Sensory organisation and reactive balance control of amateur rugby players: A Cross-sectional Study

GARY CHI-CHING CHOW[1,2], JOANNE WAI-YEE CHUNG[3], ADA WAI-WING MA[3], DUNCAN J. MACFARLANE[1], & SHIRLEY SIU-MING FONG[1,*]

[1]*School of Public Health, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong,* [2]*Faculty of Liberal Arts and Social Sciences, The Education University of Hong Kong, Hong Kong,* [3]*Department of Health and Physical Education, The Education University of Hong Kong, Hong Kong*

Correspondence: Dr. Shirley Siu-Ming Fong, School of Public Health, The University of Hong Kong, 301F 3/F, The Hong Kong Jockey Club Building for Interdisciplinary Research, 5 Sassoon Road, Pokfulam, Hong Kong.

Tel.: (852)28315260; Fax: (852)28551712

E-mail: smfong@hku.hk (S.S.M. Fong)

Word count (excluding abstract and references): 3185

Abstract word count: 248

Number of tables: 3

Number of figures: 0

Abstract

Purpose: This study compared the sensory organisation and reactive balance control of amateur rugby players and a control group. *Methods:* Forty-one participants amateur rugby players (22 males: 19 females; mean height ± SD = 168.8 ± 8.8cm; mean weight ± SD = 63.9 ± 12.5kg) and 31 control participants (22 males: 9 females; mean height ± SD = 171.5 ± 10.3cm; mean weight ± SD = 63.8 ± 10.3kg) completed the study. Their sensory organisation and standing balance performance were evaluated using a sensory organisation test (SOT), and their reactive balance performance was quantified using a motor control test (MCT). The SOT equilibrium scores (ES) and sensory ratios and the MCT motor response latencies were the major outcome measures. *Results:* The results revealed that compared to the controls, amateur rugby players had lower SOT ESs under different sensory environments ($P < 0.001$, $\eta_p^2 = 0.142–0.254$) and prolonged reactive motor response times in the MCT ($P < 0.001$, $d = 0.890$). The vestibular and visual ratios were also lower in the rugby group ($P = 0.005$, $\eta_p^2 = 0.107$ and 0.108, respectively). No significant difference was found in the somatosensory ratio ($P = 0.853$, $\eta_p^2 < 0.001$) between the two groups. *Conclusions:* Amateur rugby players demonstrated inferior standing balance performance compared to their non-trained counterparts. They relied less heavily on vestibular and visual inputs to maintain standing balance under different sensory environments. In addition, they reacted more slowly to postural disturbance, reflecting their suboptimal reactive balance ability in standing.

Key words: *Rugby, postural control, sensory organisation, motor control*

Introduction

Rugby is an Olympic sport and a fast growing recreational sport. There are over 7.23 million rugby players in over 120 countries around the world (World Rugby, 2015a). This sport is physically demanding, requiring players to have an excellent physical profile, especially power (Hendricks, Karpul, & Lambert, 2014) and repeated-sprinting ability (Ross, Gill, & Cronin, 2015). Sprinting and physical collisions (contact events) are very common during rugby games (World Rugby, 2015b; 2015c). Therefore, as a contact sport, the incidence of injuries, particularly concussion, is very high among rugby players. According to a recent epidemiology study, there were approximately 8.3 and 4.5 concussions/1000 player-match-hours in rugby sevens and rugby-15s, respectively (Fuller & Taylor, 2015; Fuller, Taylor, & Raftery, 2015).

It is well known that sport concussion (mild traumatic brain injury) adversely affects postural control (balance) performance and is related to sensory organisation deficits (Broglio & Puetz, 2008; Howell, Osternig, & Chou, 2015; Parker et al., 2005, 2006, 2007 and 2008; Williams, Puetz, Giza, & Broglio, 2015). Sensory organisation refers to the ability of an individual to maintain body balance by effectively integrating vestibular, visual and somatosensory inputs (NeuroCom, 2008a). Previous studies reported that athletes with a history of concussion demonstrated gait instability in the frontal plane especially under divided attentions (Howell, Osternig, & Chou, 2015; Parker et al., 2005, 2006 and 2007). In fact, contact sports athletes consistently demonstrate unsteady gait and impaired balance performance even in the absence of a medically diagnosed concussion (Parker et al., 2008). So, it is plausible that rugby players with a history of concussion might have a certain degree of residual balance and sensory organisation deficits, even when they appear to be fully recovered (normal neurologically) (Howell, Osternig, & Chou, 2015). However, no study has explored the sensory organisation of balance control in these apparently healthy rugby players.

The balance performance of rugby players with no history of injury, but with adequate training experience may not be adversely affected. Indeed, it is plausible that they have better balance performance, particularly reactive balance performance, than individuals with no training, as during rugby games, a successful attack in a one-on-one situation requires the players to react instantaneously to different postural disturbances (Brault, Bideau, Craig, & Kulpa, 2010). Therefore, rugby training per se might be a good reactive balance training regimen as long as players are protected from injuries. However, to the best of our knowledge, no study has documented the reactive balance ability of rugby players.

This study had two aims: (1) to compare the sensory organisation of balance control and (2) to compare reactive balance control of rugby players in general with those of active controls. The results provided a clearer picture of the postural control profiles of amateur rugby players. These findings can be used to develop an evidence-based training strategy to improve balance/sports performance and reduce injuries among rugby players.

Methods

Participants

Amateur rugby players were recruited from local tertiary institutions and rugby clubs from June 2014 to July 2015 via convenience sampling. The inclusion criteria were as follows: 1) aged between 18 and 35 years (young adults); 2) had a minimum of one year of rugby training experience; and 3) participated in rugby games (rugby union or rugby sevens) regularly. The exclusion criteria were as follows: 1) sustained serious injury within the past 12 months that may affect test performance (fully recovered from concussion or other injuries was acceptable); 2) chronic disabilities resulting from previous injuries (e.g., functional instability of the knee due to a history of anterior cruciate injury or chronic ankle instability resulting from a grade III ankle sprain); 3) significant visual, vestibular, sensorimotor, cardiovascular (e.g., hypertension), neurological or musculoskeletal disorders; or 4) elite or professional rugby players. Healthy active controls were recruited from a local tertiary institute. The eligibility criteria were the same as for the rugby group, except that they had no experience in rugby.

Ethical approval was obtained from the Human Research Ethics Committee of the University of Hong Kong. Written informed consent was obtained from each eligible participant before the data collection began. All of the participants were screened by a sports scientist according to the above inclusion and exclusion criteria. All of the procedures were performed in accordance with the Declaration of Helsinki.

Outcome measurements

The data collection was performed by a sport scientist and two trained research assistants. It took place in the Human Performance Laboratory of our Institute. Participants were asked to avoid vigorous physical activity for 24 h prior to the test day. Demographic and relevant personal information such as medical history and injury history were obtained by interviewing the participants using a modified physical examination form for a pre-participation physical evaluation (American Academy of Pediatrics, 2010). Rugby training histories including training volume ($h \cdot wk^{-1}$), age of onset of training and total years of training were recorded. After the face-to-face interview, body height and weight were measured and body mass index (BMI, $kg \cdot m^{-}$

^{2}) was calculated.

Sensory Organisation Test

The sensory organisation test (SOT) of the computerized dynamic posturography machine (CDP, SMART EquiTest®, NeuroCom® International Inc., OR, USA) was used to assess each participant's sensory organisation of balance control. The SOT is a valid (Guskiewicz, et al., 1997) and reliable ($ICC_{2,3}$ = 0.35–0.79) (Wrisley, et al., 2007) test to measure balance performance in adults. During the test, the participants were required to stand barefoot on the force platform (46 × 46 cm dual force plate) of the CDP machine while wearing a safety harness to prevent falls. Foot placement was standardized according to the individual's body height. The participants were instructed to stand quietly with their arms at their sides and facing forward to the visual surround (Nashner, 1997; NeuroCom, 2008b).

The SOT consists of a sequence of six sensory (testing) conditions, with three trials for each condition. There are three visual conditions (eyes open, eyes closed, sway referenced) and two surface conditions (fixed, sway referenced), giving six sensory conditions in total (Table I). This test is able to create sensory conflicting situations that stress the adaptive responses of the central nervous system, and to assess the individual's ability to use vestibular, visual and somatosensory inputs to balance under these conditions. Each testing trial lasts for 20 s. In this study, the participants underwent all six sensory conditions in sequence. A familiarization trial was included prior to the actual testing. The centre of force was measured during the test by the dual force platform. The machine then calculated the participant's centre of gravity using the centre of force information along with knowledge of the participant's height. Based on the above information, the machine automatically generated an equilibrium score (ES) for each trial of each sensory condition. Then, a condition ES was calculated by averaging the ESs of the three trials. In addition, a composite ES (i.e., the weighted average of all of the condition ESs), representing the participant's overall balance performance, was generated. An ES of 100 (maximum value) indicated excellent balance performance, whereas an ES of 0 (minimum value) indicated a fall had occurred. In addition, three sensory ratios (Table I), i.e., vestibular ratio, visual ratio and somatosensory ratio, were derived automatically from the ESs. These sensory ratios reflect the relative reduction in postural stability when visual and/or somatosensory inputs were disrupted, thus forcing the participants to rely primarily on the remaining available sense to balance (Nashner, 1997; NeuroCom 2008b). The calculations and implications of the three sensory ratios are detailed in Table I.

****Table I near here****

Motor Control Test

The motor control test (MCT) of the CDP machine was used to assess the automatic postural response (reactive balance control) of the participants following an unexpected platform perturbation. Participants' foot placement and standing posture during the MCT were the same as the SOT. To avoid testing effect and anticipatory postural control, the test was performed once. During the test, the participants were instructed to face forward with eyes open and to stand quietly with arms by their sides.

The platform was suddenly translated backward and then forward. Each translation direction included three consecutive magnitudes of perturbation – small, medium and large (repeated one after another). The MCT consists of a sequence of six translation conditions of three trials each.

Each translation lasted for less than one second. The distance moved was normalized to the participant's height. The latency (ms) of the motor responses (force response in each leg) to the unexpected postural perturbation was measured for each trial. Then, a composite response time (ms) was derived based on the average latency scores of the two feet during the medium and large platform translations. A longer composite response time indicates a prolonged response to external perturbation and a score close to 0 indicates an extremely efficient automatic motor response (excellent reactive balance control) (NeuroCom, 2008a; Nashner, 1997; Shepard & Janky, 2008). The MCT is a valid and reliable test ($ICC_{2,3}$ = 0.71–0.86) for measuring reactive balance control in adults (Akhbari, et al., 2015).

Statistical analyses

The SPSS Statistics 21.0 software package (Armonk, NY: IBM Corp.) was used for all of the statistical analyses. Descriptive statistics were used to describe all of the demographic and outcome variables. The normality of the data was checked using Kolmogorov-Smirnov tests and histograms. The independent t test and chi-square test were used to compare the continuous and categorical (e.g., sex) demographic data, respectively, of the rugby and control groups. Then, a multivariate analysis of variance (MANOVA) was performed twice to compare (1) the ESs of the SOT conditions 1 to 6, and (2) the sensory ratios between the two groups. A multivariate analysis was used to obtain the Bonferroni-adjusted P values and control for the overall Type I error at 5%. An independent t test was performed to compare the SOT and the groups' MCT composite scores. The effect sizes (partial eta-squared, η_p^2 for the MANOVA and Cohen's d for the independent t test) were also calculated. Partial eta-squared values of 0.01, 0.06 and 0.14 represent small, medium and large effect sizes, respectively (Cohen, 1988), whereas Cohen's d values of 0.2, 0.6 and 1.2 indicate small, medium and large effect sizes, respectively (Hopkins, et al., 2009). A significance level of 0.05 (two-tailed) was adopted for all of the statistical comparisons.

Results

Forty-two amateur rugby players and 32 active control participants were recruited. One rugby player was excluded due to a significant musculoskeletal injury within the past 12 months that could have affected test performance, and one control participant was excluded for a high resting blood pressure. Forty-one participants with regular rugby training (22 males and 19 females; mean age ± SD = 21.4 ± 2.1 years; mean height ± SD = 168.8 ± 8.8cm; mean weight ± SD = 63.9 ± 12.5kg) and 31 control participants (22 males and 9 females; mean age ± SD = 20.6 ± 0.9 years; mean height ± SD = 171.5 ± 10.3cm; mean weight ± SD = 63.8 ± 10.3kg) completed the study. No significant differences were found between the demographic variables of the two groups (Table II). The rugby training history and injury history are presented in Table II.

****Table II near here****

The MANOVA results revealed that the ESs for conditions 1 to 6 in the rugby group were significantly lower than those of the control group [Hotelling's Trace = 0.600, $F(6, 65) = 6.495$, $P < 0.001$]. When each individual condition ES was considered, the between-group difference remained significant for all of the SOT conditions, except for condition 3. The SOT composite score was 8.8% lower in the rugby group (75.83 ± 8.04) than in the control group (83.16 ± 3.89) [$t(60.835) = –5.102$, $P < 0.001$]. For those outcomes that showed significant between-group differences, the partial eta-squared values ranged from 0.142 to 0.254, whereas the Cohen's d value was 1.161, indicating large to very large effect sizes (Table III).

For the three sensory ratios, the rugby group attained lower values than the control group overall (Hotelling's Trace = 0.148, $F(3, 68) = 3.353$, $P = 0.024$). Specifically, the vestibular and visual ratios were 10.8% ($P = 0.005$) and 6.5% ($P = 0.005$), respectively, lower in the rugby group (vestibular ratio = 0.66 ± 0.13; visual ratio = 0.86 ± 0.11) than in the control group (vestibular ratio = 0.74 ± 0.09; visual ratio = 0.92 ± 0.04), indicating that participants with rugby training relied less heavily on vestibular and visual inputs to balance. Medium effect sizes (0.107 and 0.108) were found for these between-group comparisons. The somatosensory ratio showed no significant difference in mean values between the two groups ($P = 0.853$) (Table III).

The MCT composite response time was 8.4% longer in the rugby group (138.24 ± 14.18) than in the control group (127.52 ± 9.46) [$t(70) = 3.642$, $P < 0.001$]. Cohen's d value was 0.890 (medium effect size) (Table III).

****Table III near here****

Discussion

To the best of our knowledge, this is the first study to examine the sensory organisation of balance control and reactive balance control in rugby players. In most of the SOT conditions, rugby players demonstrated inferior standing balance performance than the healthy active controls. This may be related to their altered sensory organisation of balance control. In particular, rugby players swayed significantly more when they relied only on vestibular input to balance, as reflected by their lower ES scores in SOT conditions 5 and 6, and the vestibular ratio.

We postulate that the significantly lower vestibular ratio might be due to dysfunction of the vestibular system caused by repetitive minor injuries during rugby training or games (Fong & Ng, 2012). Indeed, significantly more body sway (in terms of velocity and range) has also been found in other contact sport players (e.g., American football players) compared to healthy controls (Handrigan et al., 2012). The vestibular system is intricately organised and multiple levels of sensory processing are required to maintain equilibrium and proper head and body orientation in different environments (Khan & Chang, 2013). It is actually the most stable internal sensory source for postural control (Nashner, 1997). However, during rugby games, the vestibular apparatus is prone to injury because majority of the impacts were to the tempero-parietal region and the impact forces sustained by rugby players are very high (Mcintosh, Mccrory, & Comerford, 2000). For example, the magnitude of summed forward forces during the engagement phase of scrum range from 9100 N to 16500 N in men and 8700 N in women (Preatoni, Stokes, England, & Trewartha, 2013). As for tackles, which is the major cause of concussion injuries in rugby (Lopez et al., 2016), the impact force can be as high as 536 $kg \cdot m \cdot s^{-1}$ (Hendricks et al., 2014). In addition, rugby players sometimes position their head and neck in vulnerable positions such as cervical hyper-flexion during the scrum (Lark & McCarthy, 2007). All of these unfavourable factors might predispose rugby players' vestibular system to repetitive and minor traumatic injuries. Certainly, further study is required to directly examine the vestibular apparatus of rugby players to confirm our postulation.

Our results also revealed that rugby players rely less heavily on visual input to balance, perhaps because visual information is predominantly used for game tactics rather than for body balance. This finding is in line with previous studies suggesting that long-term sports training (with increasing level of expertise) is associated with a reduction of visual reliance for balance

(Fong & Ng, 2012; Paillard, et al., 2006), and that somatosensory (proprioceptive and tactile) input is the major sensory source for postural stability in high-level athletes (Paillard, et al., 2006; Vecchio, et al., 2008).

Regarding the somatosensory ratio (i.e., SOT condition 2 ES/SOT condition 1 ES), rugby players were no different than their non-trained counterparts. This finding is in agreement with previous studies reporting that the somatosensory function of contact sport (Taekwondo) athletes was similar to that of active controls (Fong, Fu, & Ng, 2012). Perhaps because SOT condition 2 might not be able to differentiate the superior somatosensory function of athletes from controls (Fong & Ng, 2012). It is also possible that the activities in which the controlled group were involved, were equally sufficient to contribute to the somatosensory function development, thus leading to the lack of difference in the somatosensory ratio between groups. Further true experimental studies are needed to confirm the results.

In addition to evaluating the static standing balance ability of the participants using SOT, MCT is also used to evaluate the overall latency of automatic postural responses (Akhbari et al., 2015; NeuroCom, 2008) and the long-loop pathway of the participants (Shepard & Janky, 2008). The longer MCT response time demonstrated in our rugby participants indicates they had slower lower limb muscular reactions to sudden postural perturbation than healthy active controls, perhaps because athletes with intensive sports training have better neuro-motor ability in response to sport-specific stimuli, but are less sensitive to other sensory stimuli (Chung & Ng, 2012) such as anteroposterior platform translation during the MCT. In addition, habitual pre-programmed reactions developed during rugby training might override the natural reflexive postural responses (Shumway-Cook & Woollacott, 2007, p.172–173). For example, repeatedly practicing post tackle techniques (i.e., falling and rolling forward after tackle) during rugby training (Handrigan et al., 2012; Van Rooyen, Yasin, & Viljoen, 2014) might inhibit normal muscle synergies for postural control. As a result, instead of trying to maintain an upright standing posture using ankle and hip strategies in response to platform translation, in the present study, rugby players tended to fall and use a step strategy to recover body balance (Hasan, 2005; Shumway-Cook & Woollacott, 2007) leading to the suboptimal MCT result.

There are some limitations in this study that should be considered when interpreting the findings. First, this was a cross-sectional study. The inferior balance performance of the rugby players may be explained by "nature" (genetics) or "nurture" (rugby training). Further experimental study is necessary to establish the causal relationship between rugby training and balance functions. Second, our participants were amateur rugby players in their early adulthood. Therefore, our findings cannot be generalized to rugby players of other age groups or other training levels (e.g., elite rugby players). Third, the physical activity level of the participants was not quantified that could have confounded the results. Finally, although we found that the balance performance of rugby players was inferior to that of no-training controls, we do not know whether they actually fell more frequently than normal people in daily life or during sports activities. Further studies may identify the exact causes of the poorer balance performance of rugby players and its effects on their daily lives. Effective treatment or training strategies could then be developed to improve balance performance and prevent injuries among rugby players. Despite these limitations, the results of this study may benefit athletes and coaches seeking to identify the postural control profile of amateur rugby players.

Conclusion

Amateur rugby players demonstrated inferior standing balance performance compared to their non-trained counterparts. They relied less heavily on vestibular and visual inputs to maintain standing balance under different sensory environments. In addition, their reactions to postural disturbance were slower, reflecting their suboptimal reactive balance ability in standing.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Akhbari, B., Salavati, M., Ahadi, J., Ferdowsi, F., Sarmadi, A., Keyhani, S., & Mohammadi, F. (2015). Reliability of dynamic balance simultaneously with cognitive performance in patients with ACL deficiency and after ACL reconstructions and in healthy controls. *Knee Surgery, Sports Traumatology, Arthroscopy, 23*(11), 3178–3185.

American Academy of Pediatrics. (2010). Preparticipation physical evaluation-Physical examination form. Retrieved December 10, 2015, from https://www.aap.org/en-us/about-the-aap/Committees-Councils-Sections/Council-on-sports-medicine-and-fitness/Pages/PPE.aspx

Brault, S., Bideau, B., Craig, C., & Kulpa, R. (2010). Balancing deceit and disguise: How to successfully fool the defender in a 1 vs. 1 situation in rugby. *Human Movement Science, 29*(3), 412–425.

Broglio, S. P., & Puetz, T. W. (2008). The effect of sport concussion on neurocognitive function, self-report symptoms and postural control: A meta-analysis. *Sports Medicine, 38*(1), 53–67.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Chung, P., & Ng, G. (2012). Taekwondo training improves the neuromotor excitability and reaction of large and small muscles. *Physical Therapy in Sport, 13*(3), 163–169.

Fong, S. S. M., Fu, S. N., & Ng, G. Y. F. (2012). Taekwondo training speeds up the development of balance and sensory functions in young adolescents. *Journal of Science and Medicine in Sport, 15*(1), 64–68.

Fong, S. S. M., & Ng, G. Y. F. (2012). Sensory integration and standing balance in adolescent Taekwondo practitioners. *Pediatric Exercise Science, 24*(1), 142–151.

Fuller, C., & Taylor, A. (2015). World Rugby: Surveillance Studies: Sevens World Series (Men) – Summary of Results: 2008/09 to 2014/15. Retrieved December 10, 2015, from http://playerwelfare.worldrugby.org/?documentid=159

Fuller, C. W., Taylor, A., & Raftery, M. (2015). Epidemiology of concussion in men's elite Rugby-7s (Sevens World Series) and Rugby-15s (Rugby World Cup, Junior World Championship and Rugby Trophy, Pacific Nations Cup and English Premiership). *British Journal of Sports Medicine, 49*(7), 478–483.

Guskiewicz, K., Reiemann, B., Perrin, D., & Nahner, L. (1997). Alternative approaches to the assessment of mild head injury in athletes. *Medicine & Science in Sports & Exercise, 29*(7 Suppl), S213–S221.

Handrigan, G. A., Berrigan, F., Hue, O., Simoneau, M., Corbeil, P., Tremblay, A., & Teasdale, N. (2012). The effects of muscle strength on center of pressure-based measures of postural sway in obese and heavy athletic individuals. *Gait & Posture, 35*(1), 88–91.

Hasan, Z. (2005). The human motor control system's response to mechanical perturbation: should it, can it, and does it ensure stability?. *Journal of Motor Behavior, 37*(6), 484–493.

Hendricks, S., Karpul, D., & Lambert, M. (2014). Momentum and kinetic energy before the tackle in rugby union. *Journal of Sports Science & Medicine, 13*(3), 557–563.

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise, 41*(1), 3–13.

Howell, D. R., Osternig, L. R., & Chou, L. S. (2015). Return to activity after concussion affects dual-task gait balance control recovery. *Medicine & Science in Sports & Exercise, 47*(4), 673–680.

Khan, S., & Chang, R. (2013). Anatomy of the vestibular system: A review. *Neurorehabilitation, 32*(3), 437–443.

Lark, S. D., & McCarthy, P. W. (2007). Cervical range of motion and proprioception in rugby players versus non-rugby players. *Journal of Sports Sciences*, *25*(8), 887–894.

Lopez, V. Jr., V., Ma, R., Weinstein, M. G., Cantu, R. C., Myers, L. S. D., Nadkar, N. S., & Allen, A. A. (2016). Concussive injuries in rugby 7s: An American experience and current review. *Medicine & Science in Sports & Exercise, 48*(7), 1320–1330.

Mcintosh, A.S., Mccrory, P., & Comerford, J. (2000). The dynamics of concussive head impacts in rugby and Australian rules football. *Medicine & Science in Sports & Exercise*, 32(12), 1980–1984.

Nashner, L. M. (1997). Computerized dynamic posturography. In G. P. Jacobson, C. W, Newman, & J. M. Kartush (Eds.), *Handbook of balance function and testing* (pp. 261–307). St. Louis: Mosby Yearbook Inc.

NeuroCom. (2008a). *Balance Manager® Systems – Clinical interpretation guide- Computerized dynamic posturography*. Clakamas, OR: NeuroCom International, Inc.

NeuroCom. (2008b). *Balance Manager® Systems – Instructions for use*. Clakamas, OR: NeuroCom International, Inc.

Paillard, T., Noé, F., Rivière, T., Marion, V., Montoya, R., & Dupui, P. (2006). Postural Performance and Strategy in the Unipedal Stance of Soccer Players at Different Levels of Competition. *Journal of Athletic Training*, *41*(2), 172–176.

Parker, T.M., Osternig, L.R., Lee, H.J., van Donkelaar, P., & Chou, L.S. (2005). The effect of divided attention on gait stability following concussion. *Clinical Biomechanics*, 20(4), 389–395.

Parker, T.M., Osternig, L.R., van Donkelaar, P., & Chou, L.S. (2006). Gait stability following concussion. *Medicine & Science in Sports & Exercise*, 38(6), 1032–1040.

Parker, T.M., Osternig, L.R., van Donkelaar, P., & Chou, L.S. (2007). Recovery of cognitive and dynamic motor function following concussion. *British Journal of Sports Medicine*, 41(12), 868–873.

Parker, T.M., Osternig, L.R., van Donkelaar, P., & Chou, L.S. (2008). Balance control during gait in athletes and non-athletes following concussion. *Medical Engineering and Physics*, 30(8), 959–967.

Preatoni, E., Stokes, K. A., England, M. E., & Trewartha, G. (2013). The influence of playing level on the biomechanical demands experienced by rugby union forwards during machine scrummaging. *Scandinavian Journal of Medicine & Science in Sports*, 23(3), 178–184.

Ross, A., Gill, N. D., & Cronin, J. B. (2015). Comparison of the anthropometric and physical characteristics of international and provincial rugby sevens players. *International Journal of Sports Physiology & Performance*, *10*(6), 780–785.

Shepard, N. T., & Janky, K. (2008). Background and technique of computerized dynamic posturography. In Jacobson G. P. & N. T. Shepard (Eds.), *Balance function assessment and management* (pp. 339–358). San Diego, CA: Plural Publishing Inc.

Shumway-Cook, A., & Woollacott, M. H. (2007). Normal Postural Control. *Motor control: Translating research into clinical practice* (3rd ed.) (pp.157–186). Philadelphia: Lippincott Williams and Wilkins.

Van Rooyen, M., Yasin, N., & Viljoen, W. (2014). Characteristics of an ‘effective’ tackle outcome in Six Nations rugby. *European Journal of Sport Science*, *14*(2), 123–129.

Vecchio, F., Del Percio, C., Marzano, N., Fiore, A., Toran, G., Aschieri, P., … Eusebi, F. (2008). Functional cortico-muscular coupling during upright standing in athletes and nonathletes: A coherence electroencephalographic-electromyographic study. *Behavioral Neuroscience, 122*(4), 917–927.

Williams, R., Puetz, T., Giza, C., & Broglio, S. (2015). Concussion recovery time among high school and collegiate athletes: A systematic review and meta-analysis. *Sports Medicine*, *45*(6), 893–903.

World Rugby. (2015a). World Rugby annual review 2014: Year in Review 2014. Retrieved December 10, 2015, from http://www.worldrugby.org/documents/annual-reports

World Rugby. (2015b). JWC Analysis 2014: Statistical analysis and match review – The Rugby Championship 2014: IRB game analysis. Retrieved December 10, 2015, from http://playerwelfare.worldrugby.org/?documentid=156

World Rugby. (2015c). WRWC Analysis 2014: Statistical analysis and match review – Women's Rugby World Cup 2014: IRB game analysis. Retrieved December 10, 2015, from http://playerwelfare.worldrugby.org/?documentid=156

Wrisley, D.M., Stephens, M.J., Mosley, S., Wojnowski, A., Duffy, J., & Burkard, R. (2007). Learning effects of repetitive administrations of the sensory organization test in healthy young adults. *Archives of Physical Medicine & Rehabilitation, 88*(8), 1049–1054.

Table I. Sensory organization test conditions and sensory ratio analysis.

Condition	Descriptions			Sensory Inputs		
	Eyes	Platform	Surroundings	Visual	Somatosensory	Vestibular
1	Open	Fixed		Available	Available	Available
2	Closed	Fixed			Available	Available
3	Open	Fixed	Sway-referenced	Disadvantage	Available	Available
4	Open	Sway-referenced		Available	Disadvantage	Available
5	Closed	Sway-referenced			Disadvantage	Available
6	Open	Sway-referenced	Sway-referenced	Disadvantage	Disadvantage	Available
Sensory ratio analysis						
Somatosensory ratio		Condition 2 equilibrium score / Condition 1 equilibrium score		Ability to use input from the somatosensory system to maintain balance		
Visual ratio		Condition 4 equilibrium score / Condition 1 equilibrium score		Ability to use input from the visual system to maintain balance		
Vestibular ratio		Condition 5 equilibrium score / Condition 1 equilibrium score		Ability to use input from the vestibular system to maintain balance		

Table II. Participant characteristics.

	Rugby-Training Group (n = 41)	Control Group (n = 31)	*P* Value
Demographics			
Age, years	21.4 (2.1)	20.6 (0.9)	0.056
Sex (male/female), n	22 / 19	22 / 9	0.136
Height, cm	168.8 (8.8)	171.5 (10.3)	0.226
Weight, kg	63.9 (12.5)	63.8 (10.3)	0.965
Body mass index, $kg \cdot m^{-2}$	22.3 (3.1)	21.6 (1.8)	0.264
Training history			
Training volume, $h \cdot wk^{-1}$	6.7 (2.7)	---	
Age of onset training, years	18.2 (2.9)	---	
Length of training, years	3.0 (2.5)	---	
Injury history			
Mild concussion, n (%)	4 (9.8%)	---	
Sprained ankle, n (%)	28 (68.3%)	---	
Sprained knee, n (%)	9 (22.0%)	---	
Lower limb fractures, n (%)	0 (0%)	---	

Means (standard deviations) are presented unless specified otherwise.

$*P < 0.05$.

Table III. Sensory organization test and motor control test results.

	Rugby group (n = 41) Mean	SD	Control group (n = 31) Mean	SD	Mean Difference Between Groups (Rugby – Control) (95% confidence interval)		*P* Value	Effect Size
SOT Equilibrium scores								
Condition 1	93.89	(2.08)	95.90	(1.10)	-2.01	(-2.83, -1.19)	< 0.001*	$\eta_p^2 = 0.254$
Condition 2	92.48	(2.77)	94.58	(1.74)	-2.10	(-3.23, -0.97)	< 0.001*	$\eta_p^2 = 0.164$
Condition 3	92.17	(5.42)	93.07	(2.89)	-0.90	(-3.04, 1.25)	0.408	$\eta_p^2 = 0.010$
Condition 4	80.74	(10.59)	88.47	(4.45)	-7.73	(-11.78, -3.69)	< 0.001*	$\eta_p^2 = 0.172$
Condition 5	61.84	(12.53)	70.77	(8.61)	-8.94	(-14.17, -3.70)	0.001*	$\eta_p^2 = 0.142$
Condition 6	55.50	(18.42)	72.59	(8.92)	-17.09	(-24.26, -9.92)	< 0.001*	$\eta_p^2 = 0.244$
Composite	75.83	(8.04)	83.16	(3.89)	-7.33	(-10.21, -4.46)	< 0.001*	$d = 1.161$
Sensory ratio								
Somatosensory	0.99	(0.03)	0.99	(0.01)	-0.00	(-0.00, 0.01)	0.853	$\eta_p^2 < 0.001$
Visual	0.86	(0.11)	0.92	(0.04)	-0.06	(-0.11, -0.02)	0.005*	$\eta_p^2 = 0.108$
Vestibular	0.66	(0.13)	0.74	(0.09)	-0.08	(-0.14, -0.03)	0.005*	$\eta_p^2 = 0.107$
MCT composite response time (ms)	138.24	(14.18)	127.52	(9.46)	10.73	(5.16, 16.30)	< 0.001*	$d = 0.890$

Means (standard deviations) are presented unless specified otherwise. *$P < 0.05$.

d: Cohen's d; η_p^2: Partial eta-squared