 patients with mTBI, 15 orthopaedic controls and 15 non-injured controls were enrolled, in accordance with the power calculation. Study patients were contacted by phone 1–3 days after injury. All study participants received written information about the study and gave informed consent.

All data related to the injury, GCS on arrival at the ED and results of CT of the brain were collected from the medical records. Demographic data were collected by interview at the baseline examination.

Table 1	Demographic data		
	Patients with mTBI	Orthopaedic controls	Non-injured controls
Age, median (range)	25.0 (18–39)	27.0 (18–40)	26.0 (19–36)
Men, n (%)	7 (47)	11(73)	9 (60)
Women, n (%)	8 (53)	4 (27)	6 (40)
GCS 15 (%)	14 (93)	NA	NA
GCS 14 (%)	1 (7)	NA	NA
Type of trauma: n (%)	Fall: 7 (47) Bicycle: 2 (13) Horseback riding: 2 (13) Other: 4 (27)	Sports: 9 (60) Other: 6 (40)	

GCS, Glasgow Coma Scale; mTBI, mild traumatic brain injury; NA, not applicable.

All study participants were scheduled to be assessed two times: at baseline, in the subacute phase (for patients with trauma, 7–10 days after the trauma) and at follow-up 75–100 days after the injury. Due to recruitment difficulties and in order to minimise drop-out, the time frame for the first and second assessments was extended. Neuropsychological testing and visual assessment were performed at different time points on the same day or on the day before or after. The median time between injury and baseline visual assessment was 7 days (range 4–13 days) for patients with mTBI and was 8 days (range 7–12 days) for orthopaedic controls. The median time between injury and follow-up visual assessment was 103 days (range 81–232 days) for patients with mTBI and 108.5 days (range 87–322) for orthopaedic controls. No statistically significant difference was found between patients with mTBI and the orthopaedic control group regarding time between the injury and assessments (baseline and follow-up).

Patients with mTBI and orthopaedic controls underwent examination with structural MRI and resting state functional MRI of the brain at baseline and at follow-up. All participants rated anxiety and depression using Hospital Anxiety and Depression Scale[27] and fatigue using Fatigue Severity Scale,[28] and underwent neuropsychological testing. These data and imaging results will be reported separately.

Among the consecutive patients who were invited to participate in the study, a total of 99 declined; 17 mTBI and 82 orthopaedic subjects. Of those who declined, 88% of mTBI and 64% of orthopaedic subjects were men, and there was no difference regarding age between participating and non-participating individuals. The reasons stated for not participating were lack of time and inconvenience.

Two individuals in the mTBI group and two individuals in the orthopaedic control group were lost to follow-up despite several follow-up phone calls and letters.

Assessments

The visual examination was performed by licensed optometrists, using standard optometric clinical methods. It included assessment of visual acuity at far and near, refractive error, stereoacuity, near point of accommodation, facility (flexibility) of accommodation, NPC with an accommodative target, non-strabismic eye-turn (heterophoria), eye motility and fusional vergence. Diagnosis of visual dysfunctions were based on established diagnostic criteria.[29] NPC was measured using the push-up method (RAF-ruler). Positive fusional vergence (PFV) was measured with a prism bar. In both cases, the patient is instructed to try as hard as possible to maintain single vision and to report when perceiving double vision. Meanwhile, the examiner carefully observes eye alignment in order to verify the patient's response. Expected accommodative amplitude was calculated according to the Hofstetter formula (18.5−1/3 age).[29] Diagnosis of accommodative insufficiency (AI) required amplitude less than

minimum expected according to the Hofstetter formula (15–1/4 age). Diagnosis of CI required NPC ≥6 cm plus at least one of the following: reduced PFV at near (<20 prism D) or divergent heterophoria at least 4 prism D greater at near than at distance.[29] Saccadic eye movements were recorded (spatial resolution 0.15°; temporal resolution 300 Hz) using an eye tracker (Tobii TX300; Tobii, Stockholm, Sweden; www.tobii.com). The participant was positioned 60 cm directly in front of the eye tracker display. We used three test paradigms: (1) prosaccades; (2) antisaccades and (3) self-paced saccades. The stimuli consisted of a dot with a diameter of 5 mm (0.5°). In the prosaccade paradigm, the participant fixated a centred cross and then refixated to a dot that appeared at 2°, 4°, 6° or 8° to the left or right of the cross. The performance was characterised with mean latency and positional gain. In the antisaccade paradigm, the participant viewed a centred cross and then rapidly looked in the opposite direction to that of a dot presented 8° to the left or right of the centre. The performance was characterised with the latency of correctly performed saccades and proportion of erroneous saccades. In the self-paced saccade paradigm, two dots were simultaneously presented for 30 s at 8° to the left and right of centre. The participant was instructed to move the gaze rapidly, as many times as possible, between the dots. The performance was characterised with number of saccades performed in 30 s and mean intersaccadic interval (ms).

At baseline and follow-up, all study participants self-rated their symptoms using the Rivermead PostConcussion Symptoms Questionnaire (RPQ)[30] and the Convergence Insufficiency Symptom Survey (CISS).[31 32] The RPQ is based on a Likert scale and includes 16 items with ratings: 0 'no symptoms', 1 'no more of a problem or transient symptoms', 2–4 'mild to severe' symptoms. A total sum of all symptom scores ('mild to severe', excluding ratings of (1) is calculated, with a maximum score of 64. The CISS is a validated and reliable instrument[31] that evaluates near work-related visual symptoms. It includes assessment of direct symptoms, such as blurred vision and double vision, as well as indirect symptoms (eg, difficulty maintaining concentration, sleepiness while reading, headache and ocular discomfort). The survey includes 15 questions with ratings from 0 'never' to 4 'always' for assessment of visual symptoms. The total score is 60 and the cut-off score for abnormal levels of symptoms is 21. This value gives good sensitivity (97.8%) and specificity (87%) in otherwise healthy young adults who have presented to optometrists with visual symptoms.[32]

Data analyses
All data were analysed using SPSS V.23. Parametric statistics was used for oculomotor measures (accommodation, convergence, fusional vergence and saccades). A two-way repeated measures analysis of variance (ANOVA) was used for analysing the within-subject factors (baseline vs follow-up) and the between-subject factor (effect of group). Post hoc tests were performed using

Holm-Bonferroni adjustment. Fischer's exact test was applied for analysis of the categorical data.

Non-parametric Kruskal-Wallis test (three groups), Mann-Whitney U test (two groups, post hoc analysis), Wilcoxon signed-rank test and Spearman's rank correlation were used for comparison of ordinal data from questionnaires (CISS and RPQ) and stereoacuity. Two-tailed P values were used with a critical significance level of P<0.05.

RESULTS
Of the 15 patients, 2 patients with mTBI had pathological findings on CT of the brain, one had a small subdural haemorrhage and the other a small subarachnoid haemorrhage. Neither required surgery. No cranial nerve palsies or direct trauma-related eye pathology was found.

Visual examination

Accommodation
A significant effect of interaction between group and test occasions was found in the ANOVA for the deviation from expected accommodative amplitude (df=2, F=4.406, P=0.028). The post hoc analysis showed significantly reduced accommodative amplitude in the mTBI group compared with non-injured controls at baseline (P=0.001) (figure 1) but no statistically significant difference between patients with mTBI and orthopaedic controls. There were no statistically significant differences between the mTBI group and either of the control groups at follow-up. Out of 13 patients, 6 patients with mTBI still had AI at follow-up (12 out of 15 patients at baseline) compared with 5 out of 12 orthopaedic controls (no change over time) and 2 out of 15 non-injured controls at follow-up (no change over time). No statistically significant differences in accommodative facility were found within or between groups or test occasions.

Convergence
The ANOVA showed a significant interaction effect (df=2, F=3.793, P=0.042) and the post hoc analysis showed a significant difference (improvement) in the mTBI group between baseline and follow-up (P=0.015) (figure 2). There were no statistically significant differences between or within the control groups.

Fusional vergence
The ANOVA on fusional vergence did not show any significant differences at the group level at any time point.

Stereoacuity
No statistically significant difference was found between groups or test occasions regarding stereoacuity (Kruskal-Wallis test). Out of 15 patients, 5 patients with mTBI showed a reduced level of stereoacuity at baseline (120–240 s of arc) while one patient showed a reduced level at follow-up (60 s of arc or less). In the orthopaedic group, three subjects performed at the level of 120–240 s of
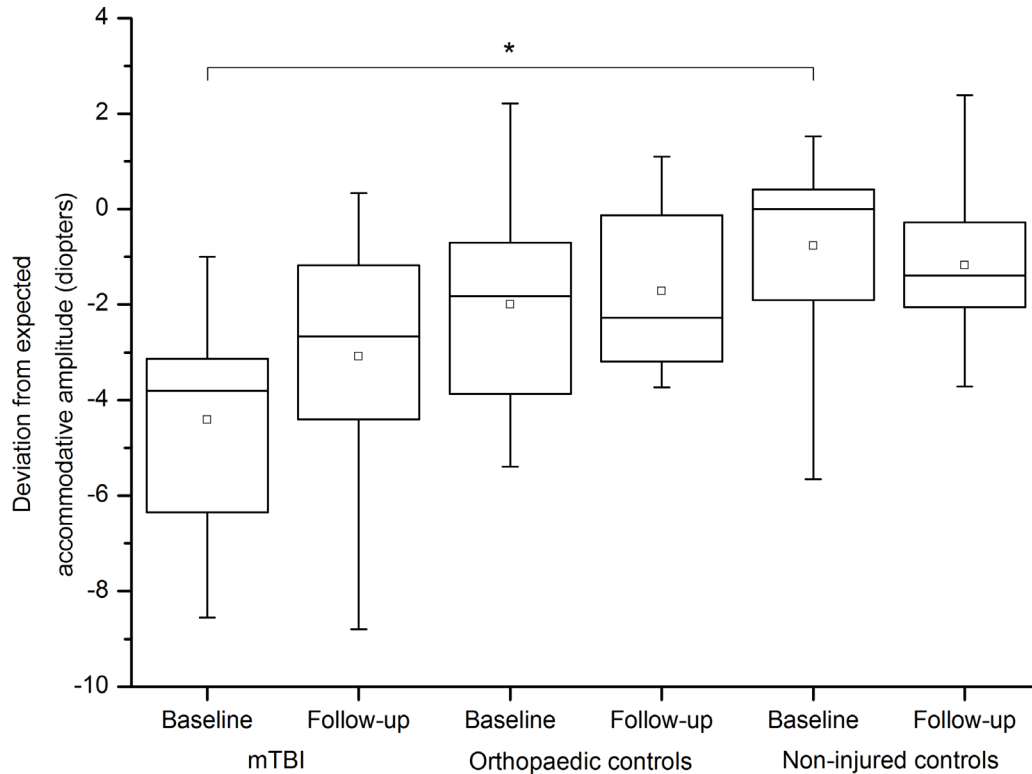
Figure 1 Deviation from expected accommodative amplitude. The lower the negative value, the greater the deviation (insufficiency). Closer to zero is better. The miniature squares indicate mean values. The box indicates median, upper and lower quartiles. The whiskers indicate minimum and maximum. * Significant difference (P=0.015). mTBI, mild traumatic brain injury.
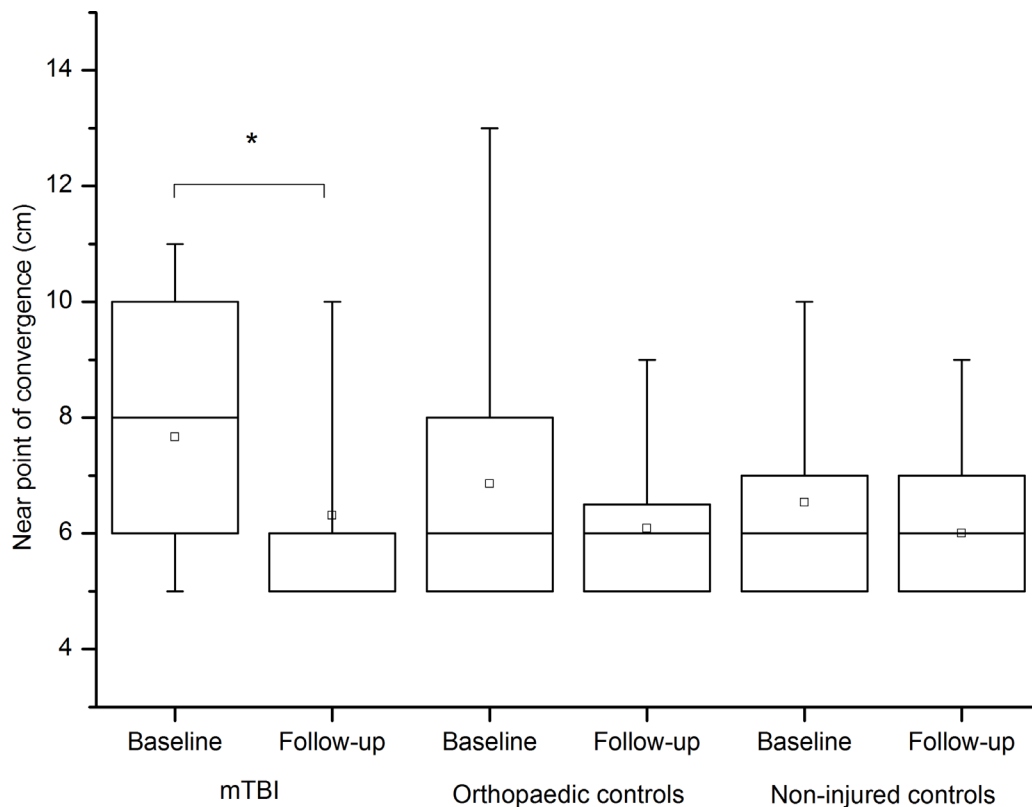
Figure 2 Near point of convergence in the mild traumatic brain injury (mTBI) group at baseline and at follow-up measured in centimetre. The lower the value, the better convergence performance. The miniature squares indicate mean values. The box indicates median, upper and lower quartile. The whiskers indicate minimum and maximum. * Significant difference (P=0.015).
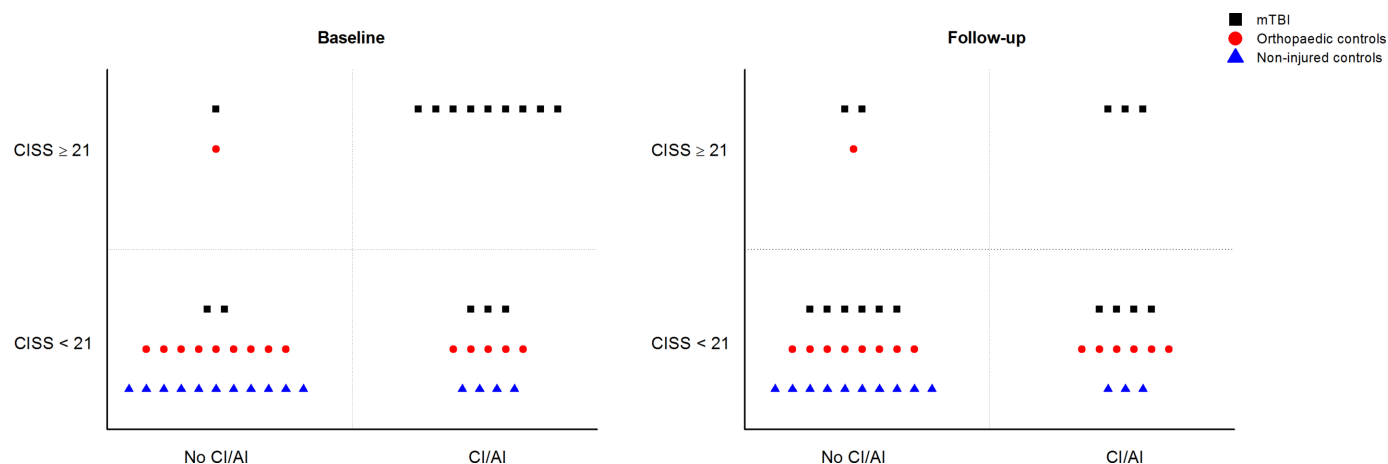
Figure 3 The association between Convergence Insufficiency Symptom Survey (CISS) score and the presence of accommodative insufficiency (AI) or convergence insufficiency (CI) in patients with mild traumatic brain injury (mTBI), orthopaedic controls and non-injured controls. The findings at baseline and at follow-up are presented in a two-by-two matrix.

arc at baseline, and two of these performed similarly at follow-up. All non-injured controls performed normally at both test occasions.

Saccade performance

In the prosaccade task, no statistically significant difference in latency or gain was found between groups or test occasions (ANOVA). No significant differences within or between groups were found in the self-paced saccade task. In the antisaccade task, all groups performed well at both test occasions with no statistically significant differences in latency or proportion of erroneous saccades.

Assessment of visual symptoms

There was a statistically significant difference between the three groups regarding CISS score at the baseline (df=2, P=0.003) (Kruskal-Wallis test). Patients with mTBI had more visual symptoms with near work, compared with the two control groups, as measured by the CISS score at baseline: patients with mTBI versus orthopaedic controls (U=47.5, P=0.012) and patients with mTBI versus non-injured controls (U=38.0, P=0.02) (Mann-Whitney U test). The median value of the CISS score in the mTBI group at baseline was 24. It then decreased to 19 at follow-up, but the change did not reach statistical significance (Wilcoxon signed-rank test). The CISS score was below cut-off level at both time points in the control groups.

At baseline, 9 out of 12 patients with mTBI were identified with CI/AI using the CISS (figure 3). At follow-up, seven patients with mTBI still had CI/AI (figure 3); one with CI and six with AI. Three of these patients scored as symptomatic on CISS. However, no association between CISS and CI/AI was found (Fisher's exact test).

In the mTBI group, CISS scores at baseline correlated with reduced PFV measured at near, that is, the capacity to maintain clear single vision while performing near work (r=−0.6; P=0.02) (figure 4).

Symptoms measured by the RPQ

There was a significant difference, regarding the sum of symptom scores on the RPQ, among the three groups at baseline (df=2, P<0.001) and at follow-up (df=2, P=0.001) (Kruskal-Wallis test). At baseline, the RPQ sum of symptom scores was significantly greater in the mTBI group compared with the orthopaedic control group (U=40.0, P=0.002) and to non-injured controls (U=29.5, P<0.001) (Mann-Whitney U test). A significant difference was found in the sum of symptom scores at follow-up, between the mTBI group and the orthopaedic control group (U=27.0, P=0.003), and between the mTBI group and non-injured controls (U=24.0, P<0.001) (Mann-Whitney U test). Sum of symptom scores decreased in the mTBI group over time (median value of the RPQ sum of symptom scores decreased from 22 at baseline to 6 at follow-up), but the difference did not reach statistical significance (P=0.092) (Wilcoxon signed-rank test).

DISCUSSION

We have observed differences in visual measurements between a well-defined mTBI group and two control groups. We also objectively measured transient visual disturbances in the mTBI group.

In agreement with a previous study,[3] a significant difference in accommodation between the mTBI group and each of the control groups at the baseline was found in our study. The mTBI group had statistically significantly lower accommodative amplitude compared with non-injured controls at baseline. Accommodative amplitude then recovered to a certain degree at follow-up, but almost half of the patients with mTBI still had deviations meeting the diagnostic criteria for AI. We know little regarding the expected course of spontaneous improvement in accommodation. There are some indications that AI may be part of issues even in the long term after injury.[21 22] Therefore, it may be necessary to consider therapeutic intervention
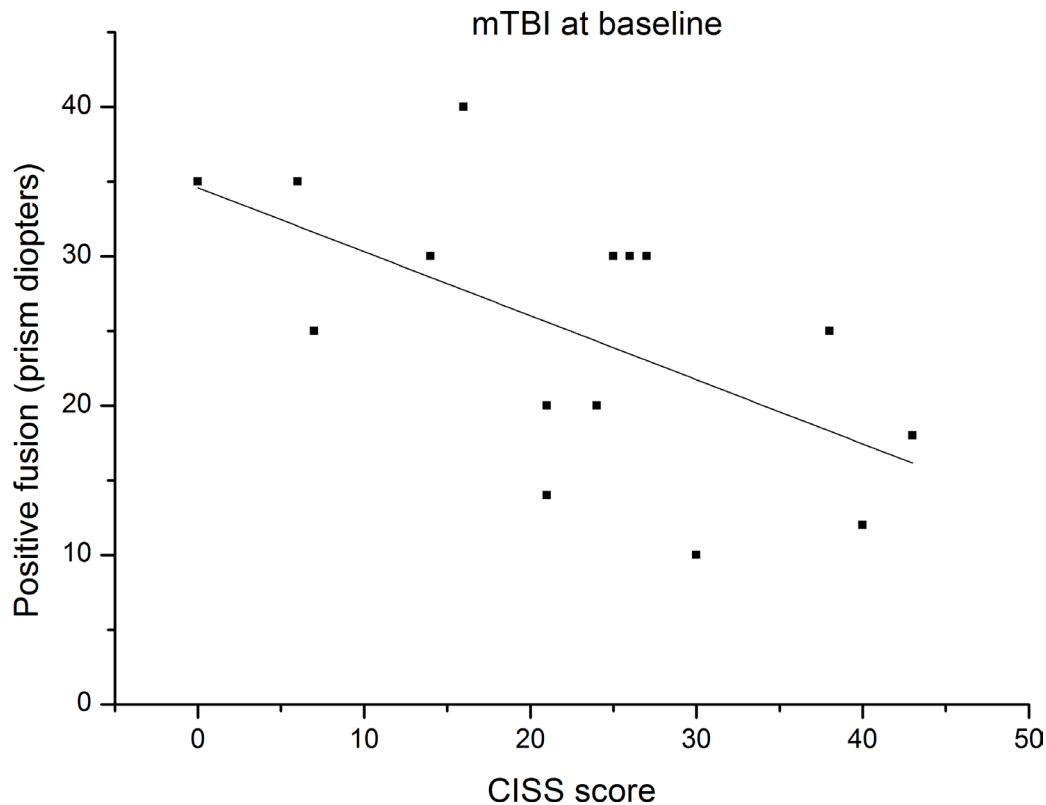
Figure 4 Convergence Insufficiency Symptom Survey (CISS) score versus positive fusional vergence in patients with mild traumatic brain injury (mTBI). Higher positive fusion value corresponds to better function.

when appropriate, for example, spectacle lenses for near work and/or vision therapy.[33]

A somewhat unexpected result was the non-significant difference in NPC between the groups. The finding of non-significant differences in NPC among groups is in contrast to that by Capo-Aponte *et al.*[3] However, we found a significant change in NPC in the mTBI group between the baseline and follow-up. The mean NPC at baseline of these patients with mTBI was just within 10 cm, which may or may not be considered clinically meaningful,[15 29] and therefore not pose a clinical sign for further examination of CI. Receded NPC has previously been proposed as a potentially sensitive vision-based biomarker after mTBI[14] and our findings tentatively support this.

The mechanism behind the spontaneous recovery of NPC in the present patient sample remains to be understood. The convergence responses are based on visual processing of binocular disparity and correct ocular alignment through vergence eye movements. Given the recovery of NPC, any manifest structural injury affecting motor function (vergence eye movements) can probably be ruled out. Some of the remaining aspects to consider are sensorimotor integration and the ability to respond appropriately to the stimulus. Certain tasks, including the push-up method for measuring NPC used in the current study, require that the subject exert maximal convergence effort to maintain single vision of a very near target. This most likely involves voluntary effort. A question for further discussion is how the constellation of somatic symptoms,

cognitive impairments and fatigue, known to be associated with mTBI, may affect the capacity to perform this test optimally. Our clinical observations during this study, along with previous research, suggest that these factors can have contributory effects.[19]

One-third of the patients with mTBI showed a deficient level of stereoacuity at baseline (120–240 s of arc), while at follow-up only one showed deficiency (>60 s of arc). These findings may suggest that the visual processing of disparity was particularly affected in the mTBI group in the acute stage. Based on the improvement in stereoacuity, we may speculate that underlying factors affecting the ability to resolve and detect stereo disparity, such as inadequate or inefficient vergence and/or accommodative function, improved with time.[34]

We were not able to replicate the findings of previous studies that found differences in measures of saccadic eye movements between patients with mTBI and controls.[3 7 13 24] An explanation could be that changes in saccadic reaction time/latency are subtle, transient and possibly only to be demonstrated directly after a trauma to the head. In our study, baseline optometric examination took place a few days after mTBI. Our findings are in line with a study of amateur boxers in which saccadic latency was measured at four time points, with baseline before the boxing match (prefight), and at 3 days, 7 days and 12 days after fight, that is, after blows to the head.[10] Results in this study showed increased saccadic latency directly after the fight; however, 12 days later the latency

had returned to baseline. The small number of participants and lack of the description of mTBI criteria limit interpretation of findings in that study.

We found that patients with mTBI had significantly more visual symptoms as measured by CISS score than orthopaedic and non-injured controls. Our findings on reported visual disturbances at near work after mTBI are consistent with a previous study.[3] We found a significant correlation between CISS score and PFV at near in the mTBI group. This correlation may appear somewhat unexpected since the PFV was normal at the group level. The symptom score (CISS) was significantly higher in the mTBI group than in the control groups. The elevated symptom score may be an indication that most patients with mTBI were indeed able to perform normally on the PFV, but at a greater effort (causing symptoms). Objective recordings of vergence eye movement have demonstrated an association between symptoms and inefficient vergence performance.[35]

The patients sustaining a trauma to the head in this study reported significantly more symptoms on the RPQ and CISS compared with both controls groups at baseline. The symptoms decreased at follow-up, but the change was not statistically significant. However, the role of brain injury for these symptoms, especially for patients with long-term problems after mTBI, has been questioned.[36] Several factors have been suggested to affect symptom reporting after mTBI, for example, recall bias and biopsychosocial factors. Furthermore, previous studies have demonstrated that similar symptoms are also present after any trauma, presumably due to emotional distress and pain related to the injury.[36 37] The strength of our study is having two control groups. Traumatic injury can generally impact on reporting of various symptoms, related to acute post-traumatic stress and pain. Therefore, to avoid confounding factors, we included a group of patients with minor orthopaedic injuries without trauma to the head, presenting at the same ED.

Study limitations
When the study population is small, there is always a risk for type II error, that is, the risk of not revealing a true difference in the studied population. The differences found between patients with mTBI and controls regarding oculomotor measures were few and the within group variations were large. The degree of overlap between groups and incomplete correlation between visual symptoms and visual measurements suggest that caution is appropriate when interpreting findings in an individual patient based on the current state of knowledge. However, several aspects merit further investigation. The sample size in the present study was based on power calculations from reports on long-lasting vision and oculomotor problems in patients after mTBI.[4 7 8] Possible bias in these studies could have led to an overestimation of the frequency of oculomotor changes, and thus an overestimation of expected effect size in our power calculation and a risk of type II error.

Study participants were 18–40 years old making the patient with mTBI group in this explorative study highly selective. This age limitation was chosen to minimise the effect of presbyopia on study results. Our findings will have relevance regarding the large number of young adults suffering head trauma, but will not be directly applicable to older patients, which limits the generalisability.

Future recommendations
Larger confirmatory studies are needed to clarify the clinical relevance of the transient visual disturbances observed in this study. The role of vergence and accommodation as potential biomarkers for mTBI and their interplay with persisting symptoms such as fatigue also need further elucidation. Furthermore, investigations of visual disturbances after mTBI should aim to determine if visual testing in the subacute phase after mTBI could help to predict long-lasting symptoms and be a target for intervention to promote recovery. Our findings, along with previous observations,[21] indicate the importance of not overlooking possible accommodative disorders in the overall assessment of the patient's capacity to return to daily activities.

CONCLUSIONS
Some transient measurable visual changes regarding convergence were noted in patients with mTBI during the subacute period after injury. The finding of persistent AI in a substantial proportion of patients with mTBI requires further evaluation. Accommodation insufficiency could be either a biomarker for persistent functional impairment in neural networks or a target for intervention to promote recovery or possibly both.

REFERENCES

1. Ventura RE, Balcer LJ, Galetta SL. The neuro-ophthalmology of head trauma. *Lancet Neurol* 2014;13:1006–16.
2. Heitger MH, Jones RD, Macleod AD, *et al*. Impaired eye movements in post-concussion syndrome indicate suboptimal brain function beyond the influence of depression, malingering or intellectual ability. *Brain* 2009;132:2850–70.
3. Capó-Aponte JE, Urosevich TG, Temme LA, *et al*. Visual dysfunctions and symptoms during the subacute stage of blast-induced mild traumatic brain injury. *Mil Med* 2012;177:804–13.
4. Ciuffreda KJ, Kapoor N, Rutner D, *et al*. Occurrence of oculomotor dysfunctions in acquired brain injury: a retrospective analysis. *Optometry* 2007;78:155–61.
5. Hunt AW, Mah K, Reed N, *et al*. Oculomotor-based vision assessment in mild traumatic brain injury: a systematic review. *J Head Trauma Rehabil* 2016;31:252–61.
6. Blennow K, Hardy J, Zetterberg H. The neuropathology and neurobiology of traumatic brain injury. *Neuron* 2012;76:886–99.
7. Brahm KD, Wilgenburg HM, Kirby J, *et al*. Visual impairment and dysfunction in combat-injured servicemembers with traumatic brain injury. *Optom Vis Sci* 2009;86:817–25.
8. Goodrich GL, Flyg HM, Kirby JE, *et al*. Mechanisms of TBI and visual consequences in military and veteran populations. *Optom Vis Sci* 2013;90:105–12.
9. Mullen SJ, Yücel YH, Cusimano M, *et al*. Saccadic eye movements in mild traumatic brain injury: a pilot study. *Can J Neurol Sci* 2014;41:58–65.
10. Pearson BC, Armitage KR, Horner CW, *et al*. Saccadometry: the possible application of latency distribution measurement for monitoring concussion. *Br J Sports Med* 2007;41:610–2.
11. Barnett BP, Singman EL. Vision concerns after mild traumatic brain injury. *Curr Treat Options Neurol* 2015;17:329.
12. Alvarez TL, Kim EH, Vicci VR, *et al*. Concurrent vision dysfunctions in convergence insufficiency with traumatic brain injury. *Optom Vis Sci* 2012;89:1740–51.
13. Cifu DX, Wares JR, Hoke KW, *et al*. Differential eye movements in mild traumatic brain injury versus normal controls. *J Head Trauma Rehabil* 2015;30:21–8.
14. Ciuffreda KJ, Ludlam DP, Thiagarajan P, *et al*. Proposed objective visual system biomarkers for mild traumatic brain injury. *Mil Med* 2014;179:1212–7.
15. von Noorden GK, Campos EC. *Binocular vision and ocular mobility: theory and management of strabismus. St*. Louis, MO: Mosby, Inc, 2002.
16. Greenwald BD, Kapoor N, Singh AD. Visual impairments in the first year after traumatic brain injury. *Brain Inj* 2012;26:1338–59.
17. Porcar E, Martinez-Palomera A. Prevalence of general binocular dysfunctions in a population of university students. *Optom Vis Sci* 1997;74:111–3.
18. Hokoda SC. General binocular dysfunctions in an urban optometry clinic. *J Am Optom Assoc* 1985;56:560–2.
19. Hellerstein LF, Freed S, Maples WC. Vision profile of patients with mild brain injury. *J Am Optom Assoc* 1995;66:634–9.
20. Lara F, Cacho P, García A, *et al*. General binocular disorders: prevalence in a clinic population. *Ophthalmic Physiol Opt* 2001;21:70–4.
21. Green W, Ciuffreda KJ, Thiagarajan P, *et al*. Accommodation in mild traumatic brain injury. *J Rehabil Res Dev* 2010;47:183–99.
22. Magone MT, Kwon E, Shin SY. Chronic visual dysfunction after blast-induced mild traumatic brain injury. *J Rehabil Res Dev* 2014;51:71–80.
23. Kerkhoff G. Neurovisual rehabilitation: recent developments and future directions. *J Neurol Neurosurg Psychiatry* 2000;68:691–706.
24. Heitger MH, Anderson TJ, Jones RD. Saccade sequences as markers for cerebral dysfunction following mild closed head injury. *Prog Brain Res* 2002;140:433–48.
25. Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine. Definition of mild traumatic brain injury. *J Head Trauma Rehabil* 1993;8:86–7.
26. Teasdale G, Jennett B. Assessment of coma and impaired consciousness. A practical scale. *Lancet* 1974;2:81–4.
27. Zigmond AS, Snaith RP. The hospital anxiety and depression scale. *Acta Psychiatr Scand* 1983;67:361–70.
28. Krupp LB, LaRocca NG, Muir-Nash J, *et al*. The fatigue severity scale. Application to patients with multiple sclerosis and systemic lupus erythematosus. *Arch Neurol* 1989;46:1121–3.
29. Scheiman M, Wick B. *Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders*. 4th ed. PA: Lippincott Williams & Wilkins, 2014.
30. King NS, Crawford S, Wenden FJ, *et al*. The rivermead post concussion symptoms questionnaire: a measure of symptoms commonly experienced after head injury and its reliability. *J Neurol* 1995;242:587–92.
31. Borsting EJ, Rouse MW, Mitchell GL, *et al*. Validity and reliability of the revised convergence insufficiency symptom survey in children aged 9 to 18 years. *Optom Vis Sci* 2003;80:832–8.
32. Rouse MW, Borsting EJ, Mitchell GL, *et al*. Validity and reliability of the revised convergence insufficiency symptom survey in adults. *Ophthalmic Physiol Opt* 2004;24:384–90.
33. Ciuffreda KJ, Ludlam D. Conceptual model of optometric vision care in mild traumatic brain injury. *Journal of Behavioral Optometry* 2011;22:10–12.
34. Rutstein RP, Daum KM. *Anomalies of binocular vision: diagnosis & management*. St. Louis, MO: Mosby, Inc, 1998.
35. Scheiman MM, Talasan H, Mitchell GL, *et al*. Objective assessment of vergence after treatment of concussion-related CI: a pilot study. *Optom Vis Sci* 2017;94:74–88.
36. Cassidy JD, Cancelliere C, Carroll LJ, *et al*. Systematic review of self-reported prognosis in adults after mild traumatic brain injury: results of the International Collaboration on Mild Traumatic Brain Injury Prognosis. *Arch Phys Med Rehabil* 2014;95:S132–S151.
37. Landre N, Poppe CJ, Davis N, *et al*. Cognitive functioning and postconcussive symptoms in trauma patients with and without mild TBI. *Arch Clin Neuropsychol* 2006;21:255–73.