HEAD ACCELERATION DURING A SIMULATED MATCH LOAD OF TACKLES

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This study aimed to determine the acceleration of the head relative to the thorax during rugby tackles and to examine the relationship between this acceleration and neck strength. Six state-level rugby players were randomly paired and engaged in 15 repeated front-on tackles. High speed motion capture recorded head movement while neck strength was measured in an isokinetic dynamometer. Mean (SD) peak head acceleration for the ball carrier and tackler were 4.2g (±4.6) and 19.8g (±10.9) respectively. Correlation analyses showed the higher the flexion to extension neck strength ratio the lower the acceleration for the tackler only (r = 0.98). There is a much greater risk of being exposed to high accelerations of the head relative to the thorax for the tackler compared to the ball carrier. Further, minimising the strength difference between the neck flexors and extensors may have an effect of reducing head acceleration during a tackle.

KEY WORDS: Rugby, contre-coup injury, tackling, contact sports, brain concussion.

INTRODUCTION: During a typical front-on tackle in rugby, the head is known to oscillate about the thorax as a result of the impact and a sudden change in velocity (Arvind et al, 2009). The effect of this type of movement has the potential to cause minor brain trauma that goes unnoticed, predisposing players to a concussion during a game (Shuttleworth-Rdwards & Radloff, 2009). Athletes with high exposures to concussive and sub-concussive events can suffer long term brain deficits and neurodegenerative diseases such as chronic traumatic encephalopathy (CTE). A recent systemic review characterised CTE sufferers as having cognitive and mental health problems with an absence of any other disease that may explain the clinical or pathological findings (Gardner et al, 2014). Besides the number of exposures that could potentially be dangerous to players in contact sports, the force of the collision during a tackle may also influence pathology. The resultant force of a tackle depends on the mass of the players, the relative speed at which both players are travelling and from which direction the impact occurs from. A front-on collision will cause rapid deceleration and therefore the contre-coup experienced is likely to be larger than the tackle impeding the player from behind (Barth et al, 2001). It has been identified during whiplash simulations, injury to the musculoskeletal structures of the head and neck occur at head accelerations above 5g (Ito et al, 2004). If 5g is enough to affect the cervical musculoskeletal structures, the question arises whether there is simultaneous micro-trauma occurring in the brain resulting from the same force?

Despite a number of field-based investigations into the effects of tackling on the head, the research methods of these studies do not give a true indication of independent head movement during a tackle nor do they describe the multi-planar nature of the movement. Thus it is unknown whether such head movement is capable of producing this adverse effect on the brain (Shuttleworth-Rdwards & Radloff, 2009). Further, since the head is stabilized by structures in the neck, it can be proposed that mechanical stability of the head may be a mechanism to alleviate the excessive movement of the head in response to a perturbation such as a contre-coup (Eckner et al, 2011). The purpose of this study was to measure three-dimensional head acceleration relative to the thorax during a simulated, game load of tackles and to determine whether mechanical strength of the neck musculature has the potential to stabilise the head during a tackle.

METHODS: An experimental, cross-sectional design with repeated measures was used for this study. Institutional Human Research Ethics Committee (HR231/2015) approved this study and all participants provided informed written consent before participation.

Six male, state-level Rugby Union players were recruited for this study. Cervical musculature strength was measured with an isokinetic dynamometer at 200Hz (Humac Norm, Computer Sports Medicine, Inc. MA, USA) to obtain peak isometric flexion and extension torque. An 18-camera motion capture system (Vicon MX, Oxford Metrics, Inc. UK) was used to obtain three-dimensional kinematics at 250Hz. Retro-reflective markers for motion tracking were applied to the participant's thorax with two markers placed 2cm posteriorly to the acromioclavicular joints, one on the xiphoid process, one on the 7th cervical spinous process and one on the superior scapula angle for referencing. A further four markers were attached to a soft rugby helmet (Xact Headgear, Gilbert) worn by the participants to represent three-dimensional head movement. The laboratory was set up with padded mats in a 3x5m area with the participants positioned 9m apart at opposite sides of the room. The ball carrier was instructed to dodge the tackler and reach the opposite side of the marked area whilst the tackler was instructed to prevent this from happening by bringing the ball carrier to the ground. The players engaged in the tackle and resumed starting positions when the ball carrier had been tackled to the ground, the tackle had come to a standstill or the ball carrier reached the opposite side of the marked area. Participants engaged in one tackle every minute for 15 min in total. Three-dimensional head acceleration relative to the thorax (HrT) was calculated from coordinate data in a customised LabVIEW program (2015 SP1, National Instruments Corp, Austin TX). This program used the mid-point of the left and right rear head markers to represent the head and the C7 marker to represent the thorax. These markers were chosen, as they were the most stable during all the trials. The program used these reference points to calculate velocity vectors in each direction (X, Y and Z) of the head relative to the thorax. The velocity vectors were then used to calculate the resultant linear acceleration (g) of the head relative to the thorax. The tackle phase was separated from the landing phase so that the results only described the tackling acceleration. An independent sample t-test was conducted to determine any significant difference between the peak accelerations of the tackler and ball carrier. A correlational analysis was run between peak isometric neck strength (flexion and extension) and the peak head acceleration of both the tackler and ball carrier. A correlation was also conducted between the neck strength ratio (flexion: extension) and the peak head accelerations to examine this relationship. All statistical analysis was conducted in SPSS (SPSS 17, Chicago, IL, USA.).

RESULTS: The participants were aged between 20 to 32 years (mean (SD) age 26.3 ± 4.7 years, height 1.77 ± 6.2m and weight 84.4 ± 6.5kg). Five of the participants had over 10 years of playing experience and the one remaining player had 3 years of experience. A total of 28 tackles were recorded successfully, the remaining tackles were excluded from the data due to issues with marker occlusion. The tackler experienced significantly greater peak head accelerations relative to the thorax compared to the ball carrier (Table 1).

Table 1
Summary of Results (Mean (SD))

	Tackler	Ball carrier
Extension neck strength (Nm)	50.7 (7.4)	48.7 (14.7)
Flexion neck strength (Nm)	24.5 (1.4)	23.7 (4.4)
Neck flexion to extension ratio	0.48 (0.06)	0.5 (0.09)
Peak acceleration (HrT) (g)	19.8 (10.9)*	4.2 (4.6)*
Peak approach velocity (m/sec)	2.8 (0.4)	3.3 (0.7)

* $P \leq 0.05$

Correlational analysis revealed a strong positive relationship between extension neck strength and average peak acceleration of the tackler (HrT) (r = 0.91) and between flexion neck strength and peak acceleration HrT of the ball carrier (r = 0.86). A strong negative relationship between the flexion extension ratio and peak acceleration, indicating that the higher the ratio the lower the peak acceleration HrT for the tackler only (r = 0.98).

DISCUSSION: In this study, the tackler's head reached an average peak acceleration of 19.8g relative to the thorax while the ball carrier experienced an average peak of 4.2g per tackle. Other studies of head kinematics during head impact in sport have also reported similar levels of acceleration. In a laboratory setting, Naunheim et al. (2003) measured head accelerations in response to heading a soccer ball and showed head accelerations of 15-20g in response to the impact. In field-based studies of head impacts using helmet accelerometers higher mean accelerations (46.7g) have been reported during American football matches (Wong et al, 2014). These researchers however showed 85% of head impacts during these games had linear accelerations of less than 30g.

In judging the severity of the head impact, Naunheim et al. (2003) quantified their results with the Gadd Severity Index (GSI), which is used to predict when a single linear acceleration may lead to brain injury (Greenwald et al, 2008). With consideration that approximately 1000 on the GSI is considered to be capable of causing death, Naunheim et al. (2003) identified the highest GSI score to be 21 in response to heading a soccer ball. It should however be noted that the GSI was developed to detect traumatic brain injuries and does not take into account rotational accelerations which are thought to be more harmful due to the increased risk of the brain scraping the inner lining of the skull. In comparison to the findings of Naunheim et al. (2003) it can be suggested that the present study's levels of accelerations do not have the potential to cause brain damage from a single hit, however the cumulative effect of this is unknown. It may therefore be more important to consider not only the high level impacts, but also the repetitive low level accelerations that occur much more frequently when hypothesizing a cumulative effect.

Crisco et al. (2011) reported in a single NFL season, players experienced an average of 420 direct impacts to the head. If we then consider the repetitive low level accelerations identified from each tackle in the current investigation, the possible cumulative effect becomes much more concerning. Although many studies have suggested this cumulative effect to possibly be injury causing, the true repercussions of these repetitive low-level accelerations of the head about the thorax are still unknown.

The difference in the accelerations of the tackler compared to the ball carrier found in this study may be attributed to a number of factors. It could be hypothesised that the ball carrier is able to better predict the impact of a front on tackle and can therefore counteract the mechanical effects of the perturbation with stiffening of the neck musculature (Danna-Dos-Santos et al, 2007). It could also be suggested that the point of impact and tackling technique contribute to this finding (Fuller et al, 2010). It has been explained how muscles can provide a shock absorption role in the neck and it is likely other muscles provide a similar role elsewhere in the body (Dezman et al, 2013). Therefore contact to the ball carrier at the waist allows more force absorption before it reaches the neck, which could explain the lower head accelerations. In contrast, the tackler uses their shoulder to impact the ball carrier and this may not allow force dissipation before reaching the neck, hence resulting in a greater transfer of momentum to the head.

A balance between the strength of the neck flexors and extensors correlated strongly with lower accelerations of the head relative to the thorax for the tackler. Dezman et al. (2013) drew similar conclusions to this when heading a soccer ball. They suggested maintaining a symmetrical balance between agonist and antagonist neck musculature as a preventative technique in limiting head accelerations. Neck strength balance therefore should be considered as a method to reduce the amplitude of head oscillations that result from indirect forces such as tackling in contact sports. Since it has been shown more experienced players are better at anticipating an impact and bracing themselves accordingly (Dezman et al, 2013), it may be much more important to protect less experienced players with strength training aimed at reducing the strength discrepancies between the neck flexors and extensors.

In this study, the tackles were conducted in a controlled environment and therefore it is hard to generalise these accelerations to the field. It can however be anticipated that accelerations on the field would only be higher due to the increased intensity of the tackles. This investigation therefore provides a good insight into what levels these players are exposed to during training sessions. If unaware of the impeding impact in a game situation players may also react differently and not have time to tense their neck muscles or align their bodies to protect their head and therefore larger accelerations may occur. Another consideration is that the sample size did not have a wide range of player characteristics and therefore future studies may need to investigate the difference between experienced and non-experienced players.

CONCLUSION: This study showed in a simulated bout of tackles that the ball carrier experiences on average peak acceleration of 4.2g whilst the tackler experiences 19.8g of acceleration of the head relative to the thorax. Results also suggested that a tackler with a more balanced neck flexion and extension ratio might experience lower levels acceleration of the head relative to the thorax. Creating a balance between neck flexor and extensor strength may be a vital method to help alleviate the magnitude of oscillations occurring at the head in response to a tackle and future study into this relationship is warranted.

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