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The diagnostic accuracy of EyeGuide Focus testing for concussion in elite male Rugby players

Gordon Ward Fuller [a], James Brown [b,c,d], Michael Dunlop [e], Martin Raftery [f] and Éanna Cian Falvey [f]

[a]Centre for Urgent and Emergency Care Research, School of Health and Related Research, University of Sheffield, Sheffield, UK; [b]Carnegie Applied Rugby Research [CARR] Centre, Carnegie School of Sport, Leeds Beckett University, Leeds, UK; [c]Institute of Sport and Exercise Medicine [ISEM], Department of Exercise, Sport and Lifestyle Medicine, Faculty of Medicine and Health Sciences, Stellenbosch University, Cape Tow, South Africa; [d]Division of Physiological Sciences, Department of Human Biology, Faculty of Health Sciences, The University of Cape Town and the Sports Science Institute of South Africa, Cape Town, South Africa; [e]BT Murrayfield Stadium, Edinburgh, UK; [f]Department of Medicine, University College Cork, Cork, Ireland

ABSTRACT

Introduction: Smooth pursuit eye movements may be affected by head impacts. The EyeGuide Focus system is a simple, portable, test of visual tracking. This study investigated the diagnostic accuracy of EyeGuide measurements for detection of concussion during elite Rugby matches.

Methods: A prospective diagnostic case–control study was performed in the elite 2021/2022 United Rugby Championship competition. The study population comprised consecutive players identified with match-related head impact events during the World Rugby Head Injury Assessment process, randomly chosen uninjured players, and players with match-related musculoskeletal injuries. The index test was blinded EyeGuide assessment performed by independent assessors. The reference standard was concussion diagnosed by the team doctor. Distributions of EyeGuide scores were compared between concussed and non-concussed players and receiver operator characteristic curves constructed.

Results: EyeGuide testing was performed in 262 cases, comprising 55 concussed players and 207 non concussed players (33 head impact events, 97 uninjured controls, and 79 musculoskeletal injury controls). The distributions of EyeGuide score were similar between concussed and non-concussed cases (medians 20,120 Vs 21,522, $p = 0.3$; difference −1,402, 95% CI −5,332–3,865). The c-index for the receiver operating characteristic curve was 0.46 (95% CI 0.36–0.55).

Conclusions: EyeGuide Focus scores did not appear to discriminate between concussed and non-concussed players in a cohort of elite Rugby players.

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Rugby; diagnostic accuracy; screening; smooth pursuits; concussion

Introduction

Concussion is a common injury in professional contact sports. Early detection with removal from play could facilitate recovery and reduce risk of further injury. Elite sports have consequently introduced processes to identify and manage head impact events during matches. These typically involve immediate removal of players with clearly apparent signs of concussion, e.g. loss of consciousness. Off-field screening tests are used to identify possible concussions where the consequences of a head impact are unclear, e.g. dangerous mechanism [1].

The current World Rugby HIA-1 off-field screening tool is a multi-modality assessment consisting of eight subtests, examining symptoms, clinical signs, balance, and cognition. It has demonstrated sensitivity of 77% and specificity of 87% for the subsequent identification of concussion [2]. The sub-optimal sensitivity suggests further research is required to develop a more accurate screening tool.

Concussion can manifest as a diverse range of somatic, cognitive, behavioral or emotional symptoms, and/or physical signs such as oculomotor deficits, loss of consciousness, and ataxia [3]. It would, therefore, be expected that several modalities should be tested in parallel to detect the full spectrum of concussion presentations; and that screening tools that test widely distributed neuronal pathways are necessary.

Visual tracking, also known as 'Smooth pursuit' or dynamic visio-motor synchronization, supports perceptual stability of a moving object of interest with a combination of saccadic and smooth pursuit eye movements [4]. Visual tracking synchronization metrics have been associated with cognitive functioning and integrity of frontal white matter tracts that are vulnerable to a concussive impact [5]. Therefore, a visual tracking task could be a useful test paradigm to augment concussion screening. The EyeGuide Focus Testing System (EyeGuide, Lubbock, Texas, United States) is a simple, portable, test for Dynamic Visio-Motor Synchronization [6].

This study aimed to determine if the EyeGuide Focus Testing System was useful as an off-field screening test for sport-related concussion. Specific objectives were to compare distributions of EyeGuide results in concussed and non-concussed Rugby players and determine the discriminative value of sideline EyeGuide measurements to detect concussion.

CONTACT Gordon Ward Fuller g.fuller@sheffield.ac.uk Centre for Urgent and Emergency Care Research, School of Health and Related Research, University of Sheffield, Regent Court, 30 Regent Street, Sheffield S1 4DA, UK

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Methods

Setting and study population

A prospective diagnostic case–control study was conducted in the 2021/2022 United Rugby Championship (URC), an elite male adult Rugby Union competition involving 16 teams from Ireland, Italy, Scotland, South Africa, and Wales [7]. The source population comprised all players registered with participating teams. The subsequent study population included consecutive players identified during matches with a meaningful head impact event and entering the World Rugby Head Injury Assessment process. Two control groups were also studied: a) randomly chosen uninjured players after matches; b) players removed from play with any musculoskeletal injury, e.g. ankle sprain.

HIA process

The 3-stage HIA process has been described in detail previously [8,9]. Briefly, players enter stage 1 of the HIA process following identification of a meaningful head impact event during a game. Players overtly demonstrating signs of concussion (termed 'Criteria 1,' e.g. tonic posturing) are immediately and permanently removed from the remainder of the match, without undergoing off-field concussion screening. Where the consequences of a head impact event are not clear (termed 'criteria 2,' e.g. possible behavior change or balance disturbance), players undergo an off-field screening assessment for possible concussion with the HIA-1 off-field screening tool, an abridged version of the SCAT5, administered by the team doctor or match day doctor [10]. All players entering the HIA process undergo detailed and standardized medical assessments by the team doctor post-match and within 3 h of the injury (HIA-2 assessment); and after two night rest (HIA-3 assessment), to monitor clinical progress and to confirm (or refute) a diagnosis of concussion. The HIA02 assessment consists of a clinical evaluation including the SCAT instrument [10].

Index test and reference standard

The index test under investigation was the EyeGuide Focus system (EyeGuide, Lubbock, Texas, United States, Figure 1) [11]. EyeGuide Focus measures 'smooth pursuit' or Dynamic Visio-Motor Synchronization (DVS) as characterized by Maruta et al. [5] Briefly, subjects look at a screen and focus on a small white target stimulus, set on a black background. The target moves in a horizontal 'lazy eight' pattern, starting at the center of the display and moving clockwise at 0.4 hz in a circular trajectory on the right side of the screen. When the stimulus returns to the center of the display, the path changes to a counter-clockwise circle on the left side of the screen. The test ends when the stimulus returns to the center of the display. A built-in digital camera tracks the pupil center coordinates during the task, and these are compared to the movements required to remain focussed on the moving circle (Figure 1). The test lasts 10 s, with pupil center coordinates measured 60 times per second. A final summary result is provided, calculated as the sum of the distances between the pupil center coordinates and the actual on-screen stimulus coordinates for the duration of the test except the first and last seconds. Thus, a score of 0 indicates flawless performance through the operational duration of the test, while higher scores indicate worse performance. Should the camera be unable to track the movement of the pupils due to a reflection or any other reason, the test aborts due to a 'pupil lock' failure. Subjects could undergo up to six attempts ('trials') to achieve three successful EyeGuide Focus test replicates. The best (i.e. lowest) score was used as the final index test result, based on the findings of a preceding test–retest reliability study [12].

All squad players participating in the URC competition underwent baseline EyeGuide testing prior to commencement of the 2021/2022 competition season. Standardized testing was performed at rest in a medical room prior to a training session, followed EyeGuide Focus recommendations, and was administered by a separate trained assessor in each separate team. Testing was performed under each player's usual training conditions, i.e. contact lens/glasses used/not used as

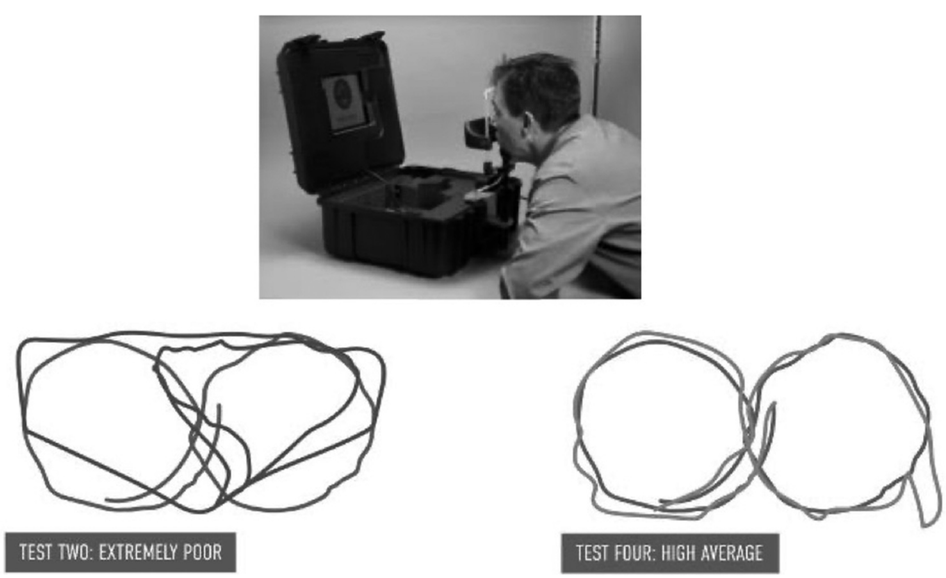

Figure 1. EyeGuide Focus equipment [upper panel] and records of user eye movements during 10 second smooth pursuit test [lower panel].

normal. Players entering the HIA process following identification of a meaningful head impact event during a game underwent EyeGuide testing by an independent trained assessor. Testing was conducted as soon as possible following removal from play for criteria 1 cases, or after completion of the HIA-1 concussion screening assessment for criteria 2 cases. Assessors were blinded to the HIA-1 assessment result. Uninjured controls underwent EyeGuide testing as soon as possible post-match. Control players removed from play with a musculoskeletal injury were tested as soon as possible after leaving the field.

The reference standard, against which performance was compared, was a clinical diagnosis of concussion during the 48 h post-injury, based on abnormal HIA-2 and/or HIA-3 assessments, determined by the team doctor and consistent with Concussion in Sport Group recommendations [1,8].

Data collection

Relevant demographic and clinical information were recorded using a standardized electronic recording form by team assessors prior to testing. EyeGuide Focus performance data were collected automatically at the time of testing by the secure, electronic EyeGuide Focus system. HIA process data are routinely recorded at the point of assessment by assessing physicians using the tablet based, web-hosted, CSx data platform [13]. Data is subsequently uploaded to the HIA database. HIA assessment forms, from each of the 3 hIA process stages, are linked deterministically using unique player identifiers. Competition coordinators are responsible for data quality and collection of outstanding information.

Analyses

The HIA process and study population characteristics were initially examined using descriptive statistics. Analysis then proceeded in four stages. First, the distributions of baseline and matchday EyeGuide focus scores were compared across five subgroups: criteria 1 concussed players, criteria 2 concussed players, criteria 2 non-concussed players, uninjured controls, and musculoskeletal controls. Kruskal–Wallis H tests were used to test a null hypothesis that mean ranks of the groups were the same. Differences between baseline and matchday scores were compared within in each subgroup using the Wilcoxon signed-rank test.

Second, the diagnostic accuracy of EyeGuide focus scores to detect concussion in HIA-1 criteria 2 players undergoing off-field concussion screening was examined. Receiver operating characteristic curves and c-index were calculated separately for the raw EyeGuide measurement and difference from baseline score.

Third, in the primary analysis, a diagnostic case–control analysis was performed analyzing all concussed players (criteria 1 and concussed criteria 2 players) compared to all non-concussed players (non-concussed criteria 2 and control players). Receiver operating characteristic curves and c-index were again calculated for raw scores, and difference from baseline.

Finally, a qualitative *post hoc* analysis of raw EyeGuide traces was conducted. A sample of 25 baseline traces, 25 matchday EyeGuide traces in concussed players, and 25 matchday traces in non-concussed players were randomly selected. The visual recording of eye tracking movements was then visually examined by a blinded EyeGuide assessor to subjectively assess if the trace represented a valid test, or whether distractions (i.e. significant, divergent visual deviations from the stimulus, with rapid correction) were present.

Available case analyses were performed. Statistical significance was defined as a *p* value of <0.05. A Bonferroni p-value correction was made when performing multiple hypothesis tests within in the same analysis. Statistical analysis were carried out using R 4.1.2 (R Core Team, 2021) using the R Studio interface. All statistical testing accounted for clustering arising from repeated testing in individual players using the R *'survey'* library.

Sample size, ethics, and governance

Using Buderer's formula a sample size of 177 cases was required for a case–control diagnostic accuracy analysis [14], assuming: prevalence of concussion of 50%; a sensitivity of 85%; a specificity of 75% for prolonged EyeGuide Focus scores to identify concussion; and a desired precision of 7.5% for the sensitivity estimate. A study protocol with an a priori investigation plan was developed prior to analysis. The investigation plan received ethical approval from an independent World Rugby Institutional Review Board. Participation was voluntary and all players provided written informed consent for inclusion in the study and use of anonymized data. Non-participation did not have any effect on the medical care provided.

Results

A total of 791 players across 16 teams were registered for the 2021/2022 URC competition, of whom 769/791 (97.2%) completed pre-season baseline EyeGuide testing. Over the 151-match season, EyeGuide testing was available in 100 matches during which there were 113 hIA-1 events in 102 players, comprising 36 criteria 1 and 77 criteria 2 cases. EyeGuide testing was not performed in 8/36 criteria 1 and 17/77 criteria 2 cases as detailed in the supplementary materials. EyeGuide testing was also conducted in 79 cases after removal from play with musculoskeletal injuries (in individual 73 players); and on 97 occasions in uninjured cases (in 90 players). The overall prevalence of concussion in HIA-1 cases was 73/113 (64.6%), comprising 36 criteria 1 cases and 37 criteria 2 cases ultimately diagnosed with concussion. Sample characteristics are described in Table 1. Derivation of the study sample is delineated in Figure 2.

There were no significant differences in the distribution of baseline EyeGuide scores across each of the five subgroups of interest as shown in Figure 2. Median baseline EyeGuide score varied from 14,014 (interquartile range (IQR) 11746–20,370) in the uninjured control group to 17,209 (IQR 13,828–21,171) in concussed criteria 2 players ($p = 0.31$). Median matchday

Table 1. Characteristics of study sample.

	Criteria 1 players	Criteria 2 concussed players	Criteria 2 non-concussed players	MSK injury players	Uninjured players
N=	36	37	40	73	90
Median age [years]	25.8	23.3	25.4	26.6	25.9
Median years of education [years]	14	10	14	14	14
Previous concussion [%]	100	76	83	71	60
Visual impairment [%]*	15	6	17	10	12
Migraine [%]	0	0	0	2.5	0
Median EyeGuide baseline score [IQR]	14,566 [12,236–19,577]	17,209 [13,828–21,171]	16,120 [12,370–22,415]	14,932 [11,994–21,404]	14,014 [11,746–20,370]
Median time to EyeGuide testing [IQR, minutes]	10 [7–17]**	12 [8–19]**	10 [9–11]**	25 [14–36]**	20 [11–24]†
Median matchday EyeGuide score [IQR]	20,332 [13,769–29,994]	17,817 [16,410–27,535]	22,186 [18,063–28,387]	22,293 [15,842–30,551]	20,785 [15,368–28,042]

IQR: interquartile range.
*Comprising refractive correction, astigmatism, color blindness.
**Time from removal from play; † time from end of game.

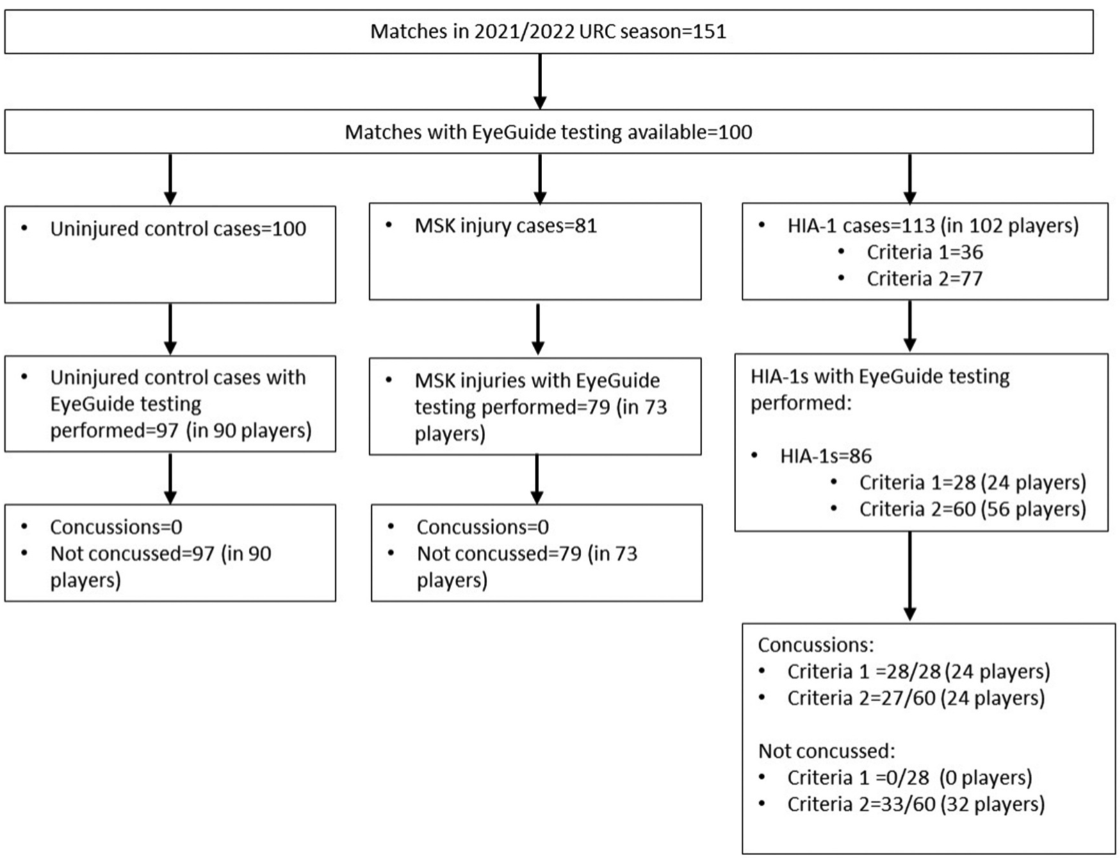

Figure 2. Derivation of the study sample.

EyeGuide score was uniformly worse than baseline scores within each subgroup, although only reached statistical significance in the musculoskeletal and uninjured control subgroups (see supplementary materials for further details). Median matchday EyeGuide score varied from 17,817 (IQR 16,410–27,535) in concussed criteria 2 players to 22,293 [12, p.842–30,551] in musculoskeletal injury controls, with no significant differences in distributions across any of the subgroups ($p = 0.53$, Figure 3).

In criteria 2 players undergoing off-field HIA1 assessment Eye-Guide scores did not appear to discriminate between concussed and non-concussed players with c-indexes of 0.41 (95% CI 0.26–0.57) and 0.42 (95% CI 0.26–0.58) for raw score and difference from baseline score, respectively. Receiver operating characteristic curves are presented in the supplementary materials.

In the primary analysis, comparing all concussed players (either criteria 1 or criteria 2) to all non-concussed players (criteria 2, musculoskeletal injury and uninjured controls) revealed similar distributions of matchday EyeGuide scores (medians 20,120 Vs 21,522, $p = 0.30$; difference −1,402, 95% CI 3,865- −5,332; Figure 3). The resulting c-index for the

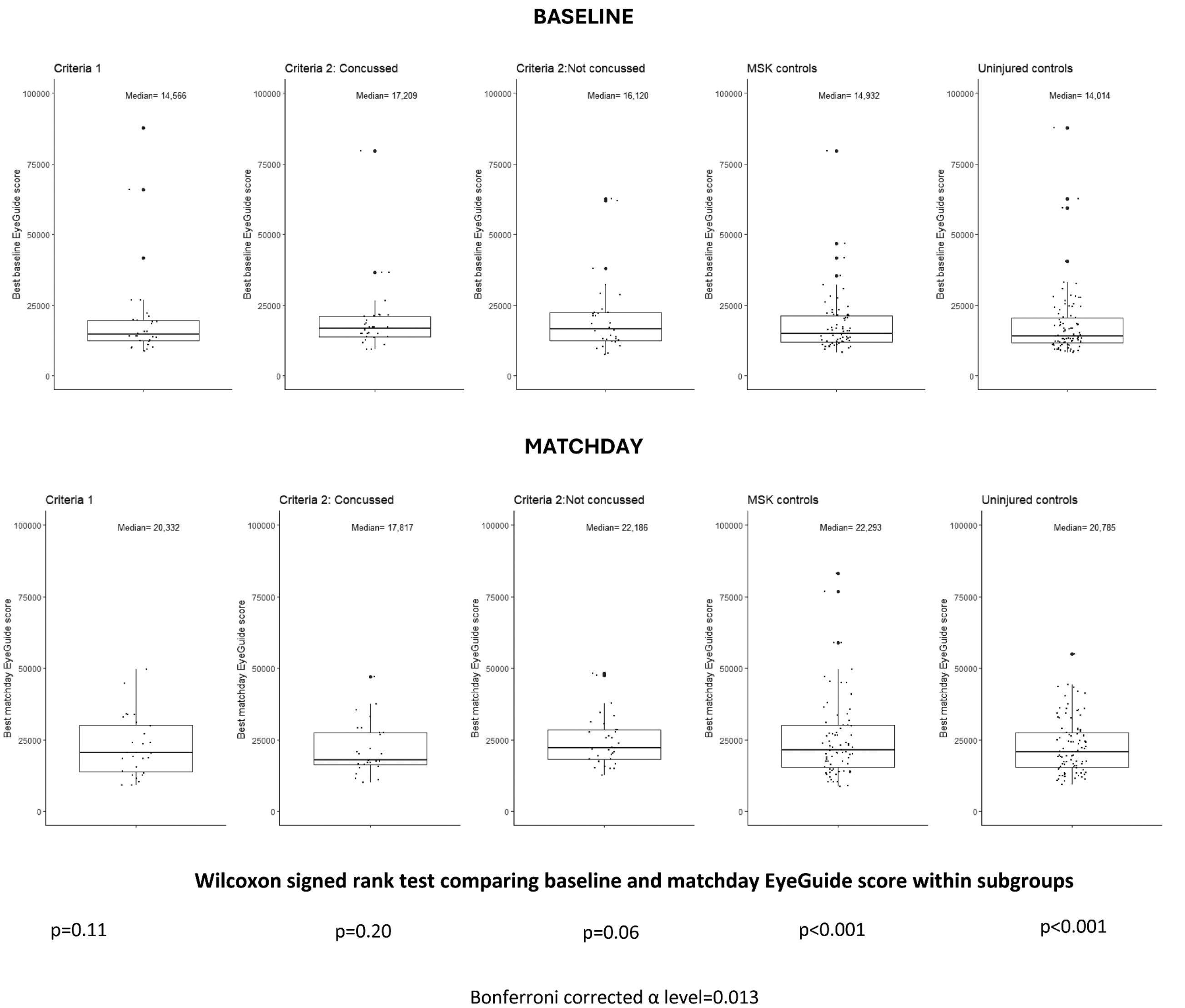

Figure 3. Distribution of baseline and Matchday EyeGuide focus scores across player subgroups.

receiver operating characteristic curve was 0.46 (95% CI 0.36–0.55, Figure 4). Results were very similar when difference from baseline score was used as the index test as detailed in the supplementary materials.

In the qualitative analysis of EyeGuide traces, 96% of randomly selected traces were classified as valid (72/75). Distractions were detected in 2/25 baseline traces and 1/25 in non-concussed players. All examined traces in concussed players were deemed valid.

Discussion

Summary of results

In a sample of elite male Rugby Union players, matchday EyeGuide scores were generally worse than baseline measurements, regardless of injury or concussion status. EyeGuide scores were similar between concussed and non-concussed players (medians 20,120 Vs 21,522, $p = 0.30$;) and did not appear to discriminate between concussed and non-concussed players (difference in median score=- difference −1,402, 95% CI 3,865- −5,332; c-index = 0.46).

Interpretation

Although a formal testing protocol has not been published, operationally EyeGuide routinely imposes an upper limit for an eligible test score of 38,842, corresponding to two standard deviations above the mean value of 22,651 from a large sample of uninjured community controls (EyeGuide Focus, personal communication, 2022). Above this level, measurements are treated as test failures and truncated. In contrast, the best achievable EyeGuide score from several replicates, regardless of its value, was defined *a priori* as the index test result for this study based on pilot research and to maximize available information [12]. Notably, 9.8% of the best scores were above the 38,842 operational threshold, but a *post hoc* analysis excluding these values was materially unchanged (see supplementary materials).

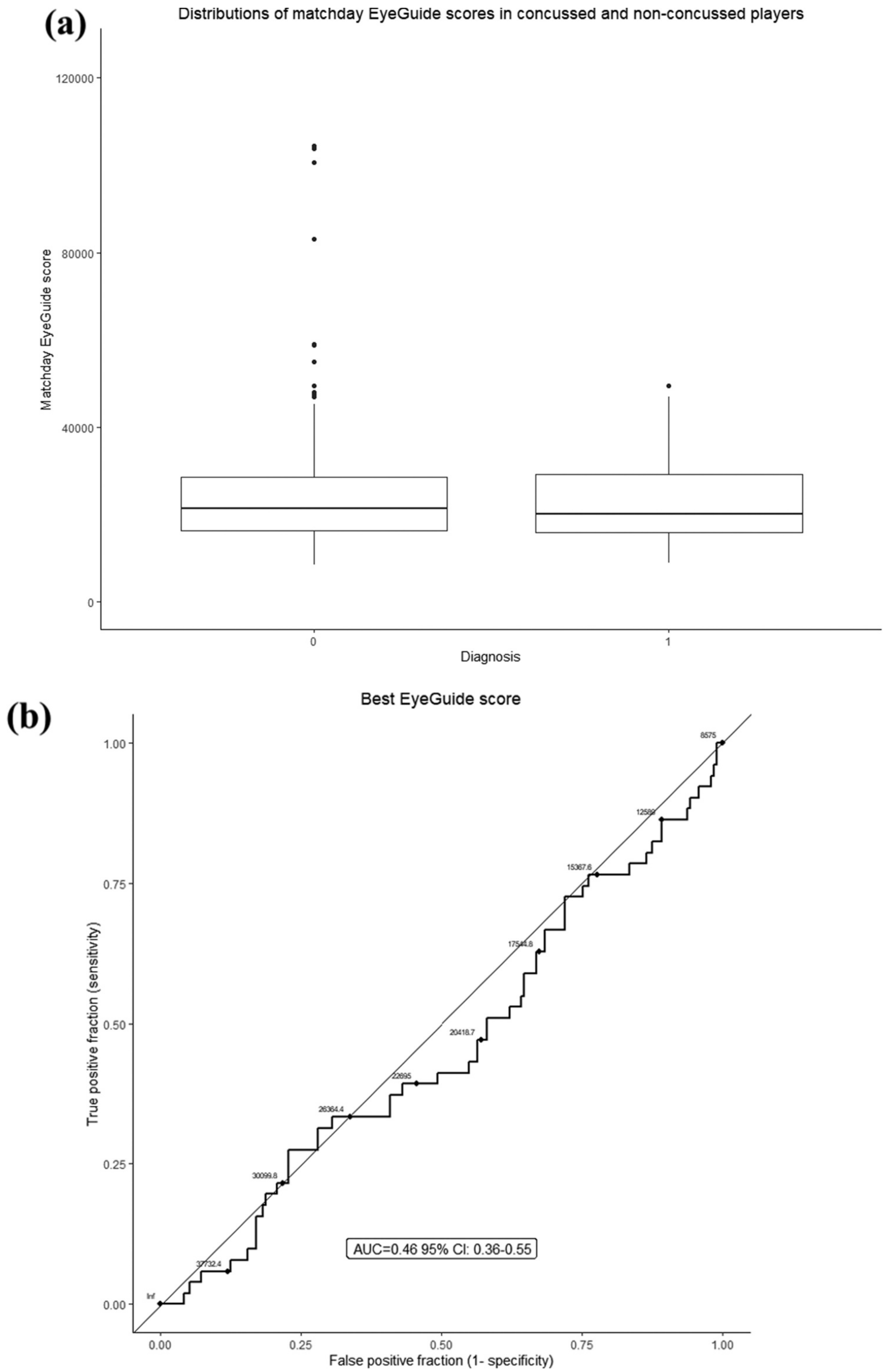

Figure 4. (a) Distributions and (b) receiver operating characteristic curve for the best EyeGuide score in concussed and non-concussed players undergoing matchday testing.

There are several reasons which could explain EyeGuide inability to discriminate between concussed and non-concussed players. Concussion includes a diverse range of phenotypes and oculomotor pathways may only be affected in a minority of players [15,16], limiting the opportunity for EyeGuide to detect cases. In this contingency, there could be a role for EyeGuide testing in monitoring recovery in the subset of concussions with visual deficits. Previous research has suggested high test–retest variability in EyeGuide measurements, and this lack of precision could limit test accuracy [6]. Finally, it is also possible that the eye tracking technology is unable, or the 10-s testing time is insufficient, to detect subtle deficits in smooth pursuits arising from concussion.

Notably, matchday EyeGuide scores were worse than baseline scores across all concussed and non-concussed player subgroups, including musculoskeletal injury and uninjured controls. Possible reasons could include exercise effects, differences in measurement conditions, or player concentration. Previous research has reported that EyeGuide measurements were similar before and after an exercise protocol [12]. However, this study used an exercise bike protocol in a controlled gymnasium setting which could plausibly differ from the effects of elite matchday Rugby. The qualitative examination of baseline and matchday traces demonstrated overwhelmingly valid traces, arguing against distractions arising from the testing environment, although performance may have been globally impaired from busier matchday conditions. It is also possible that players were less task focused compared to preseason baseline conditions.

The comprehensive study sample including elite teams from Ireland, Italy, Scotland, South Africa, and Wales should ensure excellent external validity within male professional Rugby Union. However, generalizability to other sports, amateur Rugby Union, and female or younger subjects is less certain. If deployed during the HIA-1 off field assessment it is likely that EyeGuide testing would be performed by the team doctor, contrasting with the independent assessors during the current study. And it is possible that differences in testing personal could influence EyeGuide measurements.

Comparison to literature

This is the first research to evaluate EyeGuide testing for the matchday detection of concussion using a diagnostic accuracy study design. Possible utility of visual tracking in side-line assessment of head impacts was published by Kelly (2017) who reported a significant difference in the distribution of baseline and follow-up scores in 42 athletes diagnosed with concussion [11]. However, the absence of a control group and delayed follow-up testing limits the conclusions that can be drawn. Still and colleagues (2019) studied mixed martial arts fighters before and after bouts, demonstrating a significant change from a pre-fight baseline test mean of 17,426 to a post-fight mean of 37,694 [17]. Formal assessment for concussion was not performed, and the superior baseline performance is similar to that observed in the current study. Several other video-oculography devices to test visual tracking have been described, but comparison to the current findings is difficult due to different measurement scales [15].

Limitations

This study has several strengths. The electronic data collection system allowed immediate objective data collection, EyeGuide measurements were performed by trained assessors, the reference standard was independent of the reference standard, and outcome assessors were blinded. Although the primary analysis used a two-gate case–control design, this would be expected to provide an over-optimistic 'best-case' estimate of accuracy. Conversely, there are potential limitations. EyeGuide testing was not available at all matches, and some eligible players did not undergo assessment. However, missed testing appeared to be random (e.g. concomitant blood injury or equipment failure), rather than systematic, suggesting selection bias is unlikely. EyeGuide testing was also not always performed immediately, and it is possible that transient deficits in smooth pursuits in concussed players had resolved by the time of delayed assessment leading to information bias. Finally, concussion is a subjective clinical diagnosis, although all players were subject to the standardized HIA concussion diagnostic process reference standard misclassification is possible.

Conclusions

This study reports on the accuracy of EyeGuide Focus, a low-cost ocular-based test, for detecting concussion. EyeGuide scores were similar between concussed and non-concussed players and did not appear to discriminate between concussed and non-concussed players in a cohort of elite Rugby players. Future research could investigate the role of EyeGuide testing in monitoring recovery in the subset of concussion cases with visual deficits.

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Conflicts of interest statement

JB's university salary is partially funded by World Rugby and he has received research and travel funding from World Rugby previously. EF and MR are employed by World Rugby. GF has received travel expenses to attend scientific meetings from World Rugby. MD has no conflicts of interest.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Gordon Ward Fuller http://orcid.org/0000-0001-8532-3500
James Brown http://orcid.org/0000-0002-7778-7783
Martin Raftery http://orcid.org/0000-0003-4788-837X
Éanna Cian Falvey http://orcid.org/0000-0003-3961-1805

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