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Vestibulo-ocular dysfunction in adolescent rugby union players with and without a history of concussion

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ABSTRACT

Objectives: Sport-related concussions are common in adolescent contact sports. Vestibulo-ocular dysfunction has been reported in athletes post-concussion. There is a lack of research on vestibulo-ocular function in sporting adolescents, and the influence of previous concussions on the vestibular system in this population. The aim of this study was to investigate vestibulo-ocular function in a cohort of adolescent rugby players with and without a history of concussion during pre-season assessment.
Design: Cross-sectional cohort.
Methods: 213 male adolescent (13–18 years old) rugby players were recruited from six schools in Queensland, Australia. Vestibulo-ocular assessments were conducted during the preseason and included clinical assessment of oculomotor function and the vestibulo-ocular reflex (VOR) using the clinical and video-Head Impulse Test (HIT). Players were allocated into two groups: no history of concussion in the last 12 months ($n = 165$); and concussion in the last 12 months ($n = 48$).
Results: There were no between group differences in vestibulo-ocular function for players with and without a history of concussion ($p = 0.65$). However, vestibulo-ocular dysfunction was reported in 69 (32.7%) of the players tested, who had either abnormal oculomotor control or VOR function.
Conclusions: The high prevalence of vestibulo-ocular dysfunction in adolescent rugby players suggests that positive clinical findings post-concussion need to be interpreted carefully in the absence of baseline or pre-concussion assessments.

1. Introduction

Sport-related concussions are a growing concern and are amongst the most common sporting injuries in adolescents playing contact sports (Marar et al., 2012). Concussions in this age group are of great concern due to the uncertainty surrounding the pathophysiology of concussion injuries and the effects during cognitive maturation (Guskiewicz and McLeod, 2011). The vulnerability of the developing brain places adolescents at greater risk of significant cognitive morbidity and prolonged recovery (Zuckerman et al., 2012). Like many other contact sports, there is a high incidence of concussion in rugby union (Koh et al., 2003). Compared with other sports played by adolescents, rugby union has the highest incidence of concussion (Pfister et al., 2016), and these injuries have been reported to be more common in adolescents than adult players (Yard and Comstock, 2006). Recent injury surveillance of players from school level rugby union reported that a large proportion of injuries were sustained to the head and face region, with concussions being the most common injury (Archbold et al., 2017; Leung et al., 2017a,b).

There is emerging evidence of deficits in vestibular and oculomotor function in children and adolescents following a concussion (Corwin et al., 2015; Ellis et al., 2015), with dysfunction reported in as many as 30–80% (Mucha et al., 2014; Corwin et al., 2015; Ellis et al., 2015). Dizziness is commonly reported following concussion and may reflect an underlying vestibular and/or oculomotor dysfunction (Mucha et al., 2014). Visual symptoms such as blurred vision, double vision and light sensitivity are also commonly reported after concussion and may indicate functional oculomotor control issues (Ventura et al., 2016).

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Benign paroxysmal positional vertigo (BPPV) is also a common cause of dizziness and vertigo post head trauma and has been reported in children and adolescents post-concussion (Fife and Giza, 2013; Brodsky et al., 2018). Recent research has shown that deficits in vestibulo-ocular function in this age group can be associated with delayed symptom recovery, longer time to recover from neurocognitive deficits and delayed return to school (Corwin et al., 2015; Ellis et al., 2015). The presence of vestibulo-ocular dysfunction post-concussion has also been shown to be predictive of the development of post-concussion syndrome in adolescents (Ellis et al., 2015, 2017).

Optimal vestibulo-ocular function is important for adolescents participating in sports and academic activities. The vestibular system contributes to postural control through the vestibulo-spinal reflex and gaze stabilisation during head movement through the vestibulo-ocular reflex (VOR) (Herdman, 2007; Kontos et al., 2017). Oculomotor control involves eye movements and visual fixation which, in combination with the vestibular system, maintains gaze stability and the ability to scan and keep visual targets stationary when the head is still or moving at various velocities (Kontos et al., 2017). The vestibulo-ocular component of the vestibular system functions to stabilise vision during rapid or variable head movement which is important in sports requiring stable vision while running, tracking or catching a ball. Academic activities such as reading and notetaking require integration of the oculomotor system with cognition and other processes in the central nervous system (Rine and Wiener-Vacher, 2013; Corwin et al., 2015; Kontos et al., 2017). Sensorimotor systems mature during childhood and adolescence, with the vestibular system demonstrated to be the slowest sensory system associated with postural control to mature (Hirabayashi and Iwasaki, 1995). Concussion-related disruption to the vestibular and/or oculomotor system could therefore have a significant impact in adolescents.

During adolescence, there may be a regression or delay in sensorimotor function during rapid growth spurts (Quatman-Yates et al., 2012), while other studies have reported that vestibulo-ocular dysfunction commonly occurs in children (Rine and Wiener-Vacher, 2013). There are however, a lack of studies investigating vestibulo-ocular function in sporting adolescent populations and it is unknown whether participation in contact sports during adolescent development affects vestibulo-ocular function. It is also unknown how concussion affects vestibulo-ocular function during adolescent development. Whilst many studies have documented vestibulo-ocular deficits in adolescents post-concussion (Mucha et al., 2014; Corwin et al., 2015; Ellis et al., 2015), these studies did not compare vestibulo-ocular function pre and post-concussion in order to understand the causal relationship between concussion and vestibulo-ocular deficits. Understanding usual vestibulo-ocular function in sporting adolescents is important when assessing these players post-concussion from a diagnosis and management perspective. If the stage of adolescent development negatively affects the vestibular system, there is potential for false positive results when testing adolescent players post-concussion. Another confounding variable could be the presence of residual negative effects on vestibulo-ocular function in those with a history of a previous concussion, and whether there are long term effects of concussion which could be targeted for intervention. The aim of this study was to investigate differences in vestibulo-ocular function in a cohort of adolescent rugby union players with and without a history of concussion.

2. Methods

2.1. Participants

Two-hundred and thirteen male school aged rugby union players were recruited from six schools in Queensland, Australia. The school principals gave permission for the students to participate. Players in the schools' senior playing squad or emerging playing squad at the beginning of the 2016 school rugby union season were eligible for inclusion in the study. Written informed player assent and parental consent were obtained for all participants. The study was approved by the university's ethics committee (HREC 2014-253Q).

Participants were assessed during the preseason at either the school campus or at the schools' preseason rugby camps. All participants completed a self-report questionnaire to obtain demographic information, rugby playing position, years playing rugby and medical information including history of concussion in the last 12 months. A concussion history was recorded if it met the definitional criteria of concussion based of the 4th consensus statement for concussion in sport (McCrory et al., 2013). An interview was conducted with all participants to confirm the accuracy of self-report and document the occurrence of the most recent concussion. The Dizziness Handicap Inventory (DHI) (Jacobson and Newman, 1990) was administered to determine the impact of dizziness on daily life and the 22-item Post-Concussion Symptom Scale (PCSS) (Lovell et al., 2006) was also used to establish the baseline symptom profile of players.

2.2. Assessment of vestibulo-ocular function

A standardised clinical assessment of vestibulo-ocular function was conducted by physiotherapists with additional training in the assessment of the vestibular system (AR, FL, CS). All players were screened to ensure that they had adequate cervical spine range of motion required for conducting the tests. Frenzel Goggles (Interacoustic AS, Video Frenzel Lens VF405 Unit – Monocular Vision) were worn during the assessment to record eye movements. The protocol used to evaluate vestibulo-ocular function included assessment of oculomotor function, the vestibulo-ocular reflex (VOR) and screening for benign paroxysmal positional vertigo (BPPV).

Testing of oculomotor function included assessment of smooth pursuit eye movement and testing for spontaneous and gaze-evoked nystagmus with vision, and with vision occluded (Honaker et al., 2015; Hides et al., 2017). The use of Frenzel Goggles enabled observation of spontaneous and gaze-evoked nystagmus with vision occluded. Oculomotor function was classified as normal or abnormal.

The horizontal VOR was assessed using the standard clinical-Head Impulse Test (HIT) (Fig. 1a) (Halmagyi and Curthoys, 1988) and the test was recorded with the Frenzel Goggles to identify overt saccades. The clinical-HIT was classified as normal or abnormal. The horizontal VOR was further assessed using video-oculography goggles (EyeSeeCam Interacoustics AS) with a sampling rate of 220 Hz. The Video-Head Impulse Test (VHIT) (Fig. 1b) recorded overt and covert saccades and calculated horizontal VOR gain (Mossman et al., 2015). Participants were instructed to maintain fixed gaze on a target 1 m in front of them while the examiner performed a minimum of 10 horizontal head impulses unpredictably to both left and right directions. The VOR gain represents eye velocity relative to head velocity and the VHIT software automatically calculated the instantaneous gains at 60 ms and 80 ms after the impulse to identify mean horizontal VOR gain and asymmetry between the left and right vestibular function. Gain values at 60 ms were used for further analysis as 80 ms may be affected by catch-up saccades (Mossman et al., 2015). There are currently no studies reporting normative ranges of the VOR in healthy adolescents using the VHIT EyeSeeCam system (Interacoustic AS). To establish a comparison range for use in the current investigation, preliminary results from the players with no history of concussion ($n = 115$) were used. The mean horizontal VOR gain at 60 ms for those without a history of concussion was 0.97 (SD 0.18) for the left and 0.98 (SD 0.16) for the right side. VHIT gains were dichotomized as 'normal' if they were within 2 standard deviations of the mean value and as 'abnormal' if they were outside of this range.

Screening for BPPV was conducted using vestibular positional testing. Dysfunction of the vestibular system has been demonstrated post-concussion with the presence of BPPV in patients post head trauma contributing to symptoms of dizziness and vertigo (Fife and Giza, 2013;

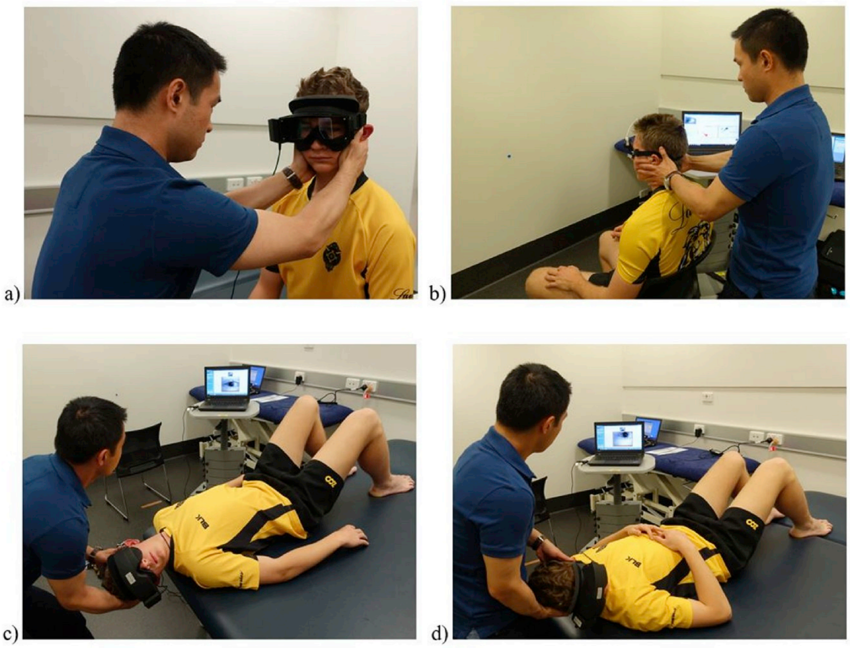

Fig. 1. Assessment of the horizontal VOR using the a) Clinical-Head Impulse Test, and b) Video-Head Impulse Test. Screening the vestibular system for BPPV in the anterior and posterior semicircular canal using the, c) Hall Pike-Dix Manoeuvre, and in the horizontal semicircular canal using the, d) Head Roll Test. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Brodsky et al., 2018). Assessment of the anterior and posterior semicircular canals was conducted using the Hallpike-Dix manoeuvre (Fig. 1c) and the horizontal semicircular canals were assessed using the Head Roll Test (Fig. 1d). During testing, dizziness symptoms were noted and presence of nystagmus recorded using Frenzel goggles. BPPV was identified if both symptoms and corresponding nystagmus were elicited during that testing manoeuvre, following standard clinical assessment guidelines (Bhattacharyya et al., 2017).

2.3. Statistical analysis

Data analysis was conducted using SPSS version 22.0 [IBM, USA]. To determine if there was a difference in vestibulo-ocular function between players with and without a history of concussion, players were categorised into two groups based on self-reported history of concussion in the last 12 months (no concussion in the last 12 months or concussion within the last 12 months). One-way analyses of variance (ANOVAs) were used to compare demographic data, DHI and PCSS between groups. Pearson's chi squared tests (χ^2) were used to compare clinical measures between groups for oculomotor function, VOR function, and vestibular positional testing (normal versus abnormal). Significance was set at $p < 0.05$. The overall vestibulo-ocular function (normal versus abnormal) was assessed with Pearson's chi squared test and Bonferroni corrections were made, with significance set at $p < 0.02$. All cases were assessed ($n = 213$) except for the VHIT measure, where VHIT gains were recorded for 210 players and recordings for 3 players were discarded due to poor data output.

3. Results

A total of 213 players participated in the study. The mean values (standard deviation) for age, height and weight of all participants were 15.9 (1.1) years, 180.5 (7.7) centimetres and 82.4 (3.6) kilograms. The mean number of years playing rugby was 8.2 (2.9) years. The distribution of players in the two groups was: no concussion in the last 12 months, $n = 165$; and concussion in the last 12 months, $n = 48$. There were no significant differences between groups for age, height, weight, number of years playing rugby, DHI and PCSS scores ($p > 0.05$) (Table 1).

There were no differences between the two groups for oculomotor function ($p = 0.91$), the vestibulo-ocular reflex ($p = 0.71$) and overall vestibulo-ocular function ($p = 0.65$). Results of vestibulo-ocular function testing are presented for each group in Table 2. While no differences between groups were found, 32–35% of adolescent rugby players were found to have deficits in vestibulo-ocular function irrespective of their history of concussion (Table 2). During the positional testing for BPPV, no players were diagnosed with BPPV. However, positional nystagmus was noted during the testing procedure in 56 players.

4. Discussion

Our study of vestibulo-ocular function in adolescent rugby players during pre-season assessment showed that there were no between group differences in oculomotor function or the horizontal VOR for players with and without a history of concussion in the last 12 months. Interestingly, our study also demonstrated that deficits in vestibulo-ocular function were present in as many as 32–35% of adolescent rugby players irrespective of their history of concussion. Establishing if a relationship exists between history of concussion and function of the vestibulo-ocular system may be important information to consider when interpreting post-concussion assessments. If residual deficits in function were shown to persist post-concussion, it would be difficult to determine if vestibulo-ocular dysfunction (if present) after an injury was actually associated with the recent concussion.

Previous studies have reported the presence of vestibulo-ocular dysfunction in adolescent athletes post-concussion. However, wide variations in the prevalence of vestibulo-ocular dysfunction were reported, ranging from 30 to 80% (Corwin et al., 2015; Ellis et al., 2015; Master et al., 2016). One possible explanation for the relatively high rates of vestibulo-ocular dysfunction observed in our current investigation, and the wide variation reported in previous studies, could be that some of the changes observed were age related. Our cohort ranged in age from 13 to 18 years. The vestibulo-ocular and vestibulo-spinal pathways are still maturing between 6 and 12 years of age and may not reach integrated function similar to an adult until 15 years of age (Herdman, 2007; Charpiot et al., 2010). The VOR may still be maturing until the age of 15 years, and its' function only becomes similar to that of adults after 16 years of age (Wiener-Vacher and Wiener, 2017). The prevalence of vestibulo-ocular dysfunction observed across the two groups in the current investigation could therefore represent

Table 1
The mean and standard deviations for demographic information, DHI and PCSS of players with and without a self-reported history of concussion within the last 12 months.

	No concussion in last 12 months (n = 165) Mean (SD)	Concussion in last 12 months (n = 48) Mean (SD)	p-value
Age	15.9 (1.2)	16.0 (0.9)	0.41
Height	180.5 (8.0)	180.6 (6.7)	0.94
Weight	82.4 (14.0)	82.5 (12.3)	0.96
Years playing rugby	8.1 (3.0)	8.5 (2.9)	0.48
Dizziness Handicap Inventory (DHI)	4.8 (7.8)	6.2 (9.9)	0.09
Post-Concussion Symptom Scale (PCSS) – Total	1.9 (2.8)	2.5 (4.0)	0.29
Post-Concussion Symptom Scale (PCSS) – Severity	3.4 (5.7)	3.8 (6.4)	0.74

Table 2
The proportion and number of adolescent rugby union players with abnormal oculomotor and VOR function, presence of BPPV and overall vestibulo-ocular dysfunction for those with and without a self-reported history of concussion within the last 12 months.

	No concussion in last 12 months (n = 165) Proportion (%)	Concussion in last 12 months (n = 48) Proportion (%)	p-value	Total Group (n = 213) Proportion (%)
Oculomotor Function				
Smooth Pursuit (Abnormal)	14/165 (8.5%)	6/48 (12.5%)		
Gaze-evoked Nystagmus – Vision (Abnormal)	2/165 (1.2%)	0/48		
Gaze-evoked Nystagmus – Vision Occluded (Abnormal)	34/165 (20.6%)	8/48 (16.7%)		
Oculomotor Dysfunction	**46/165 (27.9%)**	**13/48 (27.1%)**	**0.91**	**59/213 (27.7%)**
Vestibulo-ocular Reflex (VOR)				
Clinical-HIT (Abnormal)	8/165 (4.8%)	2/48 (4.2%)		
Video-HIT gain at 60 ms (Abnormal)	7/162 (4.3%)	3/48 (6.3%)		
VOR Dysfunction	**14/162 (8.6%)**	**5/48 (10.4%)**	**0.71**	**19/210 (9%)**
Vestibular Positional Testing				
Hall Pike Dix – (BPPV Present)	0/117	0/48		
Head Roll – (BPPV Present)	0/117	0/48		
BPPV Diagnosed	**0/117**	**0/48**	**-**	**0/213**
Vestibulo-ocular Dysfunction	**52/163 (31.9%)**	**17/48 (35.4%)**	**0.65** #	**69/211 (32.7%)**

Significance set at $p < 0.02$.

different maturation rates of the vestibular system during adolescent development. Although we are unable to verify maturation from the methodology employed in the current investigation, a systematic review has indicated that not only may sensorimotor function not be fully mature as children reach adolescence, regressions of some aspects of sensorimotor function may also occur at this time (Quatman-Yates et al., 2012). Clinical findings of vestibulo-ocular dysfunction in adolescents post-concussion therefore need to be interpreted carefully as they may be related to athlete age and stage of maturation of the vestibular and ocular systems.

The current investigation is the first study to report results of VHIT assessment of the horizontal VOR in a healthy athletic adolescent population. A recent study of the VOR using the VHIT in infants and children found rapid increases in VOR gain up until 6 years of age and a significant increase up until 16 years (Wiener-Vacher and Wiener, 2017). This study, however did not report differences in VOR gain between children aged 10–15 years and adults (Wiener-Vacher and Wiener, 2017). Variations in horizontal VOR velocity gain have been presumed to be associated with ageing in adults, however the differences reported were minor and normative ranges were therefore reported for a group of people aged from 20 to 80 years (Mossman et al., 2015) and this remained stable until 90 years of age (Matino-Soler et al., 2015). Preliminary calculation of normal horizontal VOR function in our study base on previously published normative data using the EyeSeeCam (Interacoustics AS) led to classification of a large number of players with 'abnormal' VOR function (Blodow et al., 2013; Mossman et al., 2015). These previous studies conducted on normal adult populations reported horizontal VOR velocity gain of 0.94 (SD 0.10) (Mossman et al., 2015) and 0.96 (SD 0.08) (Blodow et al., 2013). A normative range for horizontal VOR gain calculated from data of the players in our study without any history of concussion was deemed to be more appropriate to use to classify VOR function as 'normal' or 'abnormal' in our study of adolescent rugby players. The standard deviation reported in our study was considerably larger when compared with previously published normative data. Calculation of normative ranges using 2 × standard deviation from our cohort led to a larger range in gain for horizontal VOR velocity which we would propose should be considered as 'normal' for this adolescent population. Comparisons with adult VOR function may not be appropriate due to the potential influence of developmental maturation. The current study is the first to investigate vestibulo-ocular function in adolescent rugby union players. Although assessment and management of the vestibular system post-concussion has attracted great attention, our results suggest further investigation of vestibulo-ocular function in adolescents and the effect of concussion on the vestibular system is required.

This study had some limitations, in that group allocation was based on player self-reported concussion history. It is possible that some players mistakenly allocated themselves to the no concussion history group due to misconceptions and basic knowledge of concussion among adolescent rugby union players (Kearney and See, 2017). However, measures were taken in the questionnaire to ascertain history of concussion based on a definitional criteria of concussion (McCrory et al., 2013), followed by a participant interview to confirm accuracy of self-reported concussion and occurrence of the most recent concussion. Although our study adopted different vestibulo-ocular assessment protocols to the Vestibular/Ocular Motor Screen Assessment (Mucha et al., 2014), our study protocol included positional testing to identify BPPV and comprehensively assessed the VOR using instrumented head impulse testing. The instrumented equipment used in our study is commonly used clinically in vestibular physiotherapy, and was chosen because assessments were conducted at school facilities and not in a laboratory. Comprehensive assessment using laboratory-based vestibular equipment may provide a more detailed understanding of vestibulo-ocular function in adolescents. Another limitation of the current study was that the results were from a cohort of male adolescent rugby players, and results may not be generalizable to other sports, or to adolescent female athletes. Future studies could compare changes in vestibulo-ocular function assessed post-concussion with baseline pre-concussion measures to confirm that vestibulo-ocular function changes observed post-concussion in adolescents are related to the concussion.

5. Conclusion

Deficits in vestibulo-ocular function were present in as many as one third of adolescent rugby players, irrespective of self-reported history of concussion. Whilst the presence or absence of abnormal vestibulo-ocular findings are important to consider in the diagnosis and management of sports-related concussion, abnormal findings are common in this age group and could possibly be related to other factors such as maturation. Positive clinical findings post-concussion in adolescents should therefore be interpreted carefully in the absence of pre-concussion assessments. Comparison between baseline and post-concussion assessment is likely to provide further understanding of the effect of concussion on the vestibular system in adolescents.

6. Implications

- Vestibulo-ocular dysfunction was relatively common among adolescent rugby union players with and without a history of concussion.
- Health and medical practitioners require an understanding of the players' pre-injury vestibulo-ocular function in order to interpret positive clinical findings post-concussion and avoid false positives on testing.
- Vestibulo-ocular dysfunction in adolescents may be due to maturation or regression, and therefore vestibulo-ocular assessments should not be used in isolation when assessing adolescents post-concussion.
- For future research, availability of preseason measures would allow appropriate interpretation of the effect of concussion on vestibulo-ocular function in this population.

Conflicts of interest

The authors declare there were no conflicts of interest. The project was given ethics approval by the University Human Research Ethics Committee (HREC 2014-253Q). I also declare that I am funded through a post-graduate scholarship from the National Health and Medical Research Committee (NHMRC) (APP1133186). The authors declare that the manuscript submitted has not been published elsewhere or are not being considered for publication elsewhere, and that the research reported will not be submitted for publication elsewhere until a final decision has been made as to its acceptability by Musculoskeletal and Science in Practice.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.msksp.2018.12.007.

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