Concussion History and Balance Performance in Adolescent Rugby Union Players

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Background: Sports-related concussion is a worldwide problem. There is a concern that an initial concussion can cause prolonged subclinical disturbances to sensorimotor function that increase the risk of subsequent injury. The primary aim of this study was to examine whether a history of sports-related concussion has effects on static and dynamic balance performance in adolescent rugby players.

Hypothesis: Dynamic balance would be worse in players with a history of concussion compared with those with no history of concussion.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Male adolescent rugby players aged 14 to 18 years from 5 schools were recruited before the start of the 2018-2019 playing season. Participants completed questionnaires and physical tests, including dynamic Y balance and single-leg static balance (eyes closed) tests, while performing single and dual tasks. Dynamic balance was assessed using inertial sensor instrumentation. Dependent variables were normalized reach distance and the sample entropy (SEn) of the 3 axes (*x*, *y*, and *z*).

Results: Of the 195 participants, 100 reported a history of concussion. Those with a history of concussion demonstrated higher SEn in all directions, with highest values during anterior (standardized mean difference [SMD], 0.4; 95% CI, 0.0-0.7; *P* = .027) and posteromedial (SMD, 0.5; 95% CI, 0.2-0.9; *P* = .004) reach directions compared with those with no history. There was no difference between groups (concussion history vs control) in traditional Y balance reach distances in the anterior or posteromedial directions or single-leg static balance during both single- (*P* = .47) and dual-task (*P* = .67) conditions.

Conclusion: Adolescent rugby union athletes with a history of concussion had poorer dynamic balance during performance tasks compared with healthy controls. Static single-leg balance tests, either single or dual task, may not be sensitive enough to detect sensorimotor deficits in those with a history of concussion.

Keywords: sports-related concussion; balance; adolescent; dual tasking

Sports-related concussion is a public health concern worldwide. The rate of concussion in professional rugby union is estimated at 21.5 per 1000 game hours.[30] Prospective research in adolescent rugby reports an incidence of 6.1 concussions per 1000 game hours, equivalent to 3 per team per season.[3]

Concussion affects many components of cerebral function, with common symptoms presenting as headaches, dizziness, and balance problems.[12] Clinical recovery in most athletes after a sports-related concussion typically takes between 3 and 10 days.[16,25] However, there may be protracted recovery associated with a concussion,[28,33] and there is growing evidence that subgroups of athletes possess deficits in neurocognitive and sensorimotor function that extend beyond the resolution of clinical symptomatology.[5] Prospective research has also demonstrated that athletes who have sustained a concussion are more likely to sustain a subsequent musculoskeletal injury in the following year,[27] suggesting that prolonged subclinical disturbances could place athletes at greater risk of further injury.

An International consensus on concussion in sport advocate that gait and balance assessments should be included as part of a detailed neurological examination of concussion.[26] This can include the Balance Error Scoring System, which forms part of the Sport Concussion Assessment Tool 5th edition[9]; assessment of dynamic balance through the Y balance test; or the 3-m walk test.[14] However, traditional tests provide a surrogate measure of balance performance and fail to objectively measure movement control during the clinical assessment. As such, they may not be responsive to change and can miss small but important deficits in sensorimotor control.[17] Research has focused on improving the accuracy of traditional tests by leveraging wearable sensor technology to

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instrument clinical balance assessments.[20] Preliminary evidence suggests that such approaches may provide an increased level of sensitivity when compared with the current assessments, providing a means to quantify subclinical sensorimotor control deficits at the point when or after the athlete has returned to full athletic participation.[18,19,29]

Inertial sensor-based instrumentation of the Y balance test, a commonly used clinical dynamic balance assessment, is 1 such viable approach. Early research has established that inertial sensor technology can reliably capture valuable information relating to the control of an individual's balance, providing a sensitive measure of dynamic movement control.[21,22] Evidence suggests that elite male rugby union players who possessed a greater irregularity in their Y balance test movement control (high gyroscope magnitude sample entropy [SEn]) were 3 times more likely to sustain a concussion than the players who possessed more regular Y balance test movement control.[22] Furthermore, evidence suggests that concussed athletes may have persistent deficits in sensorimotor control that extend beyond the point of clinical recovery.[13] There is currently a paucity of empirical research investigating the presence of persistent subclinical balance deficits in adolescent rugby union players with a history of concussion. The primary aim of this study was to examine whether a history of sports-related concussion has effects on static and dynamic balance performance in adolescent rugby players. We hypothesized that dynamic balance would be impaired in players with a history of concussion compared with those with no history of concussion.

METHODS

This was a cross-sectional cohort study undertaken over a single playing season (2018-2019). Male participants were recruited from 5 school rugby teams across the greater Belfast region. To be eligible, participants were required to be playing at either (1) Medallion level (aged up to 15 years) or (2) First XV level (aged 16-18 years). Ethical approval was granted from the research ethics committee of Ulster University. Written informed consent was obtained from each player and from a parent or legal guardian. Unique player registration numbers were employed to maintain anonymity and medical confidentiality.

Data Collection

Baseline testing was undertaken before the start of the 2018-2019 playing season. Initially, this involved completion of a questionnaire detailing characteristics (age, weight, and height), injury history (previous concussion [yes/no]), number of previous concussions, and time loss from sport (days) associated with a previous concussion. All definitions and procedures used were compliant with the international consensus statement on injury surveillance studies for rugby.[10] An experienced researcher (M.M.) was present to assist as required with the understanding and completion of the questionnaire. This was followed by 2 physical assessments of balance: the single-leg static balance (eyes closed; SLB [single-leg balance]) and the Y balance tests. All tests were undertaken in bare feet on a flat stable indoor surface. Assessors were blinded to injury and concussion history.

SLB (Eyes Closed). Participants stood on their dominant foot in single-leg stance with hands on their iliac crests. When instructed, participants closed their eyes for 20 seconds and attempted to maintain static balance. Each trial was scored by counting the number of times (errors) the participant deviated from the proper stance, with errors defined as moving hands off iliac crests; opening eyes; step, stumble or fall; abduction or flexion of the hip beyond 30°; lifting forefoot or heel off testing surface; and remaining out of the proper testing position for >5 seconds.[9] If multiple errors occurred at the same time, only 1 was counted. The maximum number of errors was 10. This test was initially performed (SLB, single task) and was then repeated with the addition of a cognitive task (SLB, dual task), which involved reciting the months of the year backward (eg, December, November, October).

Y Balance Test. The Y balance test is a modification of the Star Excursion Balance Test.[32] During testing, participants positioned themselves on the center platform, behind the red line, with hands firmly on their hips. They were then instructed to use their nonstance leg to slide a box forward as far as possible with their foot and return to the starting upright position in 3 defined directions (anterior [ANT], posteromedial [PM], and posterolateral [PL]). Reach distances were recorded to the nearest 0.5 cm. Individuals completed 3 practice trials, followed by 3 recorded trials in a randomized order. A failed attempt was noted when any of the following errors occurred: touching of the foot down on the floor before returning to the starting

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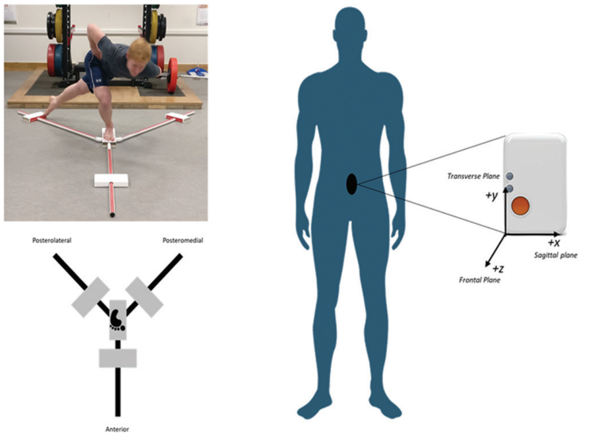

Figure 1. The Y balance test reach directions (anterior, posteromedial, and posterolateral), the inertial sensor mounting location, and the orientation of the 3 axes in relation to the planes of human movement.

position; placing the foot on top of the sliding box for balance; and flicking or kicking the sliding box for a better performance or any loss of balance.[11] In the event an individual met any of the failure criteria, the reach attempt was discarded and repeated.

An inertial sensor (Shimmer3; Shimmer Sensing) was mounted at the level of the fourth lumbar vertebra (Figure 1) and secured with a custom-made elastic belt to closely match the acceleration of the body's center of mass during the Y balance test excursions. Shimmer3 units were calibrated and configured to stream triaxial accelerometer (±2 g), gyroscope (±500 deg/s), and magnetometer (±1.9 gauss) data at 51.2 Hz via Bluetooth to an Android tablet operating a custom-developed Android application. Inertial sensor data were captured for the period that the individual was in unilateral stance during each reach excursion. Data were analyzed offline with MATLAB (2018b; MathWorks). All baseline balance testing was completed by authors (M.M., R.J.D.) experienced in the inertial sensor–instrumented Y balance test testing.

Reach distances during the Y balance test were normalized in relation to the individual's leg length[11]: The mean of the 3 trials completed in each direction (reach distances and inertial sensor variables) was obtained to ensure measurement reliability.

Movement control during the Y balance test was quantified using the following variables: normalized reach distance and the SEn of the 3 axes of the gyroscope signal (x, y, and z). SEn of the signal of length, $N = \{x_1, x_2, x_3, \ldots, x_N\}$, was calculated using the following formula:

$$Sample\,Entropy = -\log\left(\frac{A}{B}\right).$$

$\boldsymbol{A}$ was the number of template vector pairs having a Chebyshev distance $\boldsymbol{d}[\boldsymbol{X}_{\boldsymbol{m}+1}(\boldsymbol{i}), \boldsymbol{X}_{\boldsymbol{m}+1}(\boldsymbol{j})] < \boldsymbol{r}$ of length $\boldsymbol{m+1}$, and $\boldsymbol{B}$ was the number of template vectors pairs having $\boldsymbol{d}[\boldsymbol{X}_{\boldsymbol{m}}(\boldsymbol{i}), \boldsymbol{X}_{\boldsymbol{m}}(\boldsymbol{j})] < \boldsymbol{r}$ of length $\boldsymbol{m}$, where the embedding dimension, $\boldsymbol{m}$, was equal to 2 and the tolerance, $\boldsymbol{r}$, was equal to 0.1. The template vectors were defined such that $\boldsymbol{X}_{\boldsymbol{m}}(\boldsymbol{i}) = \{\boldsymbol{x}_{\boldsymbol{i}}, \boldsymbol{x}_{\boldsymbol{i}+1}, \boldsymbol{x}_{\boldsymbol{i}+2}, \ldots\ldots, \boldsymbol{x}_{\boldsymbol{i}+\boldsymbol{m}-1}\}$. SEn is a unitless nonlinear measure of the regularity/complexity of a time series, which can be appropriately applied to biomechanical data to quantify sensorimotor function.[6,7,22,31] In the current study, a low SEn score was indicative of more regular and less complex movement control during the Y balance test reach excursions, while a higher SEn score indicated a higher degree of movement irregularity/complexity, aligning with the theories related to an optimal state of variability for human motor performance, described by Stergiou and Decker.[34]

Statistical Analysis

Demographic and injury history data were summarized using means and standard deviations for scale variables and frequencies and percentages for nominal variables. Between-group comparisons (concussion history vs no concussion history) for the Y balance test reach distance measures and inertial sensor derived SEn for all 3 reach directions were made using effect sizes based on standardized mean differences (SMD), 95% CIs, and inferential statistics (independent t tests or nonparametric equivalents). Data were analyzed using the Statistical Package of Social Sciences (SPSS) (Version 14; SPSS Inc). Due to the exploratory nature of our hypothesis, the threshold for statistical significance was lowered to $P < .005$ for all tests. Furthermore, if this threshold was reached, we calculated a corresponding false positive risk (FPR) using the False Positive Risk Web Calculator (Version 1.5).[8,24] FPR is defined as the probability of observing a statistically significant P value and declaring that an effect is real when it is not.[8] FPR calculations were based on a conservative prior probability of P(H1) = 0.2; that is, we assumed that there was a 20% chance that controls would have better balance than those with a history of concussion.

RESULTS

A total of 229 participants were recruited from 5 schools, of whom 34 failed to provide adequate detail on injury history and were excluded from the analysis. In the remaining 195 participants, 51.3% (100/195) reported at least 1 previous concussion. The mean time between testing and participants' most recent concussion was 17 months. Of those who reported a previous concussion, 24% (24/100) had suffered at least 3 previous concussions. Most participants returned to play immediately after the minimum convalescence period (advised by the Irish Rugby Football Union) had lapsed (23 days). There were 8 cases where concussion was associated with a time loss from rugby greater than 24 days. Participants with a history of concussion were on average older than controls (mean difference [MD], 0.5 years; 95% CI, 0.1-0.8) but were of similar height and weight (Table 1).

TABLE 1
Characteristics and Single-leg Balance Performance[a]

	Control (n = 95)	Concussion History (n = 100)	*P* Value
Age, y	15.7 (1.2)	16.2 (1.2)	.013
Height, cm	176.3 (7.7)	177.6 (7.1)	.225
Weight, kg	74.9 (17.7)	73.1 (13.4)	.416
SLB, No. errors, median (IQ range)	2 (3)	2 (2)	.467
SLB cognitive task, No. errors, median (IQ range)	1 (3)	2 (3)	.667

[a]Values are presented as mean (SD) unless otherwise stated. IQ, intelligence quotient; SLB, single-leg balance.

Single-Leg Static Balance

SLB data were analyzed in 195 participants (n = 95 controls; n = 100 with history of concussion). Table 1 and Figure 2 show that SLB performance was unaffected by concussion history, with similar patterns of error observed across the groups (concussion history vs control) during both single- (*P* = .47) and dual-task (*P* = .67) conditions.

Y Balance Test

Y balance data were available for 125 participants (n = 57 controls; n = 68 participants with concussion history) (age, 15.9 ± 1.2 years; weight, 73.0 ± 15.9 kg; and height, 177 ± 8 cm) (Table 2). No differences in normalized reach distances were found between groups in the ANT and PM directions. Controls had a greater reach distance in the PL direction, with moderate effects reported (SMD, 0.5; 95% CI, -0.1 to 0.8; *P* = .013). With regard to movement control, participants with a history of concussion demonstrated higher SEn in all test directions compared with controls (Table 2). The largest effect sizes were recorded for movements around the *y* axis (transverse plane) during the ANT (SMD, 0.4; 95% CI, 0 to 0.7; *P* = .027) and PM reach directions (SMD, 0.5; 95% CI, 0.2 to 0.9; *P* = .004) (Figure 3), exceeding our threshold for statistical significance, with an estimated FPR of 11%.

DISCUSSION

This study sought to investigate the effect of concussion history on balance performance in a cohort of adolescent rugby union players. Our key finding was that participants with a history of concussion did exhibit altered movement control during the Y balance test compared with healthy controls. In effect, individuals with a history of concussion demonstrated less regularity or predictability in their movement control about the transverse plane during the ANT and PM reach directions of the Y balance test. We found no difference between groups in standard sensorimotor tests that included SLB performance in either single- or dual-task conditions or in Y balance reach distance.

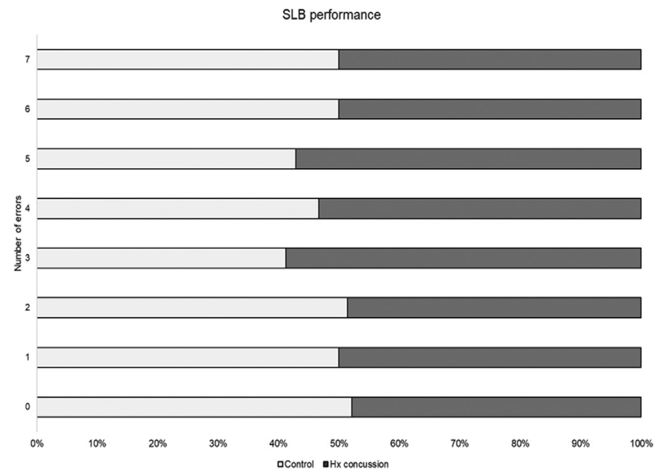

Figure 2. The number of single-leg static balance errors and the percentage attributed to both the healthy control and the concussion history cohorts.

A key detail is that at the time of testing, participants in both groups (the group with concussion history and healthy controls) were fully fit and available for team selection. Previous studies have reported persistent neurocognitive deficits, even though self-reported symptoms have resolved.[5] A related concern is that participation in sports, coupled with subclinical deficits in movement control, cumulates in an increased risk of subsequent injury.[13] Recent prospective data indicates that athletes with a history of concussion are at an increased risk of sustaining a subsequent sports-related concussion[1] and/or musculoskeletal injury.[27] Young developing brains already undergo a more complex and protracted recovery postconcussion compared with adult brains.[2] Our data seem to support the idea that persistent subclinical balance deficits mediate recurrent concussion in sports. We must continue to develop understanding of the etiology and path model associated with recurrent concussion in adolescent athletes. An important strategy has been the introduction of a conservative postconcussion convalescence time for U19 rugby union players, a minimum of 23 days. However, results from the present study suggest that deficits in sensorimotor function persist beyond the standard 23 days. Further research is needed to explore if (1) targeted rehabilitation strategies are warranted and (2) to confirm if 23 days is sufficient for full restoration of subclinical sensorimotor function.

Evidence of other concussion studies have reported alterations in nonlinear measures of movement control and balance performance within concussed athletes.[6,23] In contrast to the present study, individuals with a history of concussion presented with reductions in approximate entropy and SEn measures. The observed differences between the current study (eg, greater movement) and previous research (eg, reduced movement) may relate to variations in postconcussion follow-up time. Both Cavanaugh et al[6] and Johnston et al[18] conducted balance assessments at 48 hours after concussion, versus the present study that

TABLE 2
Traditional and Inertial Sensor-Instrumented Balance Variables for Each Group (History of Concussion Versus Control)[a]

	History of Concussion (n = 68)	Control (n = 57)	SMD (95% CIs)	*P* Value
Reach distance (%)				
ANT	59.2 (4.9)	59.5 (6.0)	0.1 (–0.3 to 0.4)	.798
PM	96.8 (8.8)	99.1 (8.7)	0.3 (–0.1 to 0.6)	.150
PL	89.9 (8.5)	93.9 (9.0)	0.5 (–0.1 to 0.8)	.013
Sample entropy *X*-axis (sagittal plane)				
ANT	1.56 (0.37)	1.52 (0.30)	0.1 (–0.2 to 0.5)	.482
PM	0.75 (0.30)	0.76 (0.29)	0.0 (–0.4 to 0.3)	.898
PL	0.74 (0.27)	0.73 (0.24)	0.0 (–0.3 to 0.4)	.832
Sample entropy *Y*-axis (transverse plane)				
ANT	1.12 (.26)	1.03 (0.20)	0.4 (0 to 0.7)	.027
PM	1.25 (0.28)	1.12 (0.22)	0.5 (0.2 to 0.9)	**.004**
PL	1.1 (0.22)	1.1 (0.22)	0.0 (–0.4 to 0.4)	.402
Sample entropy *Z*-axis (frontal plane)				
ANT	1.42 (0.27)	1.39 (0.27)	0.1 (–0.2 to 0.5)	.512
PM	1.24 (0.31)	1.18 (0.24)	0.2 (–0.1 to 0.6)	.178
PL	0.84 (0.22)	.83 (0.20)	0.1 (–0.3 to 0.4)	.895

[a]Data are presented as mean (SD) unless otherwise noted. Bolded value indicates a priori level of statistical significance, $P < .005$. ANT, anterior; PL, posterolateral; PM, posteromedial; SMD, standard mean difference.

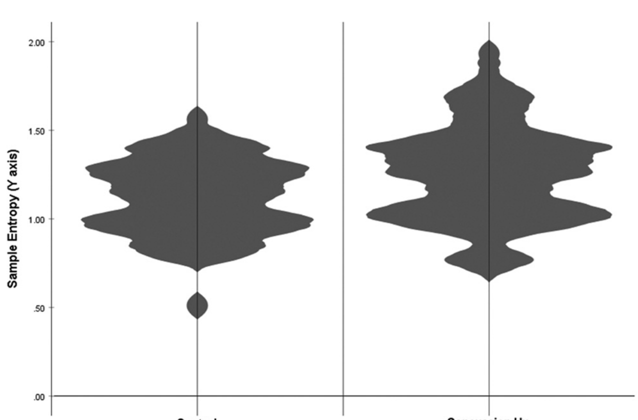

Figure 3. Sample entropy (SEn) of gyroscope *y*-axis signal during Y balance test (posteromedial direction). Violin plot compares probability density of SEn data across groups. Hx, history.

performed balance assessment preseason, capturing long-term history of concussion. It is possible that the findings from the present study represent the effects of more established aberrant changes in sensorimotor function. Nonetheless, deviations from an optimal state of movement variability can include both more predictable (low SEn) or more irregular and complex (high SEn) patterns of control.[34] In effect, both extremes of variability of movement (eg, stiffening, or greater irregular movement control) may be indicative of compensatory mechanisms to cope for deficits in sensorimotor control.

Results suggest the need for more responsive outcomes in concussion research. We found that both single- and dual-task SLB performances were unaffected by a history of a previous concussive injury. This aligns with previous investigations reporting no significant difference between collegiate athletes with and without a history of concussion in Balance Error Scoring System performance[35] or dual-task static stance performance.[4] While our study found that players with a history of concussion demonstrated reduced Y balance reach distance in the PM and PL directions (vs healthy controls), these effects were small to medium and did not reach our a priori level of statistical significance. Reach distance only quantifies how far an individual can reach outside of one's base of support. The addition of the single lumbar mounted inertial sensor to the athlete during the Y balance test provides a means to obtain objective movement control biomechanical data. Our data contribute to a growing body of evidence suggesting that the inertial sensor-based measures of performance may provide a sensitive measure of dynamic balance performance not captured by the traditional normalized reach distance[21,22] or standard static assessments.[4,35] In the case of concussion, the sensors can be used to capture subtle deficits in balance performance.

Over half of the participants in the study reported a history of concussion (100/195; 51.3%). This figure is notably higher than previously reported in a 2014-2015 study where just 26% of adolescent rugby players reported a previous concussion.[3] This increase may be due to improvements in concussion recognition and reporting. Over the past decade, there has been an increase in education provided to athletes, parents, coaches, teachers, and medical staff involved in adolescent rugby union across Ireland.[15] Many teams have also improved the structures and policies for reporting and recording injuries in Ulster Schools' rugby.

Considerations

There are several contextual considerations that should be acknowledged related to this study. First, this study followed a cross-sectional cohort study design, investigating history of concussion and balance performance during preseason screening. This design prevents determining whether there is a cause-effect relationship between the concussion and balance performance. As such, it is difficult to determine the clinical significance of the differences in balance performance observed between the healthy controls and players with a history of concussion. However, the potential clinical implication has been demonstrated by recent evidence indicating that elite rugby union players with more irregular movement control (greater SEn) during the Y balance test are at a 3-times greater relative risk of sustaining a sports-related concussion.[22] Second, this was an exploratory study undertaken on a relatively homogeneous group; and further research leveraging a larger, more representative population (male/female, across a range of sports) is required. Third, history of concussion was self-reported in this study, but recall errors were reduced by using a consistent definition of concussion[26] and by the fact that concussion in this age group necessitates a minimum of 23 days' convalescent period.

CONCLUSION

Results suggest that adolescent rugby union athletes with a history of concussion possess alterations in dynamic balance performance compared with healthy controls, despite normal performance on static balance assessments. This research highlights the need for more responsive outcomes in concussion research. These findings contribute to a growing evidence that suggest deficits in sensorimotor function persist beyond standard clinical recovery of concussion. In high impact and dynamic sports, such as rugby, clinicians should consider implementing sensorimotor rehabilitation strategies to optimize the return to play process and reduce the potential risk of future injury.

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