ARTICLE

Prevalence of Oculomotor Dysfunction in Healthy Athletes Preseason: Implications for Concussion in Sport

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ABSTRACT

Background: Measures of oculomotor function are becoming more frequently employed as part of comprehensive concussion assessments. However, performances on many of these oculomotor measures have not been examined in a healthy athletic cohort. The purpose of this study was to characterize performance of university level athletes on a battery of oculomotor tests and identify any potential influence of gender and history of concussion.

Methods: 259 healthy university level athletes (males, n = 150; females, n = 109) completed an oculomotor screening battery prior to the start of their competitive season. The battery assessed stereopsis, visual acuity, monocular amplitude of accommodation, near point of convergence, monocular and binocular accommodative facility, vergence facility, positive and negative fusional vergence, and saccades. Athletes also completed the Convergence Insufficiency Symptom Survey (CISS).

Results: Three oculomotor tests (stereopsis, convergence, saccades) showed significant differences between male and female athletes at $P<0.05$, uncorrected. A high percentage of athletes were identified as having oculomotor deficiencies including abnormal acuity (34.2%), vergence infacility (28.6%), abnormal horizontal saccades (21.7%) and accommodative infacility (18.7%). Convergence insufficiency differed by method of assessment, ranging from 11.0-15.7%.

Conclusion: A significant proportion of healthy athletes displayed abnormal performance across a variety of oculomotor indices. A history of lifetime concussion (i.e., greater than 12 months prior to study) did not significantly influence oculomotor test performance. Clinicians should be aware of such differences and potential implications associated with postconcussion evaluations.

INTRODUCTION

Concussions are a form of mild traumatic brain injury (mTBI) estimated to account for approximately 75% of all traumatic brain injuries (TBI).[1] They are highly prevalent in sports, and the Centers for Disease Control (CDC) estimated that sports or recreation related traumatic brain injuries (TBI) accounted for 207,830 emergency department visits each year between the years 2001 and 2005.[2] In Canada, sports and recreational activities are the third leading cause of TBI hospital admissions.[3] It is estimated that the incidence of concussion is approximately 500 to 600 per 100,000 of the population with about 10-15% of affected patients experiencing symptoms even after 12 months.[4]

Many athletes report a constellation of vision-related symptoms following sport-related concussion.[5] This is not surprising, given that some neuroanatomical publications have indicated that between 40-50% of the primate brain has reciprocal connections to visual or visually-related areas, and therefore is likely to be involved to some extent in concussion-based injuries.[6,7] Many of the vision difficulties reported by concussed individuals are related to impairments in convergence and accommodation, and often include headaches, asthenopia, vision blurring in and out of focus, loss of one's place while reading and copying text from distance to near.[8] Despite the relationship between vision difficulties and symptoms postconcussion, oculomotor assessment is not currently a focus of concussion management protocols.[9] In a recent systematic review of oculomotor-based vision assessment following concussion,[10] the authors concluded that the evidence for the use of these tests following concussions is preliminary at this point, and not sufficient to warrant clinical recommendations for the use of oculomotor assessment following mTBI.

The presence of convergence-related difficulties following concussion has been one of the most commonly documented oculomotor complaints,[8,11-13] with impairments typically being present during the first week following sport-related concussion.[11,12] While normative data has been published for the near point of convergence (NPC) test in the general population,[14] the importance of measuring baseline NPC values for athletes has been emphasized, since previous work has shown the prevalence of convergence insufficiency to be higher among healthy athletes than among the general population.[12] Difficulties related to vergence function among individuals with mTBI have also been assessed by measuring fusional ranges,[8] and vergence facility.[15] Vergence facility describes the ability of the eyes to binocularly converge and diverge in a sequential manner with a fixed demand of accommodation and can be tested at distance and near. Although these tests are not generally included in standardized baseline protocols or postconcussion evaluations, abilities related to vergence have been found to be impaired postconcussion.[8,15]

Accommodation is the monocular process by which innervation to the ciliary body of the eye is changed resulting in contraction or relaxation of the ciliary body in order to adjust focus on objects at varying distances. Tests measuring accommodative ability often include amplitude of accommodation,[8,16] which relates to the minimum distance at which a target can be maintained in clear focus (converted to dioptres by taking the inverse of this distance in metres). Accommodative facility measures the ability to quickly change accommodative function to view a target at various distances (i.e. from distance to near and vice-versa). In essence, amplitude represents the power of the system whereas facility represents the flexibility of the system. In the acute phase of mTBI, accommodative insufficiency (i.e. the power) has been reported to occur among 65% of patients, and may persist for several years following injury.[16]

The 2012 Consensus Statement on Concussion in Sport did not identify measures of oculomotor function as a central focus of concussion diagnosis or management.[9] However, they noted that future research should consider the efficacy of including vision tests such as the King-Devick,[9,12,17-19] which assesses saccadic eye movement. A basic saccadic eye movement is a rapid re-fixation from one point to another. In order to initiate a saccade, the visual system must not only release fixation from the point of regard, but also pre-plan where the next fixation will land, a process that ultimately requires peripheral awareness.[20] Many tests of saccadic function are designed for a clinical setting and require a computer and video-oculography. However, the King-Devick (K-D) test quickly evaluates saccadic eye movement and has shown promise in its ability to diagnose concussion in an athletic setting.[9,12,17-19]

In recent years, there has been a significant increase in research examining the utility of oculomotor tests post-concussion.[10,21-24,46,47] Although promising, the influence of pre-morbid oculomotor dysfunction on post-injury performance or the natural history of oculomotor function throughout clinical recovery is less well-understood. A recent systematic review found that few studies (20%) have assessed and reported oculomotor performance *prior* to injury.[10] Furthermore, it has been shown that reduced function on oculomotor testing (in the realms of vergence and accommodation specifically) is associated with prior concussions in athletes.[25] Since the reference values for normal vs. abnormal scores for vision-related deficits are often based on reference values of the general population, it would be potentially more appropriate to develop normative values specific to a student athlete population. This is particularly important since previous work has demonstrated that professional athletes exhibit superior ability in some oculomotor domains at baseline.[26,27] While it is possible that this finding is specific to athletes at the professional level, further research is required to examine this issue further and to determine whether unique norms are justified for the student athlete population. On the other hand, athletes would likely have greater exposure to repetitive head impacts and history of lifetime concussion compared to the general population. Therefore, the purpose of this study was to characterize performance on a battery of oculomotor measures in a cohort of healthy university level athletes. As part of this process, we examined the proportion of athletes classified as abnormal for each oculomotor test based on adopted cut-off values recommended in the literature. We also examined potential differences between male and female athletes, as well as influence of prior concussions.

METHODS

Participants

Between August and November 2014, 291 healthy inter-university student athletes completed the oculomotor testing battery prior to the start of their competitive season. These athletes were recruited from a single institution and participated in sports that presented an increased risk of concussion, which included basketball, field hockey, football, ice hockey, lacrosse, rugby, soccer, volleyball and wrestling. Eight participants were excluded because habitual eye correction was not worn at the time of testing. Given that our primary objective was to characterize performance among healthy athletes, we also excluded individuals who had sustained a concussion within the last 12-months or who were recovering from a concussion that had occurred greater than 12 months prior to the study (n = 24). A final dataset of 259 athletes was used for analyses (male = 150, female = 109). The study was approved by the Institutional Ethics Review Board (Protocol Reference # 30641).

Data Collection

All athletes completed the oculomotor test battery prior to the start of their competitive season. The battery consisted of eleven tests targeting a range of visual functions, and could be administered in approximately fifteen minutes. All tests were administered in a randomized sequence. For all tests, habitual correction was used by participants when necessary (i.e. reading glasses or contacts). A complete exam was purposely not done, as *habitual status* was desired. This situation is also more reflective of real-life scenarios whereby not all athletes will have up-to-date eye care (i.e. optimal visual acuity for example). Tests were administered by individuals trained by an optometrist with advanced training in diagnosing and treating oculomotor dysfunction (PQ). Following the training period and prior to data collection, all examiners (6 total) had to demonstrate competence under supervision.

Stereopsis

Global (random dot) and local (circles) depth perception were assessed using the Randot Butterfly Stereo Test. Participants were first asked to put on a pair of polarized glasses and identify a butterfly presented in a random dot display in order to establish a baseline depth perception capability (random dot target, global depth perception). Upon successful completion of the first task, participants were presented with a series of nine four-dot displays, and were told to indicate whether the top, bottom, left or right circle appeared slightly raised compared to the other three circles (local stereopsis). Each subsequent four-dot display represented stereopsis values ranging from 800 seconds of arc to 40 seconds of arc, with fewer seconds of arc indicating a smaller separation between two overlapping images. If the random dot target could not be seen, stereopsis testing was still undertaken with the local stereopsis targets and the local stereopsis limit recorded (two in a row incorrect required with latter level recorded as limit). The smaller the separation between the two images, the more difficult it was to perceive elevation of one of the circles. Participants' minimum seconds of arc and time to completion was recorded, with the latter representing "speed of stereopsis".

Visual Acuity

Monocular visual acuity was assessed using a standardized Snellen eye chart with more than half of the line required to give credit for the line of acuity. The limit of visual acuity on this chart was 20/10 (6/3) acuity.

Monocular Amplitude of Accommodation

Monocular amplitude of accommodation was calculated using the push-up method.[28] In this test, a "budgie-stick" with printed letters (equivalent to approximately 20/30 at 40cm) was held forty centimetres in front of the face. The budgie stick was gradually moved towards the face, and the minimum distance at which the participant was able to maintain a clear and focused view of the letters was recorded. This distance was measured three times with the last measure being taken for each eye. The corresponding amplitude of accommodation, expressed in diopters, was calculated by dividing this distance in cm into 100. As a reference, the expected minimum amplitude of accommodation for a given age was calculated according to Hofstetter's formula: 15 – 0.25 x age.[29]

Near Point of Convergence (NPC)

To measure the near point of convergence, the subject was instructed to use both eyes to focus on an accommodative target (i.e. a pen tip) as it was moved towards them. The distance at which the subject reported seeing double was recorded. In the event that the subject did not report seeing double, the point where one of the eyes was observed to turn outwards was recorded (i.e. if the patient suppressed one eye). The near point of convergence was calculated as the average of three trials, as has been recommended previously.[14]

Monocular / Binocular Accommodative Facility (MAF / BAF)

For the monocular accommodative facility test, a ± 2DS flipper lens were used to assess one eye at a time, while the other eye was covered. A budgie stick with printed letters (equivalent to 20/30) was held in place approximately forty centimetres from the face. The examiner held the plus lens over the participant's eye, and the participant was instructed to indicate when the text on the card was clear. This was the examiner's cue to flip to the minus lens. The number of cycles completed in one minute (cpm) was recorded for each eye. In the binocular accommodative facility test, the lenses were placed over both eyes at once, and the same procedure followed. Normal values of 10 and 11 cpm (SD = 5.0) have been identified for monocular and binocular accommodative facility, respectively.[30] In testing MAF data, the fellow eye is observed (under the cover) to ensure that movement occurred (inward for minus lenses and outward for plus lenses) to ensure that the patient's own response was not the only response depended on. In addition, pupil sizes were monitored as when minus lenses are cleared (i.e., positive relative accommodation) pupil size decreases, and conversely, when plus lenses are cleared (i.e., negative relative accommodation) pupil size increases. In testing BAF data, the examiners monitored the participants' eyes to ensure convergence and divergence occurred with both positive and negative relative accommodation.

Vergence Facility

This was measured with a 12 base-out / 3 base-in prism flipper, which was positioned over one eye (right eye) with both eyes open during testing. The subject fixated on the tip of a pen at near (40cm), which would initially appear as two images due to the effect of the prism. The subject indicated when they had fused the image and the examiner accordingly changed the flipper position from 12 prism diopters base out to 3 prism diopters base in. The examiner continued to rotate between the two prisms as cued by subject with the eyes also being used as objective confirmation of movement (as suppression can occur and no diplopia be perceived for example). The number of cycles completed in one minute was recorded with general normative values being 16cpm (SD = 2.6) using 12BO/3BI.[31]

Convergence Amplitude (a.k.a. Positive Fusional Vergences or PFV function)

Convergence Amplitude (measured as base-out prism to break and base-out prism to recovery) is also known as positive fusional vergence (PFV). Convergent "step vergence" was determined at near (40 cm) using a prism bar in free space and a pen tip as a target. The "break point" was the prism value at which the subject saw double and could not re-fuse, and the "recovery" was the prism value at which the pen tip could be re-fused. If participants were able to fuse the full range of positive step vergences without break (including the maximum value of 45), a value of >45 was recorded as the break point and recovery point.

Divergence Amplitude (a.k.a. Negative Fusional Vergence or NFV)

Divergence amplitude, measured as base-in break and base-in recovery, is also known as negative fusional vergence (NFV). Divergent "step vergence" was determined at near using a prism bar in free space and a pen tip as a target. The "break point" was the prism value at which the subject saw double and could not re-fuse and the "recovery point" was the prism value at which the pen tip could be refused. If participants were able to fuse the full range of negative step vergences without break (including the maximum value of 45), a value of >45 was recorded as the break point and recovery point.

Developmental Eye Movement (DEM) Test

This is a standardized oculomotor skills test, which measures the speed at which subjects can recognize and verbally identify a series of numbers.[32] The first two subtests of the DEM involve reading an array of numbers vertically, while the third subtest

Table 1. Descriptions of criteria used to identify abnormal or clinically significant scores.

Condition	Criteria for abnormal score
Convergence Insufficiency	NPC > 6 cm[12] CISS score > 20[35]
Accommodative Insufficiency	Amplitude of Accommodation for at least one eye > 2D below age-related expected minimum value, based on Hofstetter's formula: [15-(0.25*age)][29]
Accommodative Infacility	MAF < 6cpm in at least one eye or BAF < 3 cpm (1 SD below mean reported in[30])
Vergence Infacility	< 13 CPM (1 SD below mean reported in[31]
Fusional Vergence Dysfunction (+ve) Fusional Vergence Dysfunction (-ve)	Break point < 10 or Recovery point < 7 (1 SD below mean reported in[36]) Break point < 7 or Recovery point < 5 (1 SD below mean reported in[36])
Abnormal Vertical Saccades	> 31.58 seconds (1 SD below mean obtained from preliminary young adult norms for DEM scores)[37]
Abnormal Horizontal Saccades	> 33.63 seconds (1 SD below mean obtained from preliminary young adult norms for DEM scores)[37]
Abnormal Acuity	Poorer than 20/20
Abnormal Stereopsis	> 40 seconds of arc[38]

involves reading horizontally, and is an analog of the King-Devick test. All sub-tests were timed to the nearest hundredth of a second, and the score of the horizontal sub-test was adjusted to account for subject errors (i.e. errors of addition, omission, substitution and transposition). The primary outcome variables included vertical saccade time in seconds and horizontal saccade time in seconds. While a ratio of vertical and horizontal saccades is often used as the primary outcome variable for the DEM, we opted to interpret vertical and horizontal saccades separately. From a clinical standpoint, we feel that discrepancies between vertical and horizontal saccades are more accurately captured by comparing the percentile ranks of the two, rather than using a ratio.

Table 2. Demographic characteristics.

	All	Male	Female
N		150	109
Age (years)	21.1 ± 2.2	21.4 ± 2.1	20.8 ± 2.5
History of concussion (%)	57.0	57.4	42.6

Convergence Insufficiency Symptom Survey (CISS)

This is a validated questionnaire that contains 15 questions addressing problems related to convergence impairments (e.g. "Do your eyes feel tired when reading or doing close work?"). Subjects rated agreement with each of the fifteen statements on a 5-point Likert scale (0 = never, 4 = always), for a maximum possible score of 60.[33]

Statistical Analysis

Descriptive statistics were calculated for all vision tests, with mean, standard deviation, 50th percentile, and cut-offs for the lowest 25th and 10th percentiles. Non-parametric Mann-Whitney U tests were conducted to identify differences in oculomotor scores associated with gender and history of concussion. For the current study, we report both the uncorrected p-values and the false-discovery rate (FDR) adjusted p-values, which correct for multiple comparisons as described in Yekuteli & Benjamini.[34]

We also calculated the proportion of athletes classified as abnormal for each oculomotor test based on adopted cut-off values recommended in the literature. The criteria used to identify abnormal scores are provided in table 1. Chi-square test of goodness-of-fit were employed to identify if the proportion of athletes with abnormal vision tests differed according to the presence or absence of a previous concussion; this test was performed separately on male and female athletes. Statistical significance in all analyses was indicated by a p-value of ≤0.05. All

Table 3. Summary of oculomotor test performance.

Oculomotor Test	All Athletes (n = 259) Mean ± SD (50th, 75th, 90th)	Males (n = 150) Mean ± SD (50th, 75th, 90th)	Females (n = 109) Mean ± SD (50th, 75th, 90th)	Unadjusted P value	Adjusted P value
NPC	3.7 ± 1.4 (3.5, 4.5, 5.7)	3.9 ± 1.5 (3.7, 4.7, 6)	3.5 ± 1.2 (3.3. 4.2, 5.2)	0.072	0.180
Stereo Arc[ac]	-- (40, 50, 100)	-- (40, 50,100)	-- (40, 50, 60)	0.012	0.120
Stereo Speed	15.1 ± 6.2 (14.0, 18.3, 24.5)	16.0 ± 6.0 (15, 21, 25)	14.2 ± 6.2 (12.7, 16.9, 22.5)	0.003	0.060
Acuity Right[ab]	20/20 ± 1.3 (20/20, 20/20, 20/25)	20/20 ± 1.4 (20/20, 20/20, 20/30)	20/20 ± 1.2 (20/20, 20/20, 20/25)	0.473	0.676
Acuity Left[ab]	20/20 ± 1.3 (20/20, 20/20, 20/25)	20/20 ± 1.3 (20/20, 20/20, 20/25)	20/20 ± 1.2 (20/20, 20/20, 20/25)	0.785	0.907
A of A Right	17.6 ± 4.6 (16.7, 20.0, 25.0)	17.7 ± 4.3 (16.7, 20, 23.8)	17.4 ± 5.0 (16.7, 20, 25)	0.519	0.692
A of A Left	17.6 ± 4.9 (16.7, 20.0, 25.0)	17.2 ± 4.8 (16.7, 20, 25)	18.1 ± 5.0 (16.7, 20, 25)	0.292	0.531
MAF Right[a]	14.7 ± 7.0 (15.0, 10.0, 5.0)	13.6 ± 7.4 (14, 9, 3.5)	15.7 ± 6.4 (17, 12, 6.5)	0.058	0.180
MAF Left[a]	15.3 ± 7.0 (16.0, 11.0, 6.0)	15.3 ± 7.3 (15.5, 11, 6)	15.2 ± 6.8 (16.3, 12, 6)	0.816	0.907
BAF CPM[a]	13.4 ± 5.5 (14.0, 10.0, 6.0)	13.4 ± 5.7 (13, 10, 5.5)	13.4 ± 5.2 (14, 11, 6)	0.943	0.979
Vergence Facility[a]	16.1 ± 6.8 (17.0, 12.0, 6.0)	15.6 ± 6.9 (16, 12, 6)	16.6 ± 6.5 (18, 12, 6)	0.192	0.384
Base Out Break[ac]	-- (40.0, 30.0, 25.0)	-- (35.0, 30.0, 25.0)	-- (40.0, 35.0, 25.0))	0.032	0.160
Base Out Recovery[ac]	-- (30.0, 25.0, 20.0)	-- (30.0, 25.0, 20.0)	-- (35.0, 25.0, 20.0)	0.051	0.180
Base In Break[ac]	-- (14.0, 12.0, 10.0)	-- (14.0, 12.0, 10.0)	-- (14.0, 12.0, 10.0)	0.735	0.907
Base In Recovery[ac]	-- (12.0, 8.0, 6.0)	-- (12.0, 8.0, 6.0)	-- (10.0, 8.0, 6.0)	0.373	0.622
CISS Total	12.5 ± 7.6 (11.0, 16.0, 23.0)	13.2 ± 8.1 (12, 17, 25)	11.6 ± 6.9 (11, 16, 22)	0.068	0.180
DEM Vertical	26.3 ± 3.7 (25.9, 28.9, 31.4)	26.7 ± 4.0 (26.2, 29.7, 32.7)	25.7 ± 3.2 (25.5, 27.8, 30.3)	0.100	0.222
DEM Horizontal	29.4 ± 5.3 (28.3, 32.5, 36.6)	29.6 ± 5.6 (28.3, 32.4, 38.2)	29.3 ± 5.0 (28.4, 32.7, 35.5)	0.979	0.979
DEM Ratio	1.1 ± 0.2 (1.1, 1.2, 1.3)	1.1 ± 0.2 (1.1, 1.2, 1.2)	1.1 ± 0.1 (1.1, 1.2, 1.3)	0.031	0.160

[a] Reverse scoring – meaning higher values = better performance; [b] Standard deviation value refer to lines on a Snellen chart; [c] No means reported as variables are categorical

statistics were completed using Stata Version 14.1 (StataCorp, TX, USA).

RESULTS

Of the 259 student athletes, the mean age was 21.1 years (SD = 2.3; range 18-33) with no significant difference in age between male and female athletes (difference, -0.47 [95% CI, −1.00 to 0.08]; P = 0.09). For athletes with a lifetime history (i.e. not within last 12 months with continuous play within last 12 months) of concussion, the distribution was equal between male and females (X^2 = 0.97, P = 0.32). See table 2 for a summary of demographic characteristics. Our sample consisted of athletes participating in basketball (n = 21), football (n = 55), field hockey (n = 14), ice hockey (n =40), lacrosse (n = 42), rugby (n =18), soccer (n = 36), volleyball (n = 29), and wrestling (n = 4).

Table 3 summarizes group averages of oculomotor performance for the various tests, as well as cut-values for the lowest 25th and 10th percentiles. Mann-Whitney U tests identified significant differences between male and female athletes on three oculomotor tests (stereopsis, vergence amplitude, and saccades), however, no tests attained significance after adjusting for multiple comparisons (table 3). Furthermore, after adjusting for multiple comparisons, no significant differences were observed in those with a lifetime history of concussion compared with athletes with no history of concussion. However, uncorrected p-values noted significantly higher CISS symptom scores in athletes with a lifetime history of concussion and poorer fusional vergence (by lower base out break scores) in male athletes with history of

Table 4. Proportion of athletes with abnormal or clinically significant oculomotor test scores.

Condition	% Abnormal (N=259)	% Males (N=150)	% Females (N=109)
Convergence Insufficiency NPC > 6 cm CISS score > 20	 11.0 15.7	 14.2 18.1	 10.4 14.6
Accommodative Insufficiency	1.4	1.0	1.9
Accommodative Infacility	18.7	20.9	15.6
Vergence Infacility	28.6	31.2	25.4
Fusional Vergence Dysfunction (+ve)	3.1	4.3	1.7
Fusional Vergence Dysfunction (-ve)	9.7	12.9	5.9
Abnormal Vertical Saccades	9.7	14.1	4.3
Abnormal Horizontal Saccades	21.7	22.5	20.7
Abnormal Acuity	34.2	38.1	29.0
Abnormal Stereopsis	9.1	12.6	6.7

* sample sizes may vary between tests.

concussion compared to male athletes with no history of concussion.

When basic monocular visual acuity levels of the 259 athletes were examined, 34.2% of athletes did not have 20/20 acuity in *at least* one eye. Table 4 provides the proportions of athletes with abnormal or clinically significant test scores based on established norms and cutoffs. 11% (using 6cm NPC cut point) were classified as having convergence insufficiency based on NPC results. When a CISS score of > 20 was applied as determining convergence insufficiency, 15.7% of the athletes were classified as abnormal. Apart from visual acuity, the most common oculomotor deficiencies were vergence infacility (28.6%), abnormal horizontal saccades (21.7%), and accommodative infacility (18.7%). Given the differences we observed between group averages of male and female athletes, we examined whether the proportion of abnormal test results were significantly different between genders. Vergence infacility was identified more frequently in male athletes compared to females (P = 0.02) and convergence insufficiency by NPC result trended toward significance in males (table 3); however, no significant difference was found when corrected for multiple comparisons. Finally, we investigated proportion differences for each gender and the relationship with lifetime history of concussion; no significant differences were observed.

It was decided at the onset of the study not to correct participants who did not wear habitual ophthalmic correction. However, a significant proportion of athletes (n = 85) did not have 20/20 visual acuity in at least one eye. We speculated that reduced visual acuity may have been due to simple uncorrected refractive error. Thus, we conducted a follow-up analysis to examine whether reduced acuity was playing a major role in the relatively high proportion of abnormal oculomotor findings. Within the group that did not have 20/20 in one eye, we identified significantly decreased stereopsis level (uncorrected P = 0.041, FDR = 0.369) and speed of stereopsis (uncorrected P < 0.001, FDR = 0.018). Also, when a more stringent threshold was applied (20/30 or worse in at least one eye), these athletes (n = 35) displayed reduction in stereopsis level (uncorrected P < 0.001, FDR = 0.009), base in break (NFV) (uncorrected P = 0.016, FDR = 0.096), base-in recovery (NFV) (uncorrected P = 0.009, FDR = 0.081), and lower values in amplitude of accommodation in at least one eye (uncorrected P = 0.022, FDR = 0.099).

DISCUSSION

The objective of this study was to characterize the performance of healthy athletes on a variety of oculomotor tests beyond simple visual acuity, with particular interest in identifying variation in performance related to gender and concussion history (more than 12 months out with the athlete still actively playing). Our results highlight that a significant proportion of athletes displayed abnormal oculomotor function across a variety of indices. In addition, a lifetime history of concussion did not significantly influence oculomotor test performance, although we observed trends of gender-related differences, with females generally performing better than males.

We used near point of convergence as an objective measure to assess the prevalence of convergence insufficiency (CI), employing a conservative cut-off of 6cm. Using this criterion, 11% of the athlete cohort were considered to display CI, which is higher than the prevalence rates previously reported in university level students (3%)[39] and in the general population (5%).[14] Our present results are more comparable with a recent study of youth hockey players (11.5%), which employed the same cut-score of greater than 6cm.[12] Near point of convergence has also been utilized more frequently in post-concussion assessments and recently reported in approximately 42% of cases at the 1-month stage post-sports related concussion.[5,40] Furthermore, exposure to a competitive season in collision sports also appears to impact NPC scores as a recent study has shown that the repeated heading of a football alone can result in a convergence issue being induced.[41]

In addition to near point of convergence, the CISS symptom score was also used to detect convergence-related difficulties. This tool has been identified as a valid and reliable instrument for the measurement of convergence-related symptoms.[35] We employed the recommended cut-off score of >20, and found that over 15% of all athletes reported significantly symptomatology. While only 11% met the CI definition according to our criteria of 6cm, it has previously been shown that the CISS scores are associated with symptomatology in non-CI cases such as in accommodative dysfunction[42] or vergence facility dysfunction,[43] for example. Given that CI in particular appears to be a common finding post-concussion,[8,11-13] the relationship between symptom reports and objective NPC findings needs to be examined in more detail prior to concussion as it is possible that post-concussive symptomatology may be exacerbated in subjects with abnormal NPC findings and / or higher CISS symptom scores. It should be noted that while we defined convergence insufficiency using an NPC cut-point of 6cm, this is not the only method by which it can be defined. Previous work has employed a multi-criterion approach to the diagnosis of CI, and has relied on a combination of three criteria (i.e., exophoria at near > or = 4 delta than at far; insufficient fusional convergence; and receded NPC of > or = 7.5 cm break or > or = 10.5 cm recovery) to diagnose definite CI.[44]

Our group mean for vergence facility cycles completed per minute was 16.1 cycles, with a standard deviation of 6.8. This value is slightly lower than the normative value previously established for an athletic population.[45] However, the previous study used a near-far test of vergence facility (i.e., Haynes Distance Rock Test), which assesses concurrent changes in vergence and accommodation, rather than vergence facility, which includes variable vergence demand with fixed accommodative effort. We also found vergence infacility to be present in 28.6% of our study sample, which is important to note because vergence infacility has been found to be a very sensitive predictor of overall oculomotor dysfunction and reading performance,[38] with abnormal reading and tracking being common complaints post-concussion. However, little research on vergence facility at near has been done among young adults and athletes with little information on how it relates to concussion. Vergence facility testing measures the ability of the visual system to move the eyes from a converged (inward) position to a diverged (outward) position quickly and efficiently at a fixed plane (i.e. fixed accommodative effort), which can be done at distance or near. Vergence facility is essentially a reflection of the "flexibility" or "degrees of freedom" of the vergence system. Performance on this test has been found to be highly correlated with reading efficiency (using infrared eye tracking methods), therefore appearing to be a logical oculomotor test to utilize as an indicator of reading efficiency,[38] an issue which is often reported post-concussion.[8,38,46] We observed the proportion of athletes with vergence infacility to be substantially higher than the percentage of athletes with convergence insufficiency. Given the natural link between near-distance visual system "flexibility" which is important in sports, vergence facility testing likely represents a more sensitive "litmus test" for rapidly identifying the presence of overall oculomotor dysfunction, and particularly when tested at distance.[47] Accordingly, patients with convergence insufficiency would be likely to fail vergence facility testing at near and vergence facility testing at distance.[48] Our findings provide justification for examining vergence infacility in this population in future studies; also, they prompt the evaluation of vergence facility testing at distance,[47] as this removes the confounder of accommodation at near, which can sometimes mask vergence dysfunction (as the accommodation system can "kick in" to compensate for the vergence deficit at near).

We identified higher rates of negative fusional vergence dysfunction (9.7%) compared to positive fusional vergence dysfunction (3.1%). One possible explanation for observed differences in percentages between negative and positive fusional dysfunction is that our study sample consisted of individuals who do a lot of close work as full-time students (i.e., reading and studying) and being highly connected (i.e., handheld mobile devices, social media). Therefore, they are presumably good at near work and would be expected to have relatively low amounts of positive fusional deficits. It should be noted that we opted to record the break and recovery point and not include blur points (which is a limitation in the study) as we were interested in where the oculomotor system broke into diplopia rather than where it was "stressed". It is quite possible that the results may have shown a higher level of dysfunction had we looked at the blur point also. However, as this study was conducted in a sports medicine environment, the cut-off of diplopia was selected, since it can be both reported by the subject and reliably observed by the examiner (i.e., seeing the eyes deviate).

The prevalence of accommodative infacility in the general population is not well reported. Hennessey, Iosue and Rouse[49] assessed monocular and binocular facility in an asymptomatic sample of children and reported rates of 20% and 10% for binocular and monocular accommodative infacility, respectively. Although these previously reported rates were determined in a younger sample, the rates of accommodative infacility are in line with the 18.7% prevalence identified in our sample.

High rates of abnormal horizontal saccades were also identified within our sample (21.7%). Saccadic eye movement has been of particular interest in recent years in concussion assessment, with the increasing use of the King-Devick (K-D) test, which has been well validated as a sensitive sideline performance measure for concussion detection.[17,18] It is not surprising that saccades (a test of saccadic function which involves fixation and peripheral awareness, weighing aspects of the stimulus, the goal of the eye movement, motor planning and organization, and motivation) would be prone to malfunction from neurological trauma more readily than other eye movement types. It is however unclear as to the reasoning for the high percentage of abnormal saccades at baseline. One potential explanation could be the fact that DEM performance does not solely depend on saccades, and proficiency in other skills such as language speed, attention and visual processing speed are required. We did not observe proportional differences in those with a lifetime of history of concussion, however, we cannot rule out any remnant effects of repetitive head impacts associated with many sports or whether this incidence is truly this high in a non-professional level athletic cohort. Such association is aligned with studies showing that repetitive low-level impacts can be enough to even induce a convergence insufficiency,[41] therefore potentially cumulative smaller hits may explain this result.

Collectively, results from the present study highlight the significant proportion of healthy, active athletes with what appear to be undiagnosed oculomotor-related abnormalities in addition to simple acuity issues (likely refractive in nature). This is particularly relevant in the context of post-concussion evaluations, as clinical vision assessments have become more frequent due to the constellation of visual problems secondary to sports-related concussions.[46] It is largely assumed that post-injury oculomotor abnormalities are most likely directly due to the concussive insult. Although this may be true to some extent, given the high proportion of oculomotor and basic visual acuity issues among athletes in this study, pre-morbid oculomotor dysfunction must be controlled for as a variable. Therefore, knowledge of an athlete's premorbid oculomotor status would likely be substantially beneficial in the context of a postconcussion evaluation. An optimal environment for concussion assessment and management has been recommended to include pre-season evaluations, although this is not always possible due to logistical challenges and resources. However, based on this paper, it is likely warranted to screen for individuals that may benefit from a comprehensive eye examination by a qualified eye care professional, in addition to a visual skills assessment looking in more detail at oculomotor function.

Including an oculomotor assessment as part of concussion baseline assessments would also allow for an opportunity to investigate the relationship between various oculomotor deficits and neuropsychological test (e.g., ImPACT) scores. Previous research has identified an association between oculomotor test scores and ImPACT scores post-concussion,[5,12,19] and thus it is logical to question how much the issue of oculomotor dysfunction at baseline affects performance on neuropsychological assessments.

Another possible explanation for the high proportion of athletes with oculomotor dysfunction at baseline may be that the previously available cut-points in the literature are not appropriate for a university level athletic population. Therefore, the development of normative data for athletic populations is warranted. Drawing from the field of neuropsychology, it has also been highlighted that comparing an individual's performance to some population average score is appropriate only when the score is uniformly present in all individuals and when performance is not related to age, gender, race, or education.[50] Significant differences were observed between male and female athletes on a number of measures; this result being unexpected, as gender differences have rarely been reported. Therefore, the development of group averages stratified by gender (table 3), as well as cut-values (lowest 25th and 10th percentiles) for a battery of oculomotor tests would be an appropriate reference for normative data of university level student athletes in the future.

There are some limitations resulting from our study design that may potentially impact interpretation of results. First, our findings suggest that a lifetime history of concussion – beyond 12 months from testing – does not significantly impact oculomotor test performance in this population. Despite no observed differences, we acknowledge the limitations of recall bias associated with self-reported history of concussion and the potential tendency of some athletes to under-report concussions.[51-53] We were also unable to account for potential inter- and intraexaminer variability. Data collection was part of a larger pre-season medical evaluation strategy; however, previous reports have identified high inter-examiner coefficients for a number of the oculomotor tests.[44] Also, prior research utilizing more sophisticated measures (using infra-red tracking) identified poor reading performance in conjunction with oculomotor dysfunction being associated with a 10.72x increased likelihood of having previous suffered a concussion.[25] However, we omitted athletes with a history of concussion in the prior 12 months (or who had not been cleared following a concussion occurring > 12 months prior) so that our sample would be more likely to be a true representation of the healthy general athletic population, as residual effects of a recent concussion could not be ruled out. Second, although a relatively large proportion of the sample (34.2%) did not have 20/20 visual acuity in at least one eye, the nature of the underlying refractive error is important to discuss. If myopic or astigmatic in origin, then the effect on near point tasks is much less than if hyperopic in origin.[38,54] However, especially in a younger population, hyperopic refractive error rarely reduces distance visual acuity and therefore will typically reveal a "20/20" result in an eye examination (assuming no accommodative dysfunction present). Although not the aim of this paper, a refractive error assessment (including cycloplegic to relax accommodation) to determine accurately the underlying full refractive error may help to clarify how much this confounder is contributing to the relatively high amount of oculomotor dysfunction identified in this baseline athletic group. Our follow-up analyses of individuals with less than 20/20 suggests that reduced visual acuity impacts performance on a number of measures. Thus, proper correction should ideally be sought prior to formal baseline testing.

CONCLUSION

In conclusion, a significant proportion of healthy athletes displayed difficulties on a number of oculomotor measures during pre-season evaluations. Evaluation of oculomotor issues (i.e. not just simple visual acuity) in a comprehensive concussion model appears to be a useful tool in overall rehabilitation management and is in line with recently published multi-disciplinary guidelines (i.e. section 10.10).[55] Untreated persistent visual issues are likely important to recognize as a significant barrier to overall recovery post-concussion. Our findings highlight the need for an understanding of athletes' oculomotor status prior to concussion, particularly since pre-existing oculomotor dysfunction was not uncommon in our sample. Knowledge of preinjury oculomotor status of an athlete would: (i) screen for those that may benefit from a comprehensive eye examination (and where appropriate addressing significant oculomotor issues) by a qualified eyecare professional, and (ii) provide information about changes in oculomotor function in context to baseline data should a subsequent concussion occur.

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Conflict of Interests

None of the authors have a conflict of interest or financial disclosure to report.

REFERENCES

1. Centers for Disease Control and Prevention (CDC), National Center for Injury Prevention and Control. Report to Congress on mild traumatic brain injury in the United States: steps to prevent a serious public health problem. Atlanta (GA): Centers for Disease Control and Prevention; 2003.
2. Centers for Disease Control and Prevention. Nonfatal traumatic brain injuries related to sports and recreation activities among persons aged ≤19 years — United States, 2001–2009. MMWR 2011; 60(39):1337–1342.
3. Canadian Institute for Health Information. Head injuries in Canada: A decade of change (1994-1995 to 2003-2004). 2006.
4. Iverson GL. Outcome from mild traumatic brain injury. Curr Opinin Psychiatry 2005;18:301-317.
5. Master CL, Scheiman M, Gallaway M, Goodman A, Robinson RL, Master SR, Grady MF. Vision diagnoses are common after concussion in adolescents. Clin Pediatr 2016; 55:260-267.
6. Felleman DJ, Van Essen DC. Distributed hierarchical processing in the primate cerebral cortex. Cereb Cortex 1991;1:1–47.
7. Ventura RE, Balcer LJ, Galetta SL. The neuro-ophthalmology of head trauma. Lancet Neurol 2014;13:1006-1016.
8. Capó-Aponte JE, Urosevich TG, Temme LA, Tarbett AK, Sanghera NK. Visual dysfunctions and symptoms during the subacute stage of blast-induced mild traumatic brain injury. Mil Med 2012;177:804–813.
9. McCrory P, Meeuwisse WH, Aubry M, Cantu B, Dvorak J, Echemendia RJ, Engebretsen L, Johnston K, Kutcher JS, Raftery M, Sills A. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. Br J Sports Med 2013;47:250-258.
10. Hunt AW, Mah K, Reed N, Engel L, Keightley M. Oculomotor-based vision assessment in mild traumatic brain injury: a systematic review. J Head Trauma Rehabil 2016;31:252-261.
11. Mucha A, Collins MW, Elbin RJ, Furman JM, Troutman-Enseki C, DeWolf RM, et al. A brief vestibular/ocular motor screening (VOMS) assessment to evaluate concussions: preliminary findings. Am J Sports Med 2014;42:2479–2486.
12. Vernau BT, Grady MF, Goodman A, Wiebe DJ, Basta L, Park Y, et al. Oculomotor and neurocognitive assessment of youth ice hockey players: Baseline associations and observations after concussion. Dev Neuropsychol 2015;40:7–11.
13. Ventura RE, Jancuska JM, Balcer LJ, Galetta SL. Diagnostic tests for concussion: Is vision part of the puzzle? J Neuroopthalmol 2015;35:73–81.
14. Scheiman M, Gallaway M, Frantz KA, Peters RJ, Hatch S, Cuff M, et al. Nearpoint of convergence: test procedure, target selection, and normative data. Optom Vis Sci 2003;80:214–25.
15. Szymanowicz D, Thiagarajan P, Ludlam DP, Green W, Kapoor N. Vergence in mild traumatic brain injury: a pilot study. J Rehabil Res Dev 2012;49:1083-1100.
16. Green W, Ciuffreda KJ, Thiagarajan P, Szymanowicz D, Ludlam DP, Kapoor N. Static and dynamic aspects of accommodation in mild traumatic brain injury: a review. Optometry 2010;81:129–36.
17. King D, Brughelli M, Hume P, Gissane C. Concussions in amateur rugby union identified with the use of a rapid visual screening tool. J Neurol Sci 2013;326:59–63.
18. Tjarks BJ, Dorman JC, Valentine VD, Munce TA. Comparison and utility of King-Devick and ImPACT® composite scores in adolescent concussion patients. J Neurol Sci 2013;334:148-153.
19. Galetta KM, Brandes LE, Maki K, Dziemianowicz MS, Laudano E, Allen M, et al. The King–Devick test and sports-related concussion: Study of a rapid visual screening tool in a collegiate cohort. J Neurol Sci 2011;309:34–39
20. Termsarasab P, Thammongkolchai T, Rucker JC, Frucht SJ. The diagnostic value of saccades in movement disorder patients: a practical guide and review. J Clin Mov Disord 2015;2:14.
21. Collins MW, Kontos AP, Reynolds E, Murawski CD, Fu FH. A comprehensive, targeted approach to the clinical care of athletes following sport-related concussion. Knee Surg Sports Traumatol Arthrosc 2014;22:235-246
22. Ellis MJ, Leddy JJ, Willer B. Physiological, vestibulo-ocular and cervicogenic postconcussion disorders: An evidence-based classification system with directions for treatment. Brain Inj 2015;29:238-248.
23. Ciuffreda KJ, Ludlam DP, Yadav NK, Thiagarajan P. Traumatic Brain Injury: Visual consequences, diagnosis, and treatment. Adv Ophthalmol Optom 2016;1:307-333.
24. Gallaway M, Scheiman M, & Mitchell GL. Vision therapy for post-concussion vision disorders. Optom Vis Sci 2017;94:68-73.
25. Poltavski DV, Biberdorf D. Screening for lifetime concussion in athletes: Importance of oculomotor measures. Brain Inj 2014;28:475–485.
26. Christenson GN, Winkelstein, AM. Visual skills of athletes versus nonathletes: Development of a sports vision testing battery. J Am Optom Assoc 1988;59:666-675.
27. Hughes PK, Blundell NL, Walters JM. Visual and psychomotor performance of elite, intermediate and novice table tennis competitors. Clin Exp Optom 1993; 76(2):51-60.
28. Koslowe K, Glassman T. Accommodative amplitude determination: Pull-away versus push-up method. Optom Vis Dev 2010;41:28.
29. Hofstetter HW. Useful age-amplitude formula. Optom World 1950;38:42-45.
30. Scheiman M, Wick B. Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders. Lippincott Williams & Wilkins, 2014.
31. Gall R, Wick B, Bedell H. Vergence facility: Establishing clinical utility. Optom Vis Sci 1998;75:731-742.

32. Orlansky G, Hopkins KB, Mitchell GL, Huang K, Frazier M, Heyman C, et al. Reliability of the Developmental Eye Movement Test. Optom Vis Sci 2011;88:1507-1519.

33. The Convergence Insufficiency Treatment Trial (CITT) Study Group. The Convergence Insufficiency Treatment Trial: Design, Methods, and Baseline Data. Ophthalmic Epidemiol 2009;15:24–36.

34. Yekutieli D, Benjamini Y. Resampling-based false discovery rate controlling multiple test procedures for correlated test statistics. J Stat Plan Inference 1999;82:171–96.

35. Rouse MW, Borsting EJ, Mitchell GL, Scheiman M, Cotter SA, Cooper J, et al. Validity and reliability of the revised convergence insufficiency symptom survey in adults. Ophthalmic Physiol Opt 2004;24:384–390.

36. Wesson MD. Normalization of prism bar vergences. Am J Optom Physiol Opt 1982;59:628–634.

37. Powell JM, Birk K, Cummings EH, Ciol MA. The need for adult norms on the Developmental Eye Movement test. J Behav Optom 2005;16:38–41.

38. Quaid P, Simpson T. Association between reading speed, cycloplegic refractive error, and oculomotor function in reading disabled children versus controls. Graefes Arch Clin Exp Ophthalmol 2013;251:169–87.

39. Porcar E, Martinez-Palomera A. Prevalence of general binocular dysfunctions in a population of university students. Optom Vis Sci 1997;74:111–113.

40. Pearce KL, Sufrinko A, Lau BC, Henry L, Collins MW, Kontos AP. Near point of convergence after a sport-related concussion: Measurement reliability and relationship to neurocognitive impairment and symptoms. Am J Sports Med 2015;43:3055–3061.

41. Kawata K, Rubin LH, Lee JH, Sim T, Takahagi M, Szwanki V, et al. Association of football subconcussive head impacts with ocular near point of convergence. JAMA Ophthalmol 2016;134:763-769.

42. Momeni-Moghaddam H, Goss DA, Sobhani M. Accommodative response under monocular and binocular conditions as a function of phoria in symptomatic and asymptomatic subjects. Clin Exp Optom 2014;97:36-42.

43. Kapoula Z, Morize A, Daniel F, Jonqua F, Orssaud C, Bremond-Gignac D. Objective evaluation of vergence disorders and a research-based novel method for vergence rehabilitation. Transl Vis Sci Technol 2016;5:8.

44. Rouse MW, Borsting E, Deland PN. Reliability of binocular vision measurements used in the classification of convergence insufficiency. Optom Vis Sci 2002;79:254-264.

45. Coffey B, Reichow AW. Optometric evaluation of the elite athlete. Problems in Optometry 1990;2(1):32-59.

46. Tannen B, Darner R, Ciuffreda KJ, Shelley-Tremblay J, Rogers J. Vision and reading deficits in post-concussion patients: A retrospective analysis. Vision Development and Rehabilitation 2015;3:206-213.

47. Tannen B, Ciuffreda KJ, Lyon E, Shelley-Tremblay J. Distance horizontal fusional facility (DFF): A proposed new diagnostic test for concussion patients. Vision Development and Rehabilitation 2016;3:170-175.

48. Trieu LH, Das S, Myung J, Hatch S, Scheiman M. The value of vergence facility testing for the diagnosis of convergence insufficiency. Poster presented at: Annual Meeting of the American Academy of Ophthalmology; 2016 Oct 15-18; Chicago, IL.

49. Hennessey D, Iosue RA, Rouse MW. Relation of symptoms to accommodative infacility of school-aged children. Am J Optom Physiol Opt 1984;61:177–183.

50. Lezak MD, Howieson DB, Bigler ED, Tranel D. Neuropsychological Assessment. Oxford University Press; 2012.

51. McCrea M, Hammeke T, Olsen G, Leo P, Guskiewicz K. Unreported concussion in high school football players: Implications for prevention. Clin J Sport Med 2004;14:13-17.

52. Kaut KP, DePompei R, Kerr J, Congeni J. Reports of head injury and symptom knowledge among college athletes: Implications for assessment and educational intervention. Clin J Sport Med 2003;13:213–221.

53. Kroshus E, Garnett B, Hawrilenko M, Baugh CM, Calzo JP. Concussion under-reporting and pressure from coaches, teammates, fans, and parents. Soc Sci Med 2015;134:66–75.

54. Rosner J. The relationship between moderate hyperopia and academic achievement: how much plus is enough? J Am Optom Assoc 1997;68:648–650.

55. Marshall S, Bayley M, McCullagh S, Velikonja D, Berrigan L, Ouchterlony D, et al. Updated clinical practice guidelines for concussion/mild traumatic brain injury and persistent symptoms. Brain Inj 2015;29:688–700.

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