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RESEARCH

Accommodation and stereopsis in adults with traumatic brain injury

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Background: Traumatic brain injury has many adverse effects on visual functions. The aim of this study is to evaluate accommodation, stereopsis deficits and visual symptoms in Chinese patients with traumatic brain injury.
Methods: This is a cross-sectional study that included 22 patients with traumatic brain injury and 22 controls; the refractive status, stereoacuity, and accommodative ability of each subject were measured.
Results: Patients with traumatic brain injury were significantly more symptomatic than controls ($p < 0.001$). Near stereoacuity thresholds were significantly elevated in patients with traumatic brain injury compared to controls ($p < 0.001$). Accommodative amplitude (right eye: $p = 0.007$; left eye: $p = 0.01$; both eyes: $p = 0.002$) and accommodative facility rates (right eye: $p < 0.001$; left eye: $p < 0.001$; both eyes: $p < 0.001$) were significantly lower in patients with traumatic brain injury, for whom there were no significant differences between the accommodative facility rates of the pre- and post-three-minute binocular flipper sessions ($p = 0.51$). Patients with traumatic brain injury showed greater accommodative lag to 2.5 D ($p = 0.03$), 3 D ($p = 0.03$), 4 D ($p = 0.004$) and 5 D ($p = 0.001$) stimuli, but not to the 2 D ($p = 0.10$) stimulus. The regression equation of accommodative lag to stimuli was steeper for the traumatic brain injury group (slope: $p = 0.01$; y-intercept: $p < 0.0001$). There were also significant correlations between visual symptoms and clinical findings including binocular accommodative amplitude ($r = -0.480$, $p = 0.001$), binocular accommodative facility ($r = -0.445$, $p = 0.004$) and stereopsis ($r = 0.457$, $p = 0.002$).
Conclusion: Patients with traumatic brain injury have deficits in accommodation and stereopsis.

Key words: accommodation, Chinese, stereopsis, traumatic brain injury

Traumatic brain injury (TBI) is the alteration of brain function or evidence of brain pathology caused by an external force.[1] It is a complicated condition, which has become a public health problem globally. In China, TBI-related mortality and morbidity rates have remained at a high level.[2] TBI can adversely affect physical, cognitive, emotional, and visual functions.[3] Patients with visual problems caused by TBI can experience difficulty with activities of daily life as well as in reintegrating into society.

It has been reported that lesions of visual structures, vision-related symptoms and visual dysfunctions are commonly experienced after TBI.[4] These lesions mainly manifest at the optic nerve and in the retinal ganglion cell layer.[5] Previous studies have demonstrated that patients with TBI exhibit various visual symptoms, such as blurred vision, eye strain, headache, occasional double vison, and reading difficulties.[6,7] Regarding visual dysfunctions, these patients mostly experience deficits in accommodation, vergence, and eye movements, including saccades and smooth pursuit.[8] There have been studies worldwide on ocular structure lesions after TBI with humans and animal models.[9–12] Meanwhile, these visual symptoms and dysfunctions after TBI have been reported for US military and veteran personnel[7,13,14] and sporadic civilian cases from many areas,[6,15,16] nevertheless, which, have never been investigated in a Chinese population. Studies are needed to gather information on the visual dysfunctions experienced by Chinese patients with TBI.

Additionally, routine activities, including effective reading, comfortable computer use, safe driving, climbing stairs, and reaching for an object depend on accommodation and stereopsis.[4,17,18] Previous studies have reported the incidence of accommodative deficits, especially accommodative insufficiency, to be approximately 21–62 per cent in non-presbyopic patients with mild TBI;[13,15,19] this is significantly higher than that reported for healthy pre-presbyopic individuals with visual complaints (about 10 per cent).[20] Moreover, TBI patients commonly exhibit impaired stereopsis.[14,21,22] Therefore, assessment of such information on Chinese individuals with TBI must be conducted to gain additional knowledge.

Thus, this study aimed to assess the accommodation, stereopsis, and vision-related symptoms after TBI by evaluating data from self-administered questionnaires and objective measurements conducted on patients with TBI, and comparing them with

data obtained from age- and sex-matched controls to investigate the following: (1) whether visual symptoms are more common after TBI, and (2) to identify the accommodative and stereopsis deficits commonly observed in patients with TBI.

Methods

Participants

This study included 22 patients with TBI and 22 age- and sex-matched controls aged 18–40 years. Consecutive patients with TBI with visual complaints were recruited from January 2018 to February 2019 from the outpatient clinic of the Department of Neurosurgery and the Department of Rehabilitation of West China Hospital, Sichuan University. The control subjects were volunteer students/staff of Sichuan University. All the participants underwent retinoscopy (to assess refraction), random dot stereoacuity tests, accommodation tests, and also completed a brain injury visual symptoms survey questionnaire. The study was approved by the ethics committee of Sichuan University and was performed in accordance with the tenets of the Declaration of Helsinki. All participants provided written informed consent before examinations. The inclusion and exclusion criteria were as follows.

Inclusion criteria: for all participants, age between 18 and 40 years was prerequisite. Other criteria for the two groups were as follows:

1. TBI group:
   a. computed tomography or magnetic resonance imaging reports of TBI diagnosed by a doctor in the Department of Neurosurgery and the Department of Rehabilitation of West China Hospital, Sichuan University, or a well-documented history of TBI treatment during follow-up
   b. willingness to undergo physical examination
   c. ocular criteria:
      (1) no obvious signs of ocular trauma
      (2) no obvious visual field loss
      (3) no history of vision therapy
      (4) distance and near best-corrected visual acuity of 0.8 (decimal acuity) or better.
2. Control group:
   a. distance and near best-corrected visual acuity of 1.0 (decimal acuity) or better
   b. asymptomatic during near work.

Exclusion criteria (any of the following):

1. TBI group:
   a. presence of ocular or neurological disease, such as Parkinson's disease and Sjögren's syndrome
   b. presence or history of brain tumour and/or cerebrovascular accident.
2. Control group:
   a. history of TBI.
   b. presence of ocular or neurological disease.

Assessments

QUESTIONNAIRE

The questionnaire used in the present study was adapted from the Brain Injury Vision Symptom Survey (BIVSS),[6] a self-administered 28-item survey on vision-related behaviours. It was translated into Chinese based on Brislin's translation model.[23] Participants were instructed to rate the presence of any symptom on a five-point Likert scale. Each symptom question had five possible answers with an associated value — always (4), frequently (3), sometimes (2), rarely (1), and never (0).

STEREOPSIS

Near stereoacuity was assessed using the TNO stereopsis test (Lameris Ootech BV Ede, 18th edition), previously described.[24]

ACCOMMODATION TESTS

Amplitude of accommodation was measured monocularly and binocularly using the Push-Up method. Expected amplitude of accommodation was calculated according to the Hofstetter formula.[16] Deviation of accommodative amplitude was calculated by subtracting the expected amplitude of accommodation from the measured amplitude of accommodation. Additionally, accommodative insufficiency was diagnosed when the amplitude of accommodation of any measured eyes was at least 2 D below the minimum amplitude according to Hofstetter's formula: 15 D – 0.25 D × age.[25]

Accommodative facility was measured three times using a ±2.00 D lens flipper at 40 cm for one minute. First, it was measured monocularly and then binocularly after measuring the amplitude of accommodation. Accommodative facility ≥ 11 cpm monocularly and ≥ 8 cpm binocularly were normal.[26] The second measurement of accommodative facility was done binocularly after the accommodative response test described below, and was subsequently followed by a continuous three-minute binocular flipper alternation for patients with TBI. For this three-minute session, patients were instructed to alternate the flipper every 10 seconds upon examiner's command. During the 10-second period, the patient attempted to attain and maintain target clarity. The final accommodative facility measurement was taken binocularly immediately after the three-minute session. The three-minute procedure aimed to assess possible accommodative fatigue effects on the TBI patients.

Accommodative response was assessed using the WAM-5500 (Grand Seiko Co. Ltd, Hiroshima, Japan), an objective, infrared, and open-field autorefractor. For baseline refraction results, the subject was asked to fixate on a distant target at six metres; thereafter, the subject was directed to fixate on a near target at five accommodative stimulus distances, namely: 50 cm (2 D), 40 cm (2.5 D), 33 cm (3 D), 25 cm (4 D), and 20 cm (5 D). For each viewing distance, the subject's fixation lasted 15 seconds. Real-time refraction data were collected during the middle five seconds, which were recorded smoothly and blink-free, and were averaged to indicate the measured refraction. The accommodative response for each distance was calculated using the following formula: accommodative response (D) = (measured refraction [D] – baseline refraction [D]). Then, the accommodative lag or lead was determined by the value of refraction difference between the accommodative stimulus and accommodative response. The positive value indicated accommodative lag, whereas the negative value indicated accommodative lead. The variability of accommodative response was the standard deviation, which was calculated by the measured refraction data during the 15 seconds measurement by removing the data with blinking. All measurements were performed monocularly to avoid vergence accommodation under the binocular condition. For all subjects, the accommodative response was measured for both eyes and recorded by indicating the dominant and non-dominant eyes. The dominant eye was determined by the subject with a hole-in-the-card method.

Statistical analyses

Data were analysed using IBM SPSS 24.0 software. One-way analysis of variance (ANOVA) was used to examine the deviations of accommodative amplitude, accommodative facility, and accommodative responses to 2 D, 2.5 D, 3 D and 4 D stimuli.

Patients	Age	Gender	Mechanism of injury	Time after injury, months	Diagnosis of TBI	Severity of TBI	SE(D)/BCVA	DE	Ocular complaints
TBI-1	25	M	MVA	6	DAI	Severe	OD: –0.50/1.5 OS: –1.125/1.2	OD	Difficulty changing focus from near to far; decreased frequency of blinking
TBI-2	27	M	MVA	45	Right temporal contusion Left frontotemporal contusion	Severe	OD: –4.875/1.0 OS: –4.375/1.0	OD	Double vision
TBI-3	31	M	MVA	6	Right frontotemporal contusion	Severe	OS: –1.25/0.8 OD: LP	OS	OS: blurred vision, dry eye
TBI-4	20	F	MVA	6	DAI	Severe	OD: –1.50/1.5 OS: NLP	OD	OD: occasional blurred vision
TBI-5	38	M	Hitting	2	Occipital fracture; left temporal fracture	Mild	OD: 0/1.2 OS: –0.875/1.0	OD	Blurred vision in both eyes; eye pain, dry eye, and photosensitivity
TBI-6	23	F	MVA	0.2	Left frontotemporal extradural haematoma	Mild	OD: –10.50/1.0 OS: –9.50/0.8	OD	Occasional short-term amaurosis
TBI-7	18	F	Hitting	84	Right temporal contusion	Severe	OD: –3.00/1.0 OS: –2.50/1.0	OS	Occasional blurred vision for three months
TBI-8	38	F	MVA	1	Right occipital fracture	Mild	OD: –4.00/0.5 OS: –2.50/0.9	OS	Double vision, worse at far than that at near distance
TBI-9	24	M	MVA	73	Left temporal contusion	Severe	OD: –2.875/1.0 OS: –3.375/1.0	OD	Blurred vision, eye strain
TBI-10	26	M	Violence (fists)	0.2	Concussion	Mild	OD: –1.00/1.2 OS: 0/1.2	OS	OD: eye pain and dry eye
TBI-11	22	M	Hitting	3	Left occipital fracture	Mild	OD: –2.75/1.0 OS: –2.50/1.0	OS	Occasional amaurosis
TBI-12	32	M	MVA	1.3	DAI	Severe	OD: –3.50/1.2 OS: –3.00/1.0	OS	Blurred vision, difficulty when reading for a long time
TBI-13	25	M	MVA	9	Left frontotemporal contusion	Severe	OD: –0.75/1.2 OS: 0.375/1.0	OD	OS: blurred vision, eye strain
TBI-14	29	F	MVA	42	Left temporal contusion	Severe	OD: –1.925/1.0 OS: –1.765/1.0	OD	OD: blurred vision, dry eye, intermittent diplopia especially when tired
TBI-15	24	M	Hitting	3	Left frontotemporal parietal contusion	Severe	OD: –0.75/0.5 OS: 0/1.0	OS	OD: blurred vision, diplopia when focusing on the right side (sign: OD abduction limited)
TBI-16	35	M	Fall from height	0.7	Concussion	Mild	OD: –2.00/1.0 OS: –1.75/1.0	OD	Blurred vision; eye pain; sensation of eyeball falling out when reading
TBI-17	25	M	Hitting	0.5	Right parietotemporal contusion	Mild	OD: –0.25/1.5 OS: –0.50/1.5	OS	Blurred vision at near and far
TBI-18	25	M	MVA	4	Bifrontotemporal-parietal contusion	Severe	OD: –9.25/0.8 OS: –8.50/0.8	OD	Blurred vision
TBI-19	29	F	MVA	3	Right temporal contusion	Mild	OD: –1.375/1.0 OS: –1.375/1.0	OS	Diplopia (far and up to the right), especially when tired

Table 1. Demographic data and injury characteristics of the patients with traumatic brain injury

Table 1. Continued

Patients	Age	Gender	Mechanism of injury	Time after injury, months	Diagnosis of TBI	Severity of TBI	SE(D)/BCVA	DE	Ocular complaints
TBI-20	27	M	Violence (fists)	4	Left frontal contusion; left parietal-temporal extradural haematoma	Mild	OD: −1.00/0.9 OS: −1.25/0.9	OD	Blurred vision, especially after long periods of near work
TBI-21	20	M	Hitting	1	Left frontal fracture	Mild	OD: −1.00/1.5 OS: −1.50/1.2	OD	OS: blurred vision, eye pain, eye strain
TBI-22	34	F	Hitting	0.17	Concussion	Mild	OD: −1.75/1.2 OS: −1.75/1.5	OD	OS: blurred vision, eye strain, difficulty reading after a long time

BCVA: best-corrected visual acuity (decimal acuity), D: dioptres, DAI: diffuse axonal injury, DE: dominant eye, LP: light perception, MVA: motor vehicle accident, NLP: no light perception, OD: left eye, OS: right eye, SE: spherical equivalent, TBI: traumatic brain injury.

A nonparametric Mann–Whitney U-test analysed the accommodative response to 5 D stimulus because it did not fit the Levene's test for homogeneity of variances. A paired t-test was used to confirm the effect of the three-minute session on patients with TBI. The accommodative response of the two groups was tested with repeated measures analysis of variance. Additionally, group, measured distance, and interaction between group and measured distance were included in the generalised linear model to analyse the difference in the increase of accommodative lag with the stimulus increasing between the TBI group and control group. The difference in stereoacuity was determined with the Mann–Whitney U-test, which was also used to compare the visual symptoms between the two groups. Cronbach's alpha co-efficient and principal components factor analysis provided preliminary data on the reliability and construct validity of the questionnaire, respectively. Spearman's correlation coefficients were used to assess the association between the clinical signs and the BIVSS score. Fisher's exact test was applied for the analysis of categorical data. $p < 0.05$ was considered significant.

Results

Demographic data and injury characteristics

This study included 22 patients with TBI and 22 control subjects, ranging 18–38 years. The mean age was 27.22 ± 5.79 years for the TBI group and 27.36 ± 5.21 years for the control group; no statistical difference was noted between the ages of the two groups ($t(42) = -0.08$, $p = 0.94$). The demographic information of the patients with TBI and their regular ocular examination results and injury characteristics, such as the mechanism, time, diagnosis, and severity are shown in Table 1. The severity was determined with the Glasgow Coma Scale.[27]

Visual symptoms

Each included patient with TBI expressed ocular complaints. Regarding the BIVSS questionnaire, the preliminary alpha coefficient of reliability analysis was 0.91 and the Kaiser-Meyer-Olkin value of validity analysis was 0.77, which indicated that the questionnaire used in this study was valid. The mean total BIVSS score was 41.13 ± 19.74 for the TBI group, and 19.86 ± 13.29 for the control group; statistical analysis showed a significant difference between the two groups ($U = 88.5$, $p < 0.0001$). Patients with TBI had significant visual symptoms including poor eyesight clarity ($U = 58.5$, $p < 0.0001$), doubling ($U = 83.5$, $p < 0.0001$), poor depth perception ($U = 111.0$, $p = 0.004$), poor peripheral vision ($U = 124.0$, $p = 0.008$) and reading difficulty ($U = 73.5$, $p < 0.0001$) (Figure 1).

Stereopsis

Statistical analysis revealed a significant difference in stereoacuity between the two groups ($U = 81.0$, $p < 0.0001$). In the TBI group, 77 per cent (17/22) exhibited deficient stereopsis (> 60 arc seconds). In the control group, only 18 per cent (4/22) manifested deficient stereopsis.

Accommodation functions

The summaries of the mean ± standard deviation of accommodation functions for the two groups are shown in Table 2.

Analysis revealed significant differences in the accommodative amplitude deviation for the right, left, and both eyes for the two groups. Furthermore, 32 per cent (7/22) of the patients in the TBI group manifested accommodative insufficiency, whereas none manifested accommodative insufficiency in the control group. A significantly higher incidence of accommodative insufficiency was found in the TBI group than in the control group ($p = 0.009$).

The baseline, pre-, and post-three-minute session accommodative facility was also assessed. TBI patients exhibited significantly lower accommodative facility rates for all

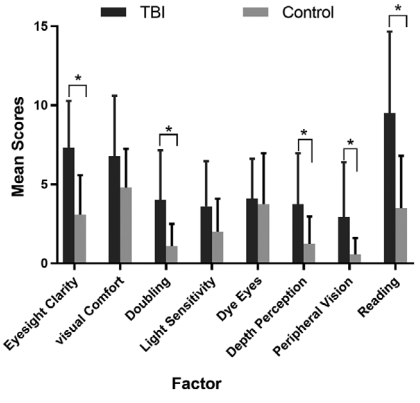

Figure 1. Mean scores for eight vision-related behaviours recorded for each group. *Significant difference. The error bars represent the standard deviation of means.

test conditions in the initial test compared with those in the control group. Additionally, approximately 82 per cent (18/22) of the TBI patients showed abnormal monocular and/or binocular facility rates; however, only 27 per cent (6/22) showed abnormal rates in the control group. Furthermore, the mean accommodative facility was 8.18 ± 4.66 cpm in the second test and 7.90 ± 4.60 cpm in the third test for patients with TBI. No statistically significant effect was found ($t[29] = 0.67$, $p = 0.51$).

In the TBI group, accommodative lags in the dominant eyes were the same as those in the non-dominant eyes ($F_{4,25} = 15.01$, $p = 0.86$) (Figure 2A). Analysis showed significantly more accommodative lag in the dominant eyes of the TBI group than in those of the control group ($F_{4,39} = 11.83$, $p < 0.0001$) (Figure 2B). The increased accommodative lag was noted to be significant for four accommodative stimuli except for the stimuli at 50 cm. The negative correlation between measured distance and accommodative lag is outlined in Figure 3. The correlation co-efficient of the TBI group was −0.44 ($p < 0.0001$) (Figure 3A), whereas the correlation co-efficient of the control group was −0.24 ($p = 0.01$) (Figure 3B). The equation of accommodative lag to measured distance and group was $y = 1.146–0.571\ x_1\text{-}0.578\ x_2 + 0.479\ x_1\ x_2$ (constant: $p < 0.0001$; x_1: $p < 0.0001$; x_2: $p < 0.0001$; $x_1 * x_2$: $p = 0.01$), where y = accommodative lag, x_1 = measured distance, and x_2 = group, indicating that the increased lag with increasing stimuli was greater in the TBI group than in the control group. The accommodative response–stimulus curves of the dominant eyes in TBI patients are shown in Figure 4. The variabilities of accommodative response under five different stimulus levels were 0.15 ± 0.06 D, 0.18 ± 0.10 D, 0.20 ± 0.08 D, 0.21 ± 0.10 D, and 0.23 ± 0.12 D for the TBI group and 0.09 ± 0.03 D, 0.10 ± 0.03 D, 0.11 ± 0.03 D, 0.12 ± 0.05 D, and 0.11 ± 0.05 D for the control group. Repeated measures ANOVA showed a significant difference between the TBI group and the control group ($F = 21.638$, $p < 0.0001$), indicating that for patients with TBI, the accommodation response was more variable when viewing a near target.

Symptoms and clinical signs

As shown in Table 3, apart from the binocular accommodative amplitude ($r = –0.480$, $p = 0.001$), binocular accommodative facility ($r = –0.445$, $p = 0.004$), and stereoacuity ($r = 0.457$, $p = 0.002$), there were no other significant correlations between symptoms measured by the BIVSS and the clinical findings.

Discussion

Traumatic injury to the head may cause focal or extensive brain injury, which may attenuate visual functions. This study was a cross-sectional observational study, which focused on assessing vision-related symptoms and visual functions including accommodation and stereopsis in patients with TBI. Since previous studies found that visual symptoms and dysfunctions were not significantly influenced by the mechanism of injury and the post-injury stage,[14,28] the impact of these characteristics on patients was not considered in this study. The present study found highly consistent abnormalities in accommodation and stereopsis in the patients with TBI, although the trauma cases of subjects had different injury mechanisms and different post-injury periods (as shown in Table 1).

The present study demonstrated that patients with TBI had significantly higher BIVSS scores, worse stereopsis, and worse accommodative function than the subjects in the control group; thus, some aspects of these abnormalities need to be addressed.

First, the higher BIVSS scores in the present study suggest that most patients with TBI indeed experience many visual problems in their daily lives. These findings are consistent with the results of previous studies.[6,14] Impairments of visual functions such as accommodation have been shown to be highly related to symptoms in patients with TBI,[14] as also proven in this study. In addition, several factors, such as cognitive and mental deficits, have been indicated to affect visual symptoms after TBI. Patients with TBI may have abnormal cognitive processes like attention deficits and memory impairment, or abnormal mental states like depression, anxiety, and irritability; these also play a role in the manifestation of visual symptoms after TBI.[29–31] Therefore, the cause of visual symptoms in patients with TBI is complex and there may be interaction effects as well.

Parameter	TBI group mean ± SD	Control group mean ± SD	p-value
Accommodative amplitude deviation (D)†			
OD	0.62 ± 3.22	3.21 ± 2.72	0.007*
OS	0.58 ± 3.02	2.74 ± 2.33	0.01*
OU	1.88 ± 3.03	5.10 ± 3.13	0.002*
Accommodative response (D)‡			
2 D	0.94 ± 0.45	0.70 ± 0.48	0.10
2.5 D	1.13 ± 0.51	0.79 ± 0.51	0.03*
3 D	1.30 ± 0.66	0.89 ± 0.56	0.03*
4 D	1.68 ± 0.88	0.98 ± 0.59	0.004*
5 D	1.96 ± 1.03	1.08 ± 0.60	0.001*
Accommodation facility (cpm)			
OD	5.68 ± 4.08	11.50 ± 4.40	<0.001*
OS	5.18 ± 3.94	11.45 ± 5.31	<0.001*
OU	5.00 ± 4.21	10.60 ± 3.71	<0.001*

D: dioptres, cpm: cycles per minute, OD: right eye, OS: left eye, OU: binocular eyes, SD: standard deviation.

*Statistically significant ($p < 0.05$).

†The positive value indicated that the accommodative amplitude was higher than expected by Hofstetter's formula.

‡The positive value signified that the accommodative responses at different stimulus levels were calculated as accommodative lag.

Table 2. Comparison of accommodation function values between two groups

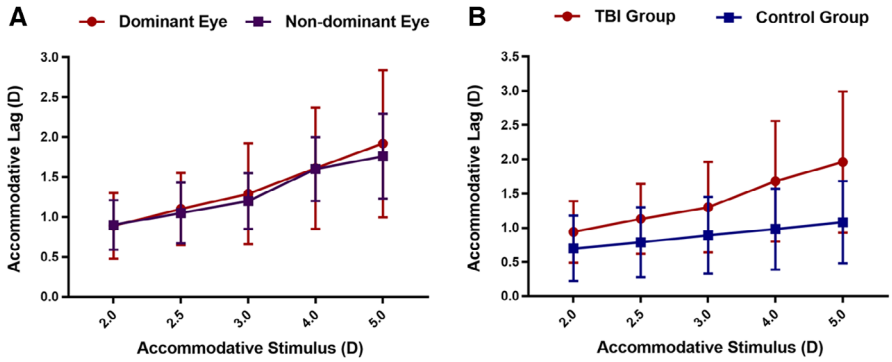

Figure 2. Accommodative lags to five different accommodative stimuli ranging from 2 D to 5 D for A: the dominant eye and non-dominant eye of the patients in the traumatic brain injury (TBI) group, B: the dominant eye of the TBI group and control group. The error bars represent the standard deviation of means.

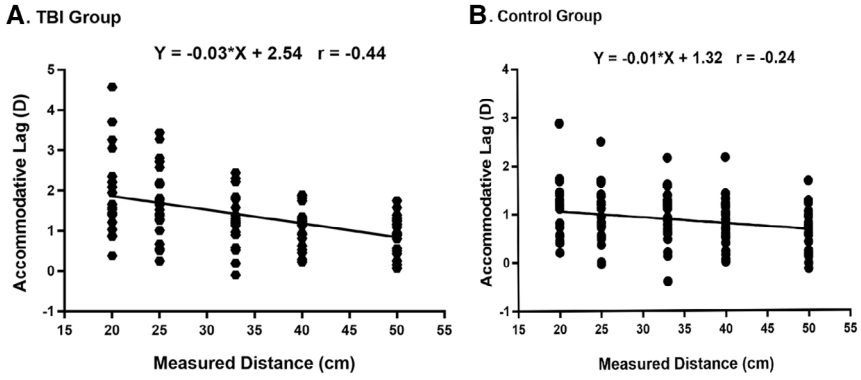

Figure 3. Correlation between accommodative lag and measured distance in A: the dominant eye of the patients in the traumatic brain injury (TBI) group, the linear regression is y = −0.03x + 2.54, r = −0.44, p < 0.001; B: the dominant eye of the subjects in the control group, the linear regression is y = −0.01x + 1.32, r = −0.24, p = 0.01.

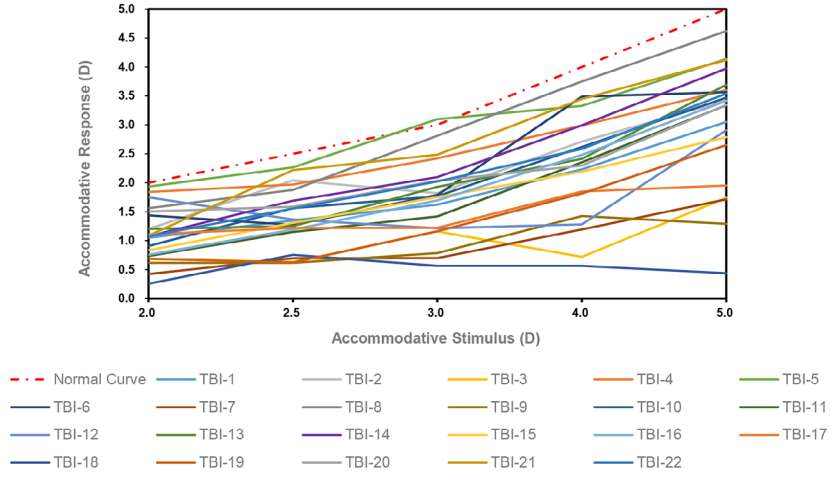

Figure 4. Accommodative response curve at different stimulus levels for patients with traumatic brain injury (TBI). The red dotted line is the standard response curve under ideal conditions, and the solid lines of different colours represent the response curves of the patients.

The results of the present study showed that the stereoacuity of patients with TBI was worse than that of controls, which is consistent with the results of previous studies.[21,32] These studies reported stereoacuity thresholds ranging from 36 to 52 arc seconds assessed by the randot stereotest in patients with mild TBI[14,21,32] but this study found higher stereoacuity thresholds (> 60 arc seconds). This discrepancy may be caused by the measurement tool, because the TNO stereotest was found to overestimate the stereo thresholds compared to the randot stereotest.[24] Additionally, the severity of the conditions of the patients included 50 per cent mild and 50 per cent severe TBI in this study (as shown in Table 1) which may explain the elevated stereoacuity thresholds.[22] Nevertheless, all the studies reported elevated stereoacuity thresholds in TBI patients compared with control subjects.[21,32] These findings suggest that the visual process of stereopsis may be vulnerable to TBI. Some studies have reported that lesions in many brain areas, including the middle temporal area, corpus callosum, parietal lobe, and visual cortical areas, and diffuse axonal injury could reduce stereopsis.[33–35] Moreover, impaired stereopsis may be the reason why patients with TBI experience visual symptoms such as difficulty in driving and navigating stairs, which contributed to the higher BIVSS scores.

In this study, a range of accommodation functions showed significantly poorer abilities in patients with TBI. The reason for this is that the pathway of the blur-driven accommodation, which consists of many brain areas and axons,[36] may be impaired by direct disturbances or injuries in axons secondary to oedema, haematoma, and haemorrhage in TBI.

The patients with TBI showed decreased amplitude of accommodation for monocular and binocular viewing conditions, which is in agreement with the results of earlier studies.[14,36] Thus, this decreased amplitude of accommodation may explain some common accommodation-related symptoms, such as blur, eye strain, and headaches, which may adversely affect reading, driving, and other daily tasks.

The rates of baseline monocular and binocular accommodative facilities in the TBI group were significantly decreased compared with those in the control group. This result is not consistent with the results reported by Green et al.,[36] perhaps because

Clinical signs	r	p-value
Accommodative amplitude (D)		
Monocular	−0.135	0.383
Binocular	−0.480	0.001*
Accommodation facility (cpm)		
Monocular	−0.257	0.101
Binocular	−0.445	0.004*
Accommodative lag (D)		
2 D	−0.158	0.306
2.5 D	−0.051	0.744
3 D	−0.159	0.304
4 D	−0.072	0.641
5 D	−0.027	0.863
Stereoacuity (arc seconds)	0.457	0.002*

cpm: cycles per minute, D: dioptres.
*Statistically significant ($p < 0.05$).

Table 3. Correlations between the Brain Injury Vision Symptom Survey score and clinical signs

they used a ±1.00 D lens flipper rather than the conventional ±2.00 D, and recorded no significant difference in the accommodative facility rates between the TBI group and control group. The higher the dioptric power, the higher the accommodative load, and the lower accommodative facility rate. In the case of an equal increase in accommodative load, the TBI patients showed a significant decrease in accommodative facility due to their own accommodation dysfunctions. Consequently, the TBI group revealed significantly decreased accommodative facility at baseline. Therefore, we believe that high accommodation load may make it easier to detect accommodative facility abnormalities in TBI patients.

For patients with TBI, the accommodative facility rates after the three-minute session were the same as those recorded in the second measurement; this result is also inconsistent with the results reported by Green et al.[36] They confirmed a significant decrease in accommodative facility after the three-minute session and attributed this decrease to accommodative fatigue. According to this theory, it was anticipated that the patients with TBI would manifest a decrease in accommodative facility after the three-minute session. Nevertheless, the ±2.00 D flipper with a training effect is widely used as an effective tool for improving accommodative facility. Theoretically, the accommodative facility could show an improvement after training. However, the periods of alternation lasted only three minutes in this study, leading to a limitation to the training effect. As a result, the rates of accommodative facility after the three-minute session remained stable rather than increasing. Perhaps repeated lens flipping with longer periods could improve accommodative facility in patients with TBI. Further experiments are needed to determine the dioptres and periods of lens flipping for training. This may be especially important in relation to vision therapy in patients with TBI.

The present study also highlighted the abnormal accommodative response of patients with TBI to five different stimulus levels. Normally, when viewing near targets, people under 40 years of age manifest a mild amount of accommodative lag.[37] However, with the accommodative stimulus increased, the TBI group presented more lag. We speculate that this was predominantly a consequence of accommodative fatigue. In addition, the accommodative response of the patients with TBI was fluctuating under different accommodative stimuli, and the shape of the accommodative response curve moved downward compared with that of healthy people aged 18–40 years in Kalsi's study,[38] suggesting that patients with TBI under 40 years may have reduced accommodation. However, the mechanism of the fluctuating and downward accommodation response/stimulus curves for the patients with TBI under 40 years require further research.

Conclusion

Patients with TBI indeed have abnormal accommodation and stereopsis even without obvious eye injury. Thus, timely ocular examination should be conducted in both inpatient and outpatient settings, especially for those without ocular complaints.

Study limitations

The present study has some limitations. First, the sample size was relatively small, mainly because of the age group of the study population and strict inclusion/exclusion criteria. The aim of the age limitation was mainly to minimise the effect of presbyopia on results. Second, not all patients with TBI had available data of a baseline visual assessment; consequently, the results of subjects who had pre-existing dysfunctions may lead to an overestimation of visual deficits associated with the injury.

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