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Pupillary dynamics and accommodative response in mild traumatic brain injury

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Abstract:

PURPOSE: To measure the pupillary dynamics and accommodative response in individuals with mild traumatic brain injury (mTBI) as compared to age-matched controls.

MATERIALS AND METHODS: This prospective comparative study was carried out at the neuro-optometry clinic of a tertiary eye care hospital. Sixty-three subjects with a history of mTBI and ninety age-matched controls were enrolled in this study. Subjects in the age range of 18–35 years were included in the study. A comprehensive neuro-optometric assessment was performed followed by pupillary dynamics and accommodation response measurements using NeurOptics® pupillary light reflex™-3000 and Grand-Seiko WAM-5500 binocular accommodation auto ref/keratometer | shigiya machinery works LTD.

RESULTS: A statistically significant difference was noticed for constriction percentage (%): 32.73 ± 9.20 versus 39.93 ± 7.36 ($P < 0.001$), average constriction velocity (mm/s): 2.24 ± 0.85 versus 2.62 ± 0.68 ($P = 0.002$), maximum constriction velocity (mm/s): 3.82 ± 1.33 versus 4.42 ± 0.93 ($P = 0.004$) and T75 (recovery period to 75% of the baseline pupillary diameter in sec): 1.38 ± 0.36 versus 2.0 ± 0.82 ($P < 0.001$) in mTBI compared to age-matched controls. A statistically significant difference was noted for accommodative response (in D) as well as in the sample as compared to age-matched controls: −1.12 ± 0.64 versus − 1.39 ± 0.47 ($P < 0.001$).

CONCLUSION: Pupillary constriction velocities and accommodative response are significantly affected in mTBI. These findings have important clinical implications in being able to understand the visual symptoms following an mTBI.

Keywords:

Accommodative response, pupillary dynamics, traumatic brain injury

Introduction

Traumatic brain injury (TBI) is defined, "as an alteration in brain function, or other evidence of brain pathology, caused by an external force."[1] It is one of the leading causes of mortality and disability in India.[2] The mode of TBI can be either due to falls, assaults, road traffic crash, and pedestrian accidentals, sports-related, industrial, and workplace-related injuries.[3] Mild TBI (mTBI) accounts for 75% among all the grades of TBI.[4] The American Congress of Rehabilitation Medicine defined mTBI as "traumatically induced physiological disruption of brain function, as manifested by at least one of the following: Any period of loss of consciousness (LOC), any loss of memory for events immediately before or after the injury, an alteration in the mental state at the time of injury (disoriented or confused), and focal neurological deficit that may or may not be transient." Visual symptoms following mTBI include near vision problems with prolonged reading, glare, photosensitivity, and difficulty maintaining fusion.[5] Diffuse axonal injury in mTBI is known to disrupt accommodation and vergence leading to oculomotor dysfunctions.[6] Moreover, the impact on the autonomic nervous system following mTBI also hampers the pupillary mechanisms in

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terms of sympathetic and parasympathetic information processing.[7]

Pupillary constriction, a key component of near triad[8] enables a human eye to stimulate accommodation for a given near stimulus. Since TBI is known to hamper the accommodation and vergence network,[9] it can also be hypothesized to negatively impact the pupillary pathway and thus accommodation. Hence, quantification of pupillary parameters becomes essential to rule out any neurological involvement.[10] Few studies have reported the objective quantification of pupillary light reflex (PLR) using monocular pupillometer in blast and nonblast mTBI.[11,12] Moreover, a study by Truong and Ciuffreda investigated the same using a binocular pupillometer under a wide range of testing conditions and found that pupillary dynamics is altered in mTBI under maximum testing conditions.[13] To the best of our knowledge, there is no existing literature that has investigated the clinical parameters of accommodation and convergence and its correlation with pupillary dynamics in mTBI. This would enable clinicians to correlate the clinical symptoms post-TBI to potential alterations in pupillary dynamics. Thus, this study aims to investigate the accommodative response and pupillary dynamics in individuals with mTBI, compared to age-matched controls.

Materials and Methods

This prospective comparative study was carried out at the neuro-optometry clinic of a tertiary eye care hospital for a period of 1 year. The project has been approved by the Institutional Review Board and followed the guidelines proposed by the Declarations of Helsinki (approval number: 700-2018-P Vision Research Foundation) and the patient consent is waived by Institutional Review Board. Subjects with persistent visual symptoms following mTBI were recruited. Inclusion criteria for mTBI group included subject's age range between 18 and 35 years, history of mTBI with a duration of 6 months of more along with persistent visual symptoms being present, best-corrected visual acuity of 6/9, Snellen's acuity or better in both eyes for distance and N6 for near, no relative afferent pupillary defect, and stable general health. Exclusion criteria included severe TBI, under corrected/high refractive errors (myopia ≤ -6.00D and hyperopia $>+5.00$D), any ocular pathology, under medications affecting pupil responsivity, neurodegenerative/demyelinating diseases (Alzheimer's/Parkinson's disease), hemianopia or gross visual field defects, any physical disability, cognitive issues, and history of any past ocular surgeries. Based on the inclusion criteria, the mTBI subjects were first screened in the general outpatient departments of the study center. Participants, who met the inclusion criterion, were then evaluated in the neuro-optometry department for binocular vision assessment and measurement of pupillary dynamics and accommodation response. The age-matched controls were considered those without any history of mTBI, with visual acuity of 6/9 or better and stable ocular and general health. The exclusion criteria for the age-matched control group included subjects with any pupillary abnormalities, binocular vision anomalies, any ocular and systemic defects. The age-matched controls were students and hospital staff of the study center who met the inclusion criteria.

Sample size calculation

Based on a previous study with mTBI prevalence,[14] the sample size was determined using the formula: $N = N \times X/(X + N - 1)$, where $X = Z_{\alpha/2}{}^2 - {}^*p^* (1 - p)/MOE^2$, and $Z_{\alpha/2}$ is the critical value of the normal distribution at $\alpha/2$, MOE is the margin of error, *P* is the sample proportion, and N is the population size. Considering the margin error of 10% with 95% CI and sample proportion of 42%, the sample calculated was 65.

Samples

A total of 63 mTBI subjects and ninety age-matched controls were included in the study.

Testing procedures

A detailed history, visual acuity testing, refraction, and anterior-posterior segment assessment following a referral to the neuro-optometry clinic was made. At the time of recruitment, the severity of TBI was classified into mild, moderate, and severe based on Glasgow Coma Scale (GCS), posttraumatic amnesia, LOC, and alteration of consciousness state,[15,16] depending on the documentation in the medical case history sheet following the mTBI. The associated history of brain injury details was also gathered from the subjects followed by Binocular vision test[17] and Neuro-optometric test[18].

Binocular vision tests carried out

- Near point of accommodation using an accommodative target (Push up method)
- Heterophoria measurement using the Modified Thorington test with a Bernell Muscle Imbalance Measure at 30 cm and 3 m
- Accommodative convergence/accommodation ratio measurement using heterophoria method
- Near point of convergence with Gulden stick and red filter with penlight
- Fusional step-vergence amplitude testing using prism bar for distance and near
- Accommodation response using monocular estimate method retinoscopy
- Positive and negative relative accommodation using plus/minus lenses at 40 cm
- Accommodative facility testing using ± 2.00 D flippers at 40 cm both monocular and binocular
- Vergence facility testing using 12 ΔBO/3 ΔBI flippers at 40 cm using a linear target binocularly.

Neuro-optometric test carried out

- Saccades and pursuit testing using North Eastern State University College of Optometry grading
- Developmental eye movement test to measure the horizontal and vertical time
- Objective eye movement testing using ReadAlyzer™.

Diagnosis of binocular vision dysfunctions in traumatic brain injury

Accommodative amplitudes in mTBI subjects were compared with age-matched controls to look at the significant changes in the parameters between the groups. Diagnosis of nonstrabismic binocular vision anomalies was made using a standard criteria proposed by Scheiman and Wick[18] and cutoff values for each parameters were considered based on the Indian normative data proposed by Hussaindeen *et al*.[19] [Supplemental Table 1].

Pupillary dynamics instrumentation and testing method

The NeurOptics® PLR™-3000is a hand-held pupillometer that enables the objective assessment and quantification of pupillary dynamics using an infrared technology.[10] The instrument consists of a self-contained infrared and visible illumination sources and a digital camera which acquires the image and analyses the data and displays a summary of the measurement. Positioning the PLR-3000 with the cup at right angle to the subjects' axis of vision, the pupillometer is focused using a positive pulse stimulus protocol, i.e. a bright pulse over a dimmer background. A white light of 50 μW intensity with pulse duration of 3 s is flashed on the pupil. The results are plotted as a function of time in a graph.

The measurements were carried out monocularly under binocular viewing conditions using a self-illuminated Maltese cross target used at 40 cm subtending 4° at the eye and the central point of each limb subtending 1 min of arc at the nodal point of the eye in a mesopic room light illumination of 4 lux.[20] While one eye being measured, the fellow eye focuses on the Maltese cross and vice-versa. A positive stimulus protocol was being used where the light stimulus of 50 μW was shined at the patient's eye for 3 s while seeing the target from the fellow eye.[21] The instrument then displayed the measurements tracking in the display which included the following elements:

Maximum diameter = The initial diameter of the pupil before responding to light.

Minimum diameter = The pupillary diameter at the peak constriction level.

Delta = Changes in the size of the pupil from maximum to minimum in the entire measurable duration.

Latency = Time of immediate response of the pupil on initiating light stimulus.

Average constriction velocity (ACV) = Average velocity of the amount of pupillary constriction measured in millimeters per second.

Maximum constriction velocity (MCV) = Maximum velocity of the amount of pupillary constriction measured in millimeters per second.

Average dilation velocity = Average velocity of the amount of change in shifting the response from a constriction to recovery phase and the dilation velocity was measured in millimeters per second.

T75 = 75% of the recovery period that a pupil takes to reach its original baseline pupillary diameter after the peak constriction period.

Accommodation dynamics instrumentation and measurement

The Grand Seiko WAM 5500 is an objective, infrared, open view instrument that uses a two-step method for measuring the refractive error,[22] with a resolution of 0.01D and 5 Hertz frequency. Three infrared light arches are projected into the retina; the reflected light from the retina then passes through a lens system (Badal optometer) that moves quickly to focus the image. The final position of the Badal optometer allows automatic software to determine the refraction of the examined eye. The measurements were recorded using the Hi-speed mode for 1 min which measures the dynamic response of the accommodation and pupil simultaneously. The response rate was measured with a self-illuminated Maltese cross target at 40 cm which subtends 4° at the eye and the central point of each limb subtends 1 min of arc at the nodal point of the eye. A Maltese cross that was chosen as the target for measuring accommodation because it possessed both high-contrast edges and a wide range of spatial frequencies (with high spatial frequency at the center) that could efficiently drive accommodation.[23] The output was then extracted using a cable connecting the instrument with the computer with a software (Warehouse Control System) being incorporated into it and the excel document gives the refractive and the pupil size measurement measured for the particular timing.

Post concussion symptom scale

In order to understand the presence of any secondary symptoms, a subjective assessment of symptoms was assessed using Post concussion symptom scale (PCSS) questionnaire.[24] It consisted of a 22-item scale designed to grade the severity of symptoms following a concussion. This scale was introduced with an aim to assess each

symptom with a numerical value in order to objectively document the frequent subjective symptoms that the individual encounter after suffering a concussion. The goal of developing this scale was to serve as an adjunct to other tools like neuropsychological testing. Each symptom had a scoring scale from 0 to 6, where 0 is the least scoring and 6 being the maximum scoring. The higher the scores, the more is the severity of symptoms.

Statistical analysis

Statistical analysis was performed using Microsoft Excel 2007, SPSS Version 20.0. (Armonk, NY: IBM Corp. IBM Corp). One sample Kolmogorov–Smirnov (K–S) test was used to check normality distribution. Descriptive statistics (mean [Standard deviation (SD)]) were calculated for the neuro-optometric parameters. Independent *t*-test was used to compare the two independent groups with 95% Confidence intervals (CI) and α-value was set at 5%.

Results

Demographics

Among the mTBI individuals, 55.6% (n = 35) were female and those of the control group 72% (n = 56) were female. The mean (SD) age of individuals in the mTBI and control group was 22 (3) years and 23 (3) years respectively (P > 0.05, Independent *t*-test). The mean (SD) spherical equivalent refraction in the TBI group was − 0.83D (1.45) and in age-matched controls was − 0.25D (0.75). The most common means of injury was blunt force to the head (n = 25, 40%). LOC at the time of injury was reported by 19% of the subject (n = 12) "[Figure 1])." None of the subject underwent any physical therapy, occupational therapy or vision therapy prior to the study visit. The mean ± SD duration of the mTBI was 16 ± 3.5 months. No statistical significant difference was noted in the mean (SD) spherical and cylindrical refractive error between mTBI and age matched controls were: −0.29 (0.49) versus − 0.25 (0.44) [P = 0.68] and − 0.25 (−0.30) versus − 0.22 (−0.31) [P = 0.58].

Binocular vision disorders among mild traumatic brain injurys

The phoria status of the TBI group for distance and near was (mean [SD]: −0.47 [1.30] prism diopter) and (mean [SD]: −3.16 [3.61] prism diopter) (minus phoria corresponds to an exodeviation and a plus phoria corresponds to an esodeviation). Similarly for the age matched controls the phoria status for distance and near included (mean [SD]: −0.50 [0.59] prism diopter) and (mean [SD]: 0.75 [1.50] prism diopter) respectively. A statistically significant difference in the binocular accommodative amplitude, relative accommodation, convergence amplitude, fusional vergence amplitude

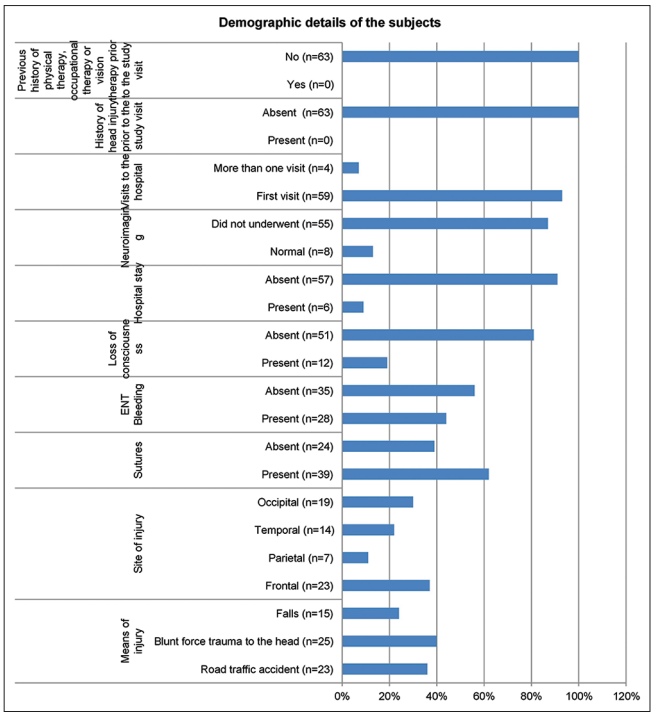

Figure 1: Demographic details of the mTBI subjects. mTBI = Mild traumatic brain injury

and accommodative facility was found in the TBI group when compared to the aged matched controls "[Table 1]." Accommodative dysfunction (Accommodative insufficiency + infacility: n = 32, 50.8%) was the most prevalent nonstrabismic binocular vision anomaly among the subjects with mTBI followed by convergence insufficiency (n = 14, 22.2%), Convergence insufficiency with accommodative insufficiency (n = 07, 11.1%) and oculomotor dysfunction (n = 01, 1.6%).

Pupillary dynamics parameters: Mild traumatic brain injury versus age matched controls

Subjects with mTBI presented with a relatively smaller constriction percentage (mean [SD]: 32.73 [9.20] [%]), decreased ACV (mm/s): 2.24 (0.85), decreased MCV (mm/s): 3.82 (1.33) and a faster recovery period (sec): 1.38 (0.36) compared to visually normal age matched controls [Table 2].

Accommodative response: Mild traumatic brain injury versus age matched controls

Subjects with mTBI exhibited a statistically significant reduced accommodative response for a 2.50D stimulus, i.e. mTBI versus aged matched controls (mean [SD]): −1.12 (0.64) D versus −1.39 (0.47) D [Table 3].

Post concussion symptom scale

Significant median (interquartile range) (range) PCSS scores between mTBI versus age matched controls were: headache (3[3] [0–6] vs. 0[0] [0–3]; P < 0.001), balance problems (0[0] [0–4] vs. 0[0] [0–2]; P < 0.001),

Table 1: Binocular vision parameters in mild traumatic brain injury and age matched controls

Parameters	Mean (SD)		*P* (independent *t*-test, 95% CI)
	mTBI	Age matched controls	
Phoria-distance (PD)	−0.47 (1.30)	−0.50 (0.59)	0.79
Phoria-near (PD)	−3.16 (3.61)	0.75 (1.50)	0.04
NPA (right eye) (dioptres)	12.97 (3.54)	13.99 (2.76)	0.11
NPA (left eye) (dioptres)	13.00 (3.60)	14.02 (2.82)	0.10
NPA (both eye) (dioptres)	13.03 (3.64)	14.27 (2.82)	0.03
NPC (accommodative target) (cm)	7.14 (3.79)	6.1 (1.09)	0.03
NPC (red-green target) (cm)	13.95 (6.83)	12.91 (1.80)	0.22
NRA (dioptres)	3.03 (0.74)	2.60 (0.29)	0.02
PRA (dioptres)	−3.83 (1.48)	−5.30 (0.18)	0.03
MEM (right eye) (dioptres)	0.77 (0.42)	0.67 (0.11)	0.04
MEM (left eye) (dioptres)	0.79 (0.40)	0.62 (0.12)	0.04
NFV break-distance (PD)	8.89 (2.37)	9.98 (2.99)	0.03
NFV recovery-distance (PD)	6.79 (2.37)	7.93 (2.91)	0.03
PFV break-distance (PD)	20.38 (7.10)	29.57 (6.40)	0.04
PFV recovery-distance (PD)	16.90 (6.18)	23.88 (7.36)	0.03
NFV break-near (PD)	13.21 (2.57)	14.42 (15.30)	0.53
NFV recovery-near (PD)	11.17 (2.55)	10.20 (2.73)	0.03
PFV break-near (PD)	27.90 (9.49)	31.39 (6.27)	0.04
PFV recovery-near (PD)	23.54 (8.63)	26.12 (5.91)	0.04
VF (12PD BO/3PD BI) (CPM)	11.83 (3.70)	11.81 (1.02)	0.88
MAF (right eye) (±2.00DS) (CPM)	7.29 (4.68)	12.10 (1.69)	0.01
MAF (left eye) (±2.00DS) (CPM)	7.27 (4.76)	11.93 (1.65)	0.01
BAF (both eye) (±2.00DS) (CPM)	6.78 (4.09)	12.13 (1.75)	0.01

NPA=Near point of accommodation, NPC=Near point of convergence, NRA/PRA=Negative/positive relative accommodation, MEM=Monocular estimated method, NFV=Negative fusional vergence, PFV=Positive fusional vergence, VF=Vergence facility, MAF=Monocular accommodative facility, BAF=Binocular accommodative facility, PD=Prism dioptre, BO=Base out, BI=Base in, CI=Confidence interval, SD=Standard deviation, CPM=Cycles per minute, mTBI=Mild traumatic brain injury

balance problems (0[0] [0–2] vs. 0[0] [0]; $P = 0.005$), light sensitivity (2[2] [0–5] vs. 0[0] [0–2]; $P < 0.001$), difficulty concentrating (0[0] [0–5] vs. 0[0] [0–1]; $P < 0.001$), difficulty remembering (0[0] [0–4] vs. 0[0] [0–2]; $P < 0.001$) and visual problem (0[0] [0–2] vs. 0[0] [0]; $P = 0.001$) [Figure 2].

Discussion

Our study result has highlighted the differences in static and dynamic pupillary and accommodative response measurements between subjects with and without mTBI. To the best of our knowledge, there is no existing literature that investigated the pupillary and accommodative response simultaneously in mTBI. This study emphasizes the role of pupillary dynamics and accommodative response following mTBI. There exist several factors that might have an impact on pupillary static and dynamic aspects including age, enthusiastic state, level of light adaptation, iris coloration, and refractive state.[7,25]

Pupillary dynamics in mild traumatic brain injury

There exists evidence of afferent based neurosensory information processing delay in PLR pathway in mTBI leading to a delay in the latency period.[11-13] The findings of these previous studies on delayed latency are however not consistent with our findings in mTBI versus age matched controls, i.e. 0.22 (0.04) sec versus 0.21 (0.02) sec ($P = 0.06$). A neurologically harmed visual pathway may show exacerbated reaction variations from the normal when the stimulus luminance is decreased.[7] In support of this assertion, the latency in mTBI was found to be delayed in every testing condition except for intense stimuli of bright white step in a study by Truong and Ciuffreda.[13] The possible reason could be the role of rapid pupillary response on bright stimulus producing robust reading; whilst with low intensities the saturation effect would not be active, thus producing more evident constriction latency.[13] However, the indifference in the latency observed in the present study could be possibly due to selection of the testing protocol, i.e. a positive pulse stimulus protocol (bright light over a dimmer background) being used. Although the pupillary latency among both the groups showed no statistical significant difference, we hypothesize that there was a mild difference between both the groups in terms of latencies which had an impact in the constriction velocities. Findings of reduction in the baseline pupillary parameters in mTBI individuals were discussed in a study conducted by Thiagarajan and Ciuffreda.[12] Interestingly, in this study no significant difference in the baseline maximum pupillary diameter was found in either of the groups. Few prior studies that the changes in the baseline pupillary diameter might be due to reduced sympathetic innervations in mTBI individuals as a result of trauma.[11,12] This reduced sympathetic innervations in previous study hypothesized that mTBI individuals' exhibit faster pupillary dilation compared to the controls.[12] However, in this study, no such significant difference in the average dilation velocities was noted in either of the groups. The difference could be possibly attributed to the stage of head injury, namely acute, sub-acute and chronic being considered.

A reduction in the MCV ($P = 0.004$) was also noted in the mTBI subjects with a mean difference of 0.59 compared to the controls. In addition, the ACV was also slower in mTBI individuals ($P = 0.002$). Similar to our study results, the maximum and average constriction velocities in previous studies also have showed a delayed response in

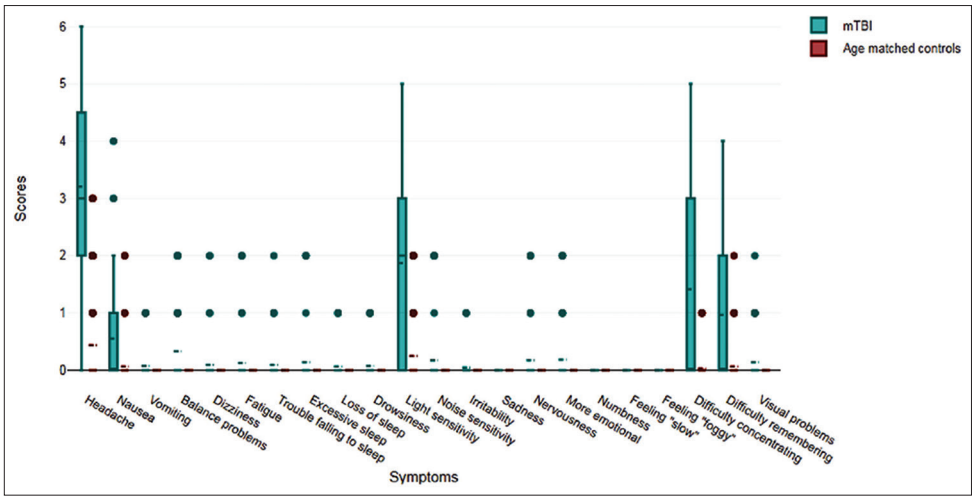

Figure 2: Box and whisker plot showing median IQR scores of PCSS between mTBI subjects and age matched controls. IQR = Interquartile range, PCSS = Postconcussion symptom scale, mTBI = Mild traumatic brain injury

Table 2: Comparison of pupillary dynamics between mild traumatic brain injury and controls

Pupillaryparameters	Mean (SD)		Mean difference (SD error)	95% CI (lower – upper)	*P* (independent *t*-test, 95% CI)
	mTBI	Controls			
MAX	4.12 (0.90)	4.35 (0.76)	−0.22 (0.13)	−0.49 – 0.03	0.09
MIN	2.71 (0.49)	2.53 (0.33)	0.18 (0.07)	0.04 – 0.31	0.009*
Constriction (%)	32.73 (9.20)	39.93 (7.36)	−7.20 (1.33)	−9.86 – −4.54	<0.001*
Latency	0.22 (0.04)	0.21 (0.02)	0.01 (0.005)	−0.006 – 0.02	0.06
ACV	2.24 (0.85)	2.62 (0.68)	−0.39 (0.12)	−0.63 – −0.12	0.002*
MCV	3.82 (1.33)	4.42 (0.93)	−0.59 (0.20)	−0.97 – −0.17	0.004*
ADV	1.02 (0.37)	0.93 (0.25)	0.09 (0.05)	−0.02 – 0.42	0.05
T75	1.38 (0.36)	2.0 (0.82)	−0.70 (0.16)	−1.03 – −0.36	<0.001*
Pupil dia_WAM	3.94 (0.65)	3.98 (0.80)	−0.50 (1.35)	−0.40 – 0.28	0.75

MAX=Maximum diameter (mm), MIN=Minimum diameter (mm), ACV=Average constriction velocity (mm/s), MCV=Maximum constriction velocity (mm/s), ADV=Average dilation velocity, T75=75% of the recovery time (s), CI=Confidence interval, SD=Standard deviation, mTBI=Mild Traumatic brain injury

Table 3: Comparison of accommodative response for 2.50 D stimulus between mild traumatic brain injury and control group

WAM parameters	Mean (SD)		Mean difference	95% CI (lower-upper)	*P* (independent *t*-test, 95% CI)
	mTBI	Control			
Accommodative response (OD) in dioptres	−1.12 (0.64)	−1.39 (0.47)	0.41 (0.82)	0.20 – 0.62	<0.001
Accommodative response (OS) in dioptres	−1.10 (0.63)	−1.35 (0.46)	0.34 (0.80)	0.13 – 0.54	<0.001

CI=Confidence interval, SD=Standard deviation, OD=Oculus dexter, OS=Oculus sinister, mTBI=Mild traumatic brain injury

mTBI subjects.[11-13] The possible explanation supporting these findings is still not clear. However, the deficient average constriction velocities in mTBI might reflect a possible deficit in feedback mechanism of PLR.[13]

An ideal PLR requires a balanced and adequate amount of pupillary constriction and dilation. Consequently, in our study, the mTBI group showed faster time required for the pupil to reach 75% of its original size ($P < 0.001$). Similar finding of faster 75th% recovery time in mTBI was also reported in a study conducted by Truong and Ciuffreda.[26] However, there was a statistically significant increase in the baseline minimum pupillary diameter of the mTBI individuals in this study. Since the baseline minimum pupillary diameter is larger in mTBIs, the tendency of the pupil to reach its original size would also be faster when compared to the controls. With light stimulation, rod and cone photoreceptors control initial pupil constriction, while Intrinsically photosensitive retinal ganglion cells (ipRGCs) control postillumination pupil response after light offset. The postillumination redilation dynamics corelate with faster because the ipRGCs play a major role in the latter "sustained" constriction response phase. It could also be hypothesized that if the sensor complex of the ipRGCs were disrupted and rendered dysfunctional, it would result in a baseline pupil diameter offset, which might lead to wider pupils and a reduced sustained constriction response (i.e. a faster redilation or recovery period), both of which would enable more light to enter the eye

and potentially lead, at least in part, to the sensation of photosensitivity.[27]

Accommodative response in mild traumatic brain injury versus age matched controls

This study also investigated the accommodative response using Grand Seiko WAM 5500 open field auto refractor, which was found to be significantly reduced in mTBI individuals than the control group ($P < 0.001$). The laboratory-based dynamic testing of accommodation measuring the peak velocity of accommodation played a unique feature in estimating the accommodation dynamics in mTBI. An earlier study conducted by Green *et al*.[25] also measured the dynamic peak velocity in the mTBI population in 12 subjects with age group 18–40 years. They found a relatively reduced accommodative dynamic response in mTBI individuals compared to controls in terms of peak velocity. The study results are consistent to the findings of the present study where the mTBI subjects exhibited slower dynamic accommodation response for a 2.50D stimulus when compared to aged-matched controls. This reduction could be attributed by the fact that the mTBI individuals also exhibited a poor dynamic pupillary constriction velocity, leading to a secondary reduction in dynamic accommodation measurements. We also observed that there was a significant reduction in the accommodative facility testing (both monocular and binocular) in mTBI.

However, the decrease in the dynamic response of accommodation in mTBI subjects might occur due to a combination of a decrease in the burst cells response to a certain stimuli and the results of aphasic cell in shearing the axons present as a consequence of mTBI.[12,28]

Given the broad neural pathways related to accommodationrk, it is possible that a mTBI could impact accommodation related neural locales or their axonal interconnections.[27] These disturbances of accommodation can clinically present as blurred vision, intermittent diplopia, headache and strain, impacting the reading ability of the individuals. Interestingly, the most common issue related to pupillary abnormality, i.e. photosensitivity was reported by a study by Truong and Ciuffreda.,[26] where 67% of the subjects with mTBI experienced photosensitivity; the key objective biomarker being large pupillary diameter present along with increased recovery pupillary period. Surprisingly, in the present study, photosensitivity has not been reported by any of the subjects as a primary complaint, rather noted as secondary issues. This might be because the patients were unaware of the extent and visual effects of the mTBI and considered photosensitivity as one of the preexisting symptom, not affecting their daily activities.[29,30] However, photosensitivity was reported as one of the most common symptom by the mTBI group on PCSS. Although this present study did not emphasized more on the association of symptoms and pupillary dynamics due to the subjective nature of assessing the symptoms, future studies could correlate the persisting symptoms in more objective manner with the variability noted in pupillary dynamics.

Conclusion

This study concludes that pupillary dynamics and accommodative function are impaired in mTBI as compared to age-matched controls. Dynamic measurement of accommodation and pupils in individuals with mTBI could provide insights about the visual disturbances experienced by these subjects following mTBI.

Data availability statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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Nil.

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The authors declare that there are no conflicts of interest in this paper.

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Supplementary Materials

Supplementary Table 1: Normative reference values for diagnosis of nonstrabismic binocular vision anomalies

BV parameters	Normative indian data
NPC-AT-break	3±3
NPC-AT-recovery	4±4
NPC-PLR-break	7±5
NPC-PLR-recovery	10±7
Amplitude of accommodation M/O (diopters)	7–10 years: 13±3 11–17 years: 11±2
Amplitude of accommodation B/O (diopters)	7–10 years: 13±3 11–17 years: 11±3
Near PFV, PD-break	26±10
Near PFV, PD-recovery	21±10
Near NFV, PD-break	15±4
Near NFV, PD-recovery	11±4
Distance PFV, PD-break	17±8
Distance PFV, PD-recovery	12±7
Distance NFV, PD-break	8±2
Distance NFV, PD-recovery	6±2
Accommodative facility M/O (CPM)	7–12 years: 11±4 13–17 years: 14±5
Accommodative facility B/O (CPM)	7–12 years: 10±4 13–17 years: 14±5
Vergence facility (CPM)	7–12 years: 12±4 13–17 years: 14±4
Horizontal Phoria	Distance: 0.02±1 Near: −0.40±2
MEM	0.4±0.2
AC/A	5.4±0.6

AC/A=Accommodative convergence/accommodation ratio, M/O=Monocular, B/O=Binocular, CPM=Cycles per minute, MEM=Monocular estimate method, NFV=Negative fusional vergence, NPC-AT=Near point of convergence with accommodative target, NPC-PLR=Near point of convergence with penlight and red filter, PD=Prism diopters, PFV=Positive fusional vergence