Determinants of sport-specific postural control strategy and balance performance of amateur rugby players

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Short title: Balance analysis of rugby players

Abstract

Objectives: Postural control strategy and balance performance of rugby players are important yet under-examined issues. This study aimed to examine the differences in balance strategy and balance performance between amateur rugby players and non-players, and to explore training- and injury-related factors that may affect rugby players' balance outcomes.

Design: Cross-sectional and exploratory study.

Methods: Forty-five amateur rugby players and 41 healthy active individuals participated in the study. Balance performance and balance strategies were assessed using the sensory organization test (SOT) of the Smart Equitest computerized dynamic posturography machine. Rugby training history and injury history were solicited from the participants.

Results: The SOT strategy scores were 1.99–54.90% lower in the rugby group than in the control group ($p < 0.05$), and the equilibrium scores were 1.06–14.29% lower in the rugby group than in the control group ($p < 0.05$). After accounting for age, sex and body mass index, only length of rugby training (in years) was independently associated with the SOT condition 6 strategy score, explaining 15.7% of its variance ($p = 0.006$). There was no association between SOT condition 6 strategy/equilibrium scores and injury history among the rugby players ($p > 0.05$).

Conclusions: Amateur rugby players demonstrated inferior balance strategy and balance performance compared to their non-training counterparts. Their suboptimal balance strategy was associated with insufficient training experience but not with history of injury.

Keywords: Postural balance; movement; rugby; athletic injuries

1. Introduction

Rugby, a field-based contact sport, is played throughout the world. Its popularity has been increasing in the past 20 years. Both rugby league and rugby union are physically demanding, requiring frequent bouts of intense activity (e.g., sprinting, collisions and tackles) separated by short periods of low-intensity activity (e.g., jogging).[1-3] Rugby players' sport-related physical fitness (e.g., agility and body balance) is of paramount importance.

Previous studies have examined rugby players' agility, a physiological measure closely related to body balance, at different playing levels.[1-3] Agility was found to improve with increasing age and rugby playing experience.[1] Long-term sports training might also enhance sensorimotor and balance functions.[4-6] It is therefore plausible that experienced rugby players (with more years of training) might have better/above-average balance ability. In addition, previous study has suggested that the starting age of motor training affects the development of sensorimotor abilities and postural control.[4] Therefore, we postulated that the age of onset of training might also influence balance performance of the rugby players. However, to the best of our knowledge, no study has examined the balance ability of rugby players directly, despite balance being fundamental to the execution of powerful technical movements and crucial for the prevention of injuries.[4,7] Also, no study has explored the relationship between playing experience (including length of training and age of onset of training) and balance ability.

Body balance (postural control) is defined as the ability to maintain the center of gravity within the base of support.[8] To maintain balance in a fixed stance, hip and ankle balance strategies are used.[9,10] The hip strategy involves hip flexion and extension and opposing ankle dorsiflexion and plantar flexion. It is not an ideal balance strategy because the center of gravity displacement is relatively large and thus induces greater postural instability. The ankle strategy is a better choice because it maintains standing balance by rotating the body as a rigid mass about the ankle joints and thus results in smaller displacements of the center of gravity.[10,11]

Previous research has revealed that preparation and execution of balance strategies are adversely affected in athletes suffering from concussion (mild traumatic brain injury). This may be due to alterations in posture-related cortical potentials or disturbance of the neuronal networks.[12,13] Lower limb musculoskeletal injuries including ankle ligamentous injuries are also known to have long-term negative effects on body balance.[14] As approximately 83% of rugby players sustain these types of injury with the knee (25%) and ankle (21%) most commonly injured; and the incidence is 1.52 injuries per player overall,[7] it is reasonable to explore whether or not balance strategies, especially the ankle strategy, and balance performance are being compromised. This study had two aims: (1) to examine the difference in balance performance and balance strategy between rugby players and non-players, and (2) to explore the training- and injury-related factors that may affect rugby players' balance performance and balance strategy.

2. Methods

This was a cross-sectional and exploratory study. From June 2014 through May 2015, amateur rugby players were recruited from local and university rugby clubs by convenience sampling (via website and poster advertising). The inclusion criteria were (1) trained in rugby for at least one year, (2) regular rugby training (> 3 hours/week), and (3) aged between 18 and 33 years. The exclusion criteria were (1) serious injury that may affect balance performance (previous injuries that were fully recovered were acceptable), (2) significant musculoskeletal, cardiovascular (e.g., hypertension), neurological (e.g., peripheral neuropathy), visual, vestibular or other sensorimotor disorders, and (3) muscle fatigue on the day of the assessment.[15] Healthy active control participants were recruited from the university community by convenience sampling. The eligibility criteria were the same as those for the rugby group except that the control participants did not have rugby training experience or receive other regular sports training.

Ethical approval was provided by the Human Research Ethics Committee of the University of Hong Kong. Each participant gave informed written consent before joining the study. Data collection was performed by an experienced sports scientist in the Human Performance Laboratory of the Hong Kong Institute of Education. All experimental procedures were conducted in accordance with the Declaration of Helsinki.

Demographics, history of rugby training and history of injury, including all injuries sustained in past training years, were obtained by interviewing the participants. Body height and weight were measured and body mass index (BMI) was then calculated. Participants' standing balance performance and balance strategy under different sensory conditions were assessed using the sensory organization test (SOT) of the Smart Equitest computerized dynamic posturography (CDP) machine (NeuroCom International Inc., Clackamas, OR, USA). The SOT is a valid[16,17] and reliable ($ICC_{2,3} = 0.35\text{-}0.79$)[18] test for measuring postural stability and postural control strategy in adults.

During the test, participants wore a security harness and stood barefoot on both feet on the force platform of the CDP machine. Foot placement was standardized and determined by the participant's height. Participants were instructed to stand as steadily as possible with their arms resting by their sides and to look forward at a distant visual target. Each participant was then exposed to six different sensory conditions in order. Each sensory condition provided specific sensory inputs to the participant – condition 1: accurate somatosensory, visual and vestibular inputs; condition 2: accurate somatosensory and vestibular inputs and no visual input; condition 3: accurate somatosensory and vestibular inputs and inaccurate visual input; condition 4: accurate visual and vestibular inputs and inaccurate somatosensory input; condition 5: accurate vestibular input, inaccurate somatosensory input and no visual input; and condition 6: accurate vestibular input and inaccurate somatosensory and visual inputs.[19] So, practically, in conditions 1, 2 and 3, participants stood on a stable support surface with their eyes open, eyes closed and eyes open in a sway-referenced visual surround, respectively; in conditions 4, 5 and 6, participants stood on a sway-referenced platform with their eyes open, eyes closed and eyes open in a sway-referenced visual surround, respectively.[10,20] All participants underwent three 20-second testing trails for each sensory condition (i.e., 18 trials) (a video demonstration of the testing procedures - https://youtu.be/aM-Xafo2wjk). A familiarization trial was performed before data collection to minimize learning effects.[18]

The force platform of the CDP machine captured the trajectory of each participant's center of pressure (COP) during the testing trials, and this was then used to derive the equilibrium score (ES). ES is actually a non-directional percentage that compares the individual's peak amplitude of anterior-posterior (AP) sway to the theoretical limits of AP stability. An ES of 100 indicates no AP body sway in static standing whereas an ES of 0 represents an AP body sway exceeding the limit of stability, which would result in a fall or a corrective step to recover balance.[10,20] After obtaining the three ESs in each of the six sensory conditions, the mean ES in each condition was generated along with a composite ES, which is the weighted average of the six condition ESs.[20] The condition ESs and composite ES were used for analysis.

Apart from registering the trajectory of the COP of each participant, the center force transducer of the CDP machine also detected horizontal shear forces in the AP direction.[20] A strategy score (SS) quantifying the amount of hip and ankle sway used in maintaining upright standing balance during each 20-second SOT trial was derived. An SS close to 100 indicates that the participant predominantly used an ankle strategy to maintain standing balance and an SS approaching 0 reveals that the participant predominantly used a hip strategy to maintain equilibrium.[20] When healthy individuals respond to postural perturbations of increasing magnitude and velocity, they gradually shift from using an ankle strategy to a hip strategy and so the SS decreases.[10,11,21] In this study, the mean SS of the three trials of each SOT condition and the mean SS of all 18 trials (i.e., the composite SS) were used for analysis.

The following statistical analyses were performed using SPSS software version 20.0 (IBM, Armonk, NY). A significance level of 5% (two-tailed) was set. Descriptive statistics were calculated for demographic and outcome variables. Before running the parametric tests, Kolmogorov-Smirnov tests and/or histograms were used to check the normality of the data. Independent t-tests and chi-square tests were used to compare the continuous and categorical participant characteristics, respectively, of the rugby and control groups. To account for the possible confounding effect of BMI when comparing the SOT results of the two groups, multivariate analysis of covariance (MANCOVA) was performed twice – the first MANCOVA incorporated the ES of SOT conditions 1 to 6 and the second MANCOVA incorporated the SS of SOT conditions 1 to 6. Separate independent t-tests were performed to compare the composite scores of the two groups. Effect sizes (partial eta-squared for MANCOVA and Cohen's d for the independent t-test) were also calculated.

Pearson's correlation coefficient (r) and Spearman's correlation coefficient (rho) were used to examine the bivariate associations between SOT condition 6 scores and the rugby players' training history and injury history, respectively. SOT condition 6 was selected because this is the most challenging condition[10,20] and best resembles the sensory challenges faced during rugby games.[22] Next, multiple linear regression analyses were performed to identify the determinants of SOT condition 6 ES and SS among the rugby players. First, demographics including age, sex and BMI were added to the regression model. Then, the rugby training history (including training hours per week, age of onset of training and length of training) and injury history (including incidents of mild concussion, sprained ankle and sprained knee) that were significantly associated with SOT condition 6 ES or SS in the correlational analysis were entered into the regression model. Multicollinearity was checked – any predictors that had a variance inflation factor of >10 and a tolerance value of <0.1 were not included in the same regression model.

3. Results

Fifty-three amateur rugby players and 50 active control participants were screened. Forty-five rugby players and 41 controls were eligible to participate in the study. The participant characteristics are presented in Table 1. The demographics of the two groups were similar except that the rugby players had significantly higher BMI ($p < 0.05$) and higher incidents of ankle joint sprain ($p < 0.001$) and knee joint sprain ($p = 0.006$).

The MANCOVA results revealed an overall significant difference in condition SSs (Hotelling's trace = 4.537; F(6,78) = 58.977; $p < 0.001$) and close to significant difference in condition ESs (Hotelling's trace = 0.169; F(6,78) = 2.195; $p = 0.052$). When each individual SS and ES was considered, the between-group difference remained significant for all condition SSs and ESs ($p < 0.05$), except condition 3 ES ($p = 0.373$) and condition 5 ES ($p = 0.155$). The condition SSs were 1.99–54.90% lower in the rugby group than the control group, and the condition ESs were 1.06–14.29% lower in the rugby group than the control group. The composite SS and ES were also significantly lower in the rugby group, by 20.29% (t(84) = -18.580; $p < 0.001$) and 4.84% (t(84) = -2.590; $p = 0.011$), respectively. For those SSs and ESs that showed significant between-group differences, partial eta-squared values ranged from 0.053 (medium effect size) to 0.709 (very large effect size), and Cohen's d values ranged from 0.564 (medium effect size) to 4.072 (very large effect size)[23] (Table 2).

Bivariate correlation analyses showed that SOT condition 6 ES was positively correlated with age of onset of rugby training (r = 0.346; p = 0.020) and SOT condition 6 SS was positively correlated with length of rugby training (r = 0.435; p = 0.003). However, no significant correlations were found between SOT condition 6 scores and rugby training hours per week ($p > 0.05$) or the injury history (i.e., incidents of mild concussion, sprained ankle or knee) of the rugby players (all $p > 0.05$). So, only age of onset of rugby training and length of rugby training were used in the subsequent regression analysis.

In the first regression model (Table 3, model 1), age of onset of rugby training was used to predict SOT condition 6 ES. After adjusting for the effects of age, sex and BMI (confounders), the association of SOT condition 6 ES and the age of onset of rugby training was no longer significant (p = 0.659). In the second regression model (Table 3, model 2), length of rugby training was used to predict SOT condition 6 SS. After accounting for age, sex and BMI (confounders), length of rugby training remained independently associated with SOT condition 6 SS, explaining 15.7% of its variance (p = 0.006).

4. Discussion

We discovered that amateur rugby players with an average of 6.8 years of rugby experience (range: 1–14 years) demonstrated atypical postural control strategies and inferior static standing balance performance compared with active controls. The results are particularly concerning because both the composite ES and composite SS achieved by the rugby players were well below the healthy control values (composite ES effect size: 0.564 (medium); composite SS effect size: 4.072 (very large)). It seems that regular rugby training might compromise balance strategy and associated balance performance.

We found that the SOT condition SSs were 1.99–54.90% lower in the rugby group than the control group and the composite SS was also significantly lower in the rugby group by 20.29%. These findings collectively suggested that rugby players over relied on hip balance strategies and decreased reliance on ankle strategy to maintain postural stability. This inferior balance strategy observed in the rugby players might be explained by the specific movement patterns used during rugby matches. Biomechanical (movement) analysis has shown that during rugby matches, players use exaggerated body movements to deceive their opponents into thinking that they will run in a given direction, while minimizing postural control parameters to disguise sudden changes in posture to modify the final running direction. This requires a ‘bottom-up strategy’ in which displacement of the base of support is followed by a reorientation of the upper body. Sometimes, movement of the upper body is in the opposite direction to the direction of displacement of the base of support.[24] Therefore, hip sway may be the most common balance movement performed by rugby players. Habitual and exaggerated hip sway (i.e., use of a hip strategy) will compromise standing balance performance.[8]

Despite these negative findings, subsequent correlation analysis showed that SOT condition 6 SS was positively correlated with the length of rugby training. This result hinted that rugby players’ poor balance strategy is associated with insufficient training experience (in terms of years of training). With increasing training/playing experience, rugby players shifted their postural control strategy from a predominantly hip strategy to an ankle strategy (SOT condition 6 SS increased). Indeed, the length (years) of rugby training could explain 15.7% of the variance in the SOT condition 6 SS. Improved postural control strategy suggests that balance performance also improves as a result.[8] Our finding is in agreement with a previous study of rugby players that found that agility, which is closely related to balance, progressively improved with playing experience.[1] Hammami et al.[25] also reported that practicing rugby at the elite level may lead to long-term improvements in balance performance. The superior balance performance of experienced athletes may be related to repetitive training experiences that improve motor responses.[26] Further study is needed to explore the optimum/minimum training duration needed to enhance the balance strategy and performance of rugby players.

Our results also revealed that age of onset of rugby training is positively associated with balance performance in a sensory challenging environment but it is not a significant predictor. Previous research has suggested that introducing balance training at specific ages in children is crucial for the maturation and development of sensorimotor abilities and postural control.[4] Our previous study also showed that contact sports training may speed up the development of postural control and vestibular function in adolescents aged 11 to 14 years.[27] Further study is necessary to explore how the age of onset of training influences balance performance among child rugby players.

We also found that a history of mild concussion, sprained ankle or sprained knee was not associated with balance strategy or performance in the rugby group. Perhaps because we solicited both long-term and short-term injury histories (ranging from 1 to 14 years), recall bias or spontaneous full recovery might have occurred over time. Studies have shown that residual postural control (posturography) deficits usually last up to only 30 days after a concussion.[12,13,28] Holder-Powell and Rutherford[14] also found no relation between decrement in balance performance and lower limb injury (sprained ankle and knee) history. It seems that there is no long-term disability in postural control associated with rugby injuries. However, since our participants were recruited by convenience sampling and those who sustained severe injury were excluded, selection bias may be present and the results should be interpreted with caution.

This study has several more limitations. First, it is a cross-sectional study. No cause-and-effect relationship between rugby training and postural control can be established. Second, given the dynamic nature of rugby training, the SOT used in this study may not be the best method to assess the dynamic balance ability of rugby players. Further studies should measure participants' dynamic postural control instead of static postural control. Third, our regression model only explained 15.7% of the variance in SOT condition 6 SS, indicating some potentially important factors affecting postural control strategies (e.g., sensory organization and lower limb muscle strength and activation)[29,30] were not captured. Future studies could explore other factors affecting balance strategy and performance among rugby players. Finally, the results of this study can only be generalized to amateur rugby players aged 18–33 years, not rugby players of other training levels or age groups. Nevertheless, the results of this study will be of use to athletes and coaches seeking to identify postural control profiles of amateur rugby players.

5. Conclusion

Amateur rugby players predominantly relied on a hip, rather than ankle, strategy to maintain standing balance and demonstrated inferior balance performance compared to their non-training counterparts. Their poor balance strategy was associated with insufficient training experience but not with injury history.

Practical implications

- Suboptimal balance strategy and performance were demonstrated in rugby players.
- Their inferior balance strategy is associated with insufficient training experience but not history of injury.
- Results of this study will be of use to athletes and coaches seeking to identify postural control profiles of amateur rugby players.

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Conflict of interest

The authors have no conflicts of interest that are directly related to the content of this paper.

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Tables

Table 1

Participant characteristics.

	Rugby group **(n = 45)**	**Control group** **(n = 41)**	**p value**
Demographics			
Age, yr	21.9 ± 2.9	21.0 ± 1.4	0.052
Sex (male/female), n	25 / 20	23 / 18	0.960
Height, cm	168.7 ± 9.1	164.5 ± 8.2	0.027*
Weight, kg	64.3 ± 12.6	57.2 ± 7.9	0.002*
Body mass index, kg/m^2	22.4 ± 3.0	21.1 ± 2.7	0.037*
Rugby training history			
Training duration, hours/week	6.8 ± 2.8	---	
Age of onset of training, yr	18.4 ± 3.0	---	
Length of training, yr	3.4 ± 2.8	---	
Injury history			
Mild concussion, n (%)	4 (8.9%)	0 (0%)	0.051
Sprained ankle, n (%)	32 (71.1%)	3 (7.3%)	<0.001*
Sprained knee, n (%)	10 (22.2%)	1 (2.4%)	0.006*
Lower limb fractures, n (%)	0 (0%)	1 (2.4%)	0.292

Means ± standard deviations are presented unless specified otherwise.

*p <0.05.

Table 2

Sensory organization test results.

	Rugby group (n = 45)	**Control group (n = 41)**	**p value**	**Effect size**
Equilibrium scores				
Condition 1	94.03 ± 2.07	95.04 ± 1.62	0.020*	0.064
Condition 2	92.58 ± 2.69	93.67 ± 1.62	0.035*	0.053
Condition 3	92.23 ± 5.21	93.06 ± 2.98	0.373	0.010
Condition 4	80.95 ± 10.15	85.21 ± 7.66	0.007*	0.086
Condition 5	62.14 ± 12.21	65.11 ± 12.59	0.155	0.024
Condition 6	56.92 ± 18.66	66.41 ± 13.93	0.005*	0.092
Composite	76.11 ± 7.78	79.98 ± 5.80	0.011*	0.564
Strategy scores				
Condition 1	97.19 ± 1.93	99.16 ± 1.04	<0.001*	0.250
Condition 2	96.86 ± 1.99	99.14 ± 0.94	<0.001*	0.315
Condition 3	95.99 ± 4.90	98.92 ± 1.44	0.001*	0.122
Condition 4	70.97 ± 18.06	89.76 ± 3.21	<0.001*	0.326
Condition 5	36.19 ± 15.96	80.25 ± 9.32	<0.001*	0.746
Condition 6	39.99 ± 14.99	81.27 ± 11.55	<0.001*	0.709
Composite	72.87 ± 5.83	91.42 ± 2.74	<0.001*	4.072

Means ± standard deviations are presented unless specified otherwise.

*p <0.05.

Table 3

Multiple regression analyses for predicting sensory organization test equilibrium score and strategy score among rugby players (n = 45).

Model	**Predictor**	**F**	**R^2**	**Adjusted R^2**	**R^2 change**	**Unstandardized regression coefficient (B)**	**95% Confidence interval for B**	**Standardized regression coefficient (β)**	**p value**
Dependent variable 1: Sensory organization test condition 6 equilibrium score									
Model 1		$F_{4,40}$ = 4.777, P = 0.003	0.323	0.256					
	Age, yr				0.212	2.790	0.749, 4.832	0.433	0.009*
	Sex (male = 1, female = 2)					-12.252	-23.372, -1.132	-0.330	0.032*
	Body mass index, kg/m^2					-0.192	-2.038, 1.653	-0.031	0.834
	Age of onset of training, yr				**0.003**	**0.438**	**-1.553, 2.428**	**0.070**	**0.659**

Dependent variable 2: Sensory organization test condition 6 strategy score									
Model 2		$F_{4,40} = 3.181$, $P = 0.023$	0.241	0.165					
	Age, yr				0.038	-0.451	-2.182, 1.280	-0.087	0.601
	Sex (male = 1, female = 2)					-0.249	-9.546, 9.049	-0.008	0.957
	Body mass index, kg/m^2					1.095	-0.467, 2.658	0.219	0.164
	Length of training, yr				**0.157**	**2.513**	**0.747, 4.279**	**0.476**	**0.006***

*$p < 0.05$.