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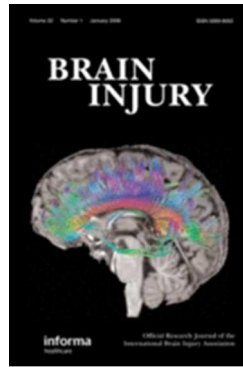
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Risks associated with significant head impact events in elite rugby union

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Risks associated with significant head impact events in elite rugby union

Keywords:

Sport; Video Analysis; Statistical Analysis

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For Peer Review Only

Abstract

Primary Objectives: To conduct video and statistical analysis on Rugby Union play, focusing mainly on the tackle, to establish the player to player configurations for Significant Direct Head Impacts and Non Direct Head Impacts.

Research Design: Quantitative, observational cohort study

Methods and procedures: Video analysis of 52 Significant Direct Head Impacts (31 Tackle, 10 Ruck, 7 Dive and 4 Ground) and 40 Non Direct Head Impact tackles from 2014/15 International Rugby Union matches. Relative risk, 95% CI and p values were calculated for a range of tackle variables.

Main outcome and results: Upper Body Tackles and Lower Body Tackles accounted for 37% (19) and 23% (12) of cases respectively with the Tackler as the Head Impacted Player for 97% (30) of cases.

The majority (81%) of tackle related Significant Direct Head Impacts occurred in the second half of the game with 63% of Upper Body Tackle Significant Direct Head Impacts occurring in the final quarter. Tackler head placement and high speed tackles had statistical significance as well as foot planting and difference in Tackler and Ball Carrier mass for Upper Body Tackles and Ball Carrier change in direction for Lower Body Tackles.

Conclusion: Tackle variables that statistically increased the risk of Significant Direct Head Impact were identified which can aid player protection strategies.

1. Introduction

Impacts are integral to the sport of Rugby Union but head impacts can result in concussion related symptoms [1]. Concussion has been defined as “a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces” [1] as well as “a clinical syndrome of biomechanically induced alteration of brain function, typically affecting memory and orientation, which may involve loss of consciousness (LOC)” [2]. The reported incidence of concussion injuries in English Rugby Union is high, 10.5/1000 player-hours [3]. A recent study reported an incidence of 8.9/1000 player-hours in the 2013/14 English Premiership season, which had increased significantly from 6.6/1000 player-hours in the previous season [4]. Concussion has been found to account for around 5% of injuries in elite Rugby Union in Australia and New Zealand [5, 6]. One study found, in one season, that 23% of elite level Rugby Union participants received a concussion [7]. Some epidemiological head injury specific research has been carried out in elite level Rugby Union [3, 8, 9] and there are attempts to quantify the magnitude of head impact events in rugby using wearable sensors [10]. Video analysis has been a technique for analysing concussion injuries in elite Rugby League [11] as well as elite level Ice Hockey and Soccer [12, 13]. Nonetheless, there is still little documented knowledge on the specific elite player motion patterns, just before and during direct head impact events, which could be used to guide prevention strategies in Rugby Union.

A detailed epidemiological study was conducted to define the incidence, nature, severity and causes of head injuries in Rugby Union professional players using 757 male participants from 13 English Premiership clubs over three seasons [8]. For match play, it was found that 6.6 overall head injuries per 1000 player-hours occurred, resulting in 14 days lost-time on average. Concussion injuries contributed to 4.1 injuries per 1000 player-hours making concussion the third most common match injury for all Rugby Union players [8]. More recently, an England professional Rugby Union injury surveillance report found that concussion injuries contributed to 10.5 injuries per 1000 player-hours, and this is a significant increase to that previously reported [3, 8]. However concussion

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3 injuries can be unreported due to insufficient knowledge of concussion symptoms, players not
4
5 wanting to be removed from the game and/or a delay in diagnosis [14, 15]. Nonetheless, in 2013-14,
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7 concussion was, for the third consecutive season, the most commonly reported English Premiership
8
9 match injury and accounted for 12.5% of all match injuries [3]. Cross et al. (2015) found that players
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11 are 60% more likely to get injured following a concussion, which indicates the importance of
12
13 prevention.

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16 One study found that the Midfield Backs (Fly half, Inside Centre and Outside Centre) were at highest
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18 risk for concussion [8]. Others found that Backs suffer from a greater number of concussions due to
19
20 the high speed nature of their role and are therefore involved in more high speed collisions [16, 17].
21
22 However, others have reported that Forwards are more likely to sustain concussion as they engage
23
24 in potentially more dangerous aspects of the game, such as rucks and mauls [5, 18, 19]. In the 2011
25
26 Rugby World Cup Forwards were reported to have suffered 8.8 concussion injuries per 1000 player-
27
28 hours in comparison to Backs who suffered 6.7 concussion injuries per 1000 player-hours [20]. An in-
29
30 depth epidemiological study on professional Irish Rugby Union players [15] found that concussions
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32 were reported for every playing position.
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36 The tackle is considered the most regular cause of injury in Rugby Union [5, 16-19, 21, 22], with the
37
38 middle to high tackle being the most common tackle to cause injury for both the Tackler and the Ball
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40 Carrier [16]. Accordingly, tackling head-on has been identified as a high risk factor for match
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42 concussion [8, 17], with collisions and being tackled head-on reported as the second and third main
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44 cause respectively [8]. However, there has been no further analysis to guide player concussion
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46 protection strategies.
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50 Accordingly, the aim of this study is to use video analysis to analyse Significant Direct Head Impact
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52 events which occurred in elite rugby union games, focusing mainly on tackling, to establish the
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54 player to player configurations just before and during Significant Direct Head Impact events, and also
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56 for Non Direct Head Impact events. A Significant Direct Head Impact was defined for this paper as
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3 one for which the player received a direct impact to the head and then received on-field medical
4 treatment to the head and/or was required to undergo a Head Injury Assessment (HIA) during the
5 game as seen on the video. A Non Direct Head Impact was defined as one for which the player
6 contacted another player but did not receive a direct impact to the head.
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12 Although Non Direct Head Impacts have been associated with concussion injuries [1, 23, 24], this
13 analysis is aimed at providing an evidence base for player actions which can help to decrease the risk
14 of a Significant Direct Head Impact occurring. A particular focus is given to player stance, orientation
15 and kinematics leading up to, and during, tackles.
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20 21 **2. Methods**

22 **2.1. Research Design**

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24 A quantitative observational cohort study design using video evidence was used to identify a range
25 of phase-of-play specific variables (Table 1 and 2) associated with Significant Direct Head Impacts in
26 elite Rugby Union play. As the data was freely available online and no medical data is reported in this
27 study, ethical permission was not required.
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36 **2.2. Data collection**

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38 Video data was collected by retrospectively reviewing online live update articles of International Test
39 Rugby matches from 2014 and 2015 for Significant Direct Head Impact cases. This dataset was
40 compiled of all matches from the RBS 6 Nations 2014, Guinness Autumn Test Series 2014, RBS 6
41 Nations 2015, Rugby World Cup Warm Up games 2015 (Home nation games only) and the Rugby
42 World Cup 2015 (all games). A total of 52 Significant Direct Head Impact cases, of which 48 resulted
43 in Head Injury Assessments (HIA), were identified and the video data of these cases were obtained
44 from freely available online resources.
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2.3. Significant Direct Head Impacts

2.3.1. General

Two reviewers (**Biomechanists**) independently viewed and analysed the video data for each Significant Direct Head Impact event. The videos were viewed using VLC media player software which allowed frame-by-frame viewing of the videos. Differences between reviewers were resolved by a review and discussion of the footage until a consensus was reached. **For this study, a tackle was defined as either an Upper Body Tackle or a Lower Body Tackle, see Table 1.** The initial analysis focused on finding the general cause of the Significant Direct Head Impact event and five main categories were identified:

- Head Impact from an Upper Body Tackle
- Head Impact from a Lower Body Tackle
- Head Impact in a Ruck
- Head Impact from a Dive
- Head Impact with the Ground

No Significant Direct Head Impact events occurred as a result of a maul. Further analysis was then carried out for each category following a series of discussions involving elite level (**Pro 12**) Rugby Union personnel including a coach, physiotherapist, video analyst and referee.

2.3.2. Tackles

For this study, a Tackle was defined as “when the ball-carrier was contacted (hit and/or held) by an opponent without reference to whether the ball-carrier went to ground” [16].

2.3.2.1. Upper Body Tackles

For Upper Body Single Tackles (one tackler), the Tackle variables were grouped into three main categories; Tackler and Ball Carrier Data (Retrieved from freely available online player profiles), Pre-tackle (**e.g. direction of tackle, see Figure 1**) and Tackle (Table 1). For Upper Body Double Tackles

(two tacklers), the type of Tackle, Impacting Player, Striking Body Region and Time in Game were analysed, see Table 1.

2.3.2.2. Lower Body Tackles

All Lower Body Tackles involved single tackles (One Tackler). For Lower Body Tackles, the Tackle variables were grouped into three main categories; Tackler and Ball Carrier Data (Retrieved from online player profiles), Pre-tackle and Tackle (Table 1).

Insert Table 1 near here.

To aid with the analysis, a side camera view of the Tackle was viewed, where the direction of the impact was almost perpendicular to the camera axis and two-dimensional representations of the players at the point of impact were created (Figure 2). Tackle direction was assessed using the definitions presented in Figure 1. Figure 2 allowed for Upper Body and Lower Body Tackles to be distinguished (see Table 1) as well as representing player speed upon impact and identifying the Head Impacted player.

Insert Figure 1 near here.

Insert Figure 2 near here.

2.3.3. Ruck, Dive and Ground Impact Analysis

This analysis was conducted whenever a player received a Significant Direct Head Impact due to involvement in the ruck phase of play, diving towards the ground or directly impacting their head with the ground. The variables for this analysis were grouped into a framework involving three main categories: main cause, striking body region and time in game (Table 2).

Insert Table 2 near here.

2.4. Non Direct Head Impacts

2.4.1. Tackles

For Tackle cases, video data from a total of 40 Non Direct Head Impact Single Tackle cases (20 Upper Body Tackles and 20 Lower Body Tackles) from two randomly chosen Rugby World Cup 2015 games, including northern and southern hemisphere teams, were also analysed. This allowed key differences in Tackle configuration between Significant Direct Head Impact and Non Direct Head Impact cases to be identified. The Tackle variables were grouped into three main categories; Tackler and Ball Carrier Data, Pre-tackle and Tackle (Table 1). Head Impacted Player, Impacting Player and Striking Body Region, see Table 1, were not applicable for Non Direct Head Impact cases.

2.4.2. Other

Non Direct Head Impact cases for Upper Body Double Tackles (Two Tacklers), Rucks, Dives and Ground Impacts were not analysed as direct head impacts in these contact configurations are less avoidable through prevention strategies.

2.5. Statistical Analysis

The Tackle data for this study was analysed using descriptive and inferential statistics. A Shapiro-Wilk test was used to confirm that the Single Tackle (one tackler) data analysed was normally distributed. An unpaired t-test was carried out between Ball Carrier and Tackler mass and height for both Significant Direct Head Impact and Non Direct Head Impact cases. Statistical significance was considered if the p -value was <0.05 . The null hypothesis for this study was: "For a tackle, player data/pre-tackle/tackle variables have no effect on the likelihood of occurrence of a Significant Direct Head Impact."

For Single Tackle cases, the Relative Risk (RR), 95% Confidence Interval (CI) and probability (p) values were calculated for the pre-tackle variables [26]. The RR for each variable was calculated by comparing the frequency of occurrence for the Significant Direct Head Impact cases with the

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2
3 frequency of occurrence in the Non Direct Head Impact cases, similar to Fuller et al. [25]. An RR=1
4 indicates that the variable has no greater propensity to cause a Significant Direct Head Impact than
5 that anticipated by chance; an RR>1 and RR<1 indicates that the variable has a greater and lesser
6 propensity to cause a Significant Direct Head Impact than expected by chance, respectively [25]. In
7 cases where frequency of occurrence was zero, RR was calculated according to Pagano et al. [27]. A
8 variable was considered to have statistical significance if the 95% CI for the RR value did not include
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18 3. Results

19 3.1. General

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22 Tackles accounted for 31 of the 52 Significant Direct Head Impacts (60%) with Upper Body Tackles
23 and Lower Body Tackles accounting for 19 (37%) and 12 (23%) cases respectively, see Figure 3.

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28 Within Upper body tackles, single tackles (One Tackler) accounted for 15 Significant Direct Head
29 Impacts whereas double tackles (Two Tacklers) accounted for 4 Significant Direct Head Impacts.

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32 None of the Tackler related Significant Direct Head Impacts were regarded as foul play by the
33 referee in the game. A large majority (n=25; 81%) of Significant Direct Head Impacts due to a Tackle
34 occurred in the second half of the game, with a disproportionate number of Significant Direct Head
35 Impacts from Upper Body Tackles (n=12; 63%) occurring in the final quarter of the game (Figure 4). A
36 total of 4 Double Tackle (two tacklers) Significant Direct Head Impacts occurred, and all were Upper
37 Body Tackles and all occurred in the final quarter of the game. Rucks, dives and ground head impacts
38 accounted for 10 (19%), 7 (13%) and 4 (8%) of Significant Direct Head Impacts respectively and
39 occurred with a relatively even distribution with respect to time in the game. The Non Direct Head
40 Impact events occurred with a relatively even distribution with respect to time in the game. One
41 Ruck related Significant Direct Head Impact was regarded as foul play by the referee in the game.
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Insert Figure 3 near here.

Insert Figure 4 near here.

3.2. Tackles

3.2.1. Upper Body Tackles

From the 19 Upper Body Tackle cases with a Significant Direct Head Impact, the tackler was the Head Impacted Player in 18 cases, with the Ball Carrier the Impacting Player for 14 cases (Table 3). The 4 remaining cases involved Double Tackle (two tacklers) where the Head Impacted Player's team-mate was the Impacting Player, and the head was the Striking Body Region (Figure 5). The most common Upper Body Tackle related Significant Direct Head Impact scenario was a Single Tackler event in which the Tackler was the Head Impacted Player, with the Ball Carrier as the Impacting Player and the Striking Body Region being the shoulder (Figure 5).

Insert Table 3 near here.

Insert Figure 5 near here.

For Single tackle cases, unpaired t-tests were conducted on the difference in Ball Carrier and Tackler mass and height for Significant Direct Head Impacts and Non Direct Head Impacts (Table 4). Difference in Ball Carrier and Tackler mass had statistical significance ($n=15$; $p<0.01$) for Significant Direct Head Impacts but not for Non Direct Head Impact cases ($n=20$; $p=0.71$), with the Ball Carrier on average weighing 12kg and 2kg more than the tackler in Significant Direct Head Impact and Non Direct Head Impact cases respectively. Difference in average Ball Carrier and average Tackler height had no statistical significance for Significant Direct Head Impacts ($n=15$; $p=0.51$) and Non Direct Head Impact cases ($n=20$; $p=0.37$), and the average height difference between the Ball Carrier and the Tackler for the Significant Direct Head Impacts was only 2cm.

Insert Table 4 near here.

The results for pre-tackle variables and player position are presented in Table 5. At least one player entering the Tackle fast ($p=0.03$), Tackler head placement in front of the Ball Carrier ($p<0.01$) and Tackler foot planting ($p=0.02$) had a statistically higher propensity to cause a Significant Direct Head

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3 Impact. Tackler head placement to the side of the Ball Carrier ($p<0.01$) had a statistically higher
4 propensity to prevent a Significant Direct Head Impact. The Ball Carrier leading with the
5 arm/shoulder, upper arm raising and accelerating pre-tackle had no statistically significant
6 correlation with Significant Direct Head Impact occurrence. In 9 out of 15 (60%) of the Significant
7 Direct Head Impact cases the tackler was a Midfield Back, but this playing position showed no
8 statistically significant higher propensity to influence Significant Direct Head Impact risk.

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17 Insert Table 5 near here.

18 19 3.2.2. Lower Body Tackle

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22 In all 12 Lower Body Tackle cases, the Tackler was the Head Impacted Player and the Ball Carrier was
23 the Impacting Player. The knee was the main Striking Body Region and accounted for 5 Significant
24 Direct Head Impacts (42%), with the hip accounting for 4 cases (33%), see Figure 6.

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29 Insert Figure 6 near here.

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31
32 Unpaired t-tests were conducted on the difference in Ball Carrier and Tackler mass and height for
33 Significant Direct Head Impacts and Non Direct Head Impact Lower Body Tackle cases (Table 6).
34 Difference in Ball Carrier and Tackler mass had no statistical significance for Significant Direct Head
35 Impacts ($n=12$; $p=0.91$) or Non Direct Head Impact cases ($n=20$; $p=0.05$). Difference in Ball Carrier
36 and Tackler height surprisingly had statistical significance for Non Direct Head Impact cases ($n=20$;
37 $p=0.02$), but not for Significant Direct Head Impacts ($n=12$; $p=0.10$).

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46 Insert Table 6 near here.

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49 The results for pre-tackle variables and player position for Lower Body Tackles are presented in Table
50 7. At least one player entering the Tackle at fast speed ($p=0.02$), Tackler head placement in front of
51 the Ball Carrier ($p<0.01$) and Ball Carrier change in direction ($p=0.04$) had a statistically higher
52 propensity to cause a Significant Direct Head Impact. Tackler head placement to the side of the Ball
53 Carrier ($p=0.02$) had a statistically higher propensity to avoid a Significant Direct Head Impact. Ball
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Carrier and Tackler accelerating pre-tackle and Tackler foot planting had a higher propensity to cause a Significant Direct Head Impact but there was no statistical significance. Front Row players received 4 out of 12 (33%) of the Significant Direct Head Impacts with Midfield Backs and Back Three players accounting for 3 out of 12 (25%) each. These playing positions showed no statistically significant higher propensity to influence Significant Direct Head Impact risk.

Insert Table 7 near here.

3.3. Ruck, Dive and Ground

The Main Causes and Striking Body Region for Ruck, Dive and Ground Significant Direct Head Impacts are presented in *Table 8*. For rucks, an opposing player entering the ruck was the main cause (70%, n=7) of Significant Direct Head Impacts. Diving for a loose ball that was either spilled on the ground or in the air was the main cause of Dive related Significant Direct Head Impacts (86%, n=6) and impacting the head off the ground after making a tackle was the main cause of Ground related Significant Direct Head Impacts. The knee was the predominant Striking Body Region for both Ruck (50%) and Dive (57%) related Significant Direct Head Impacts.

Insert Table 8 near here.

4. Discussion

4.1. General

This study set out to identify the general cause of Significant Direct Head Impacts in elite Rugby union play. It was found that the Tackle accounted for 60% (31 out of 52) of Significant Direct Head Impacts, of which 61% (19 out of 31) were Upper Body Tackles and 39% (12 out of 31) were Lower Body Tackles. Of the 31 Tackle related Significant Direct Head Impact cases, the Tackler was the Head Impacted Player in 30 cases (97%). The remaining Significant Direct Head Impacts occurred from Rucks (19%), Diving for a loose ball/scoring a try (13%) and head impacts with the ground (8%), see *Table 8*.

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3 The study then set out to establish the player to player configurations just before and during
4
5 Significant Direct Head Impact and Non Direct Head Impact events in the Tackle phase of play. A
6
7 number of relevant Tackle related variables for the Ball Carrier and Tackler were chosen based on
8
9 discussions with elite level Rugby Union personnel (Coach, Physiotherapist, Video Analyst and
10
11 Referee).
12

13
14 The majority of Significant Direct Head Impacts due to a Tackle occurred in the second half of the
15
16 game (81%), with 63% of Upper Body Tackle related Significant Direct Head Impacts occurring in the
17
18 last quarter (Figure 4). **Assuming the player played from the beginning of the game**, this potentially
19
20 illustrates the influence of repeated impacts and player fatigue on tackling technique and general
21
22 injury risk [28, 29], or that players are more likely to place themselves in high risk scenarios or have
23
24 less time to get into a defensive formation when the end of a game is near. Time in the game did not
25
26 appear to influence Ruck, Dive or Ground Significant Direct Head Impacts (Figure 4). **Further work**
27
28 **should look at the number of tackles the player was involved in or the elapsed playing time of the**
29
30 **player before receiving the Significant Direct Head Impact.**
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34 **4.2. Tackles**

35 *4.2.1. Upper Body Tackles*

36 *4.2.1.1. Player Mass*

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38 For Significant Direct Head Impacts from Upper Body Single Tackler cases, difference in Ball Carrier
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40 and Tackler height had statistical significance ($p < 0.01$), and the Ball Carrier was on average 12kg
41
42 heavier than the Tackler, see Table 4. This could increase the risk of causing a Significant Direct Head
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44 Impact as the Ball Carrier could have greater momentum in comparison to the Tackler [17, 30] or the
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46 mass difference could potentially have a psychological effect on the Tackler and thus adversely
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48 affect tackling proficiency.
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54 *4.2.1.2. Player Speed*

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3 At least one player entering the Tackle at speed had statistical significance, $p=0.03$, for causing a
4
5 Significant Direct Head Impact for Upper Body Tackles. This indicates the propensity of fast player
6
7 speed to cause Significant Direct Head Impacts, however Ball Carrier and Tackler speed showed no
8
9 statistically significant greater propensity to cause a Significant Direct Head Impact. This is similar to
10
11 the findings of Fuller et al. [25] for general tackle injuries and does not support the hypothesis that
12
13 the player entering the Tackle with lower speed is more likely to be injured [30].
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16 17 4.2.1.3. Head Placement

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19 For Upper Body Tackles, placing the head in front of the Ball Carrier was a substantial risk factor for
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21 causing a Significant Direct Head Impact, see Table 5, and this is similar to the findings of Hendricks
22
23 et al. [31] for amateur players. When the head was placed in front of the Ball Carrier, it was generally
24
25 in line with the Ball Carrier's trajectory and was thus impacted by the Ball Carrier. These findings
26
27 suggest that Tackler head placement to the side of the Ball Carrier and not in line with the Ball
28
29 Carrier's trajectory is an effective means to prevent Significant Direct Head Impacts, see Table 5 and
30
31 Table 7.
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35 When the Tackler's head was placed to the side of the Ball Carrier, it was generally not in line with
36
37 the Ball Carrier's trajectory. However changes in Ball Carrier direction when the Tackler has
38
39 committed to the tackle or if the Ball Carrier is side shuffling could place the head in line with the
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41 Ball Carrier's trajectory and thus potentially cause a Significant Direct Head Impact. This could
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43 explain why a visible change in Ball Carrier direction had a greater propensity to cause a Significant
44
45 Direct Head Impact for Lower Body Tackles.
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49 In Non Direct Head Impact cases, when the Tackler's head was placed in front of the Ball Carrier,
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51 either a change in direction of the Ball Carrier or the Ball Carrier's speed being Slow/Stationary
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53 prevented the occurrence of a Significant Direct Head Impact.
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4.2.1.4. Foot Planting

For Significant Direct Head Impacts related to Upper Body Tackles, the Tackler planting their feet when committing to the Tackle **or at the time of impact** had a greater propensity to cause a Significant Direct Head Impact (Table 5). Foot planting might compromise the Tackler's technique and timing. This compromise in Tackler technique and timing could potentially have led to the Tackler being unable to place their head to the side of the Ball Carrier during the Tackle.

4.2.2. Lower Body Tackles

4.2.2.1. Player Height

Player Height had no statistical significance for Significant Direct Head Impact causation for Lower Body Tackles. Difference in Ball Carrier and Tackler height surprisingly had statistical significance for Non Direct Head Impact cases, with the Ball Carrier being on average 6cm taller than the Tackler.

This is discussed further in the Limitations section.

4.2.2.2. Player Speed

Similar to Upper Body Tackles, at least one player entering the Tackle at speed had statistical significance, $p=0.02$, for causing a Significant Direct Head Impact for Lower Body Tackles.

4.2.2.3. Head Placement

Similar to Upper Body Tackles, placing the head in front of the Ball Carrier was a substantial risk factor for causing a Significant Direct Head Impact, see Table 7.

4.2.2.4. Change in Direction

For Significant Direct Head Impacts related to Lower Body Tackles, a visible change in Ball Carrier direction once the Tackler had committed to the Tackle had a greater propensity to cause a Significant Direct Head Impact (see Table 7). A change in Ball Carrier direction is generally used to evade contact with the Tackler, however in the Significant Direct Head Impact Cases, the Ball Carrier

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3 change in direction generally placed the Tackler's head in front of the Ball Carrier and therefore at a
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5 higher risk of receiving a Significant Direct Head Impact.
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8 **4.3. Limitations**

9 10 *4.3.1. General*

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13 This study was based on all Significant Direct Head Impacts in the games reviewed, as defined in the
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15 Methodology section of this paper. It is possible that there were other Significant Direct Head
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17 Impact cases in the games considered: this would occur if they were not reported in the online live
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19 updates, but HIA cases are now routinely reported so the chance of having omitted cases is low.
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23 The assessments remain partially subjective and only semi-quantitative (Acceleration/Deceleration
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25 estimates etc), but differences in categorization between the two reviewers only occurred for
26
27 Direction of Tackle for two Lower Body Tackle cases, and this was a statistically insignificant variable.
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29 These differences were resolved by a review and discussion of the footage until consensus was
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31 reached.
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34 *4.3.2. Sample Size*

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37 The sample size for this study was based on all reported Significant Direct Head Impacts for
38
39 International Rugby Union games for a number of competitions/series over a two year period. The
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41 sample size could be considered small given the level of analysis conducted meaning t-test results
42
43 could potentially be affected by outliers. To improve the confidence in these result, the player data
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45 for Upper Body Tackles and Lower Body Tackles were assessed to identify any outliers (Tables 5 & 7).
46
47 It was found that statistically both significant variables (1. Difference in Ball Carrier and Tackler Mass
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49 for Upper Body Tackles with Significant Direct Head Impacts and 2. Difference in Ball Carrier and
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51 Tackler Height for Lower Body Tackles with Non Direct Head Impacts) had outliers (defined as Ball
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53 Carrier or Tackler height/mass outside two standard deviations of the mean). When these outliers
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55 were removed and the t-tests were repeated, the Upper Body Tackle Significant Direct Head Impact
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3 difference in player mass still showed statistical significance ($p < 0.01$) whereas Lower Body Tackle
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5 Non Direct Head Impact difference in player height did not ($p = 0.09$), as might be expected.
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8 *4.3.3. Application to Amateur and Youth Level Rugby Union*

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10 This study analysed International Rugby Union games which is the elite level and the results are
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12 therefore applicable to the elite game. It is possible that the results are applicable to amateur level
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14 and youth level rugby however further research in these areas would be needed to conclude this.
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17 **5. Conclusion**

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20 The Tackle phase of play is a major cause of Significant Direct Head Impacts in elite Rugby Union
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22 players with the Tackler being much more likely to receive a Significant Direct Head Impact than the
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24 Ball Carrier. A number of Tackle related variables that statistically increased the risk of Significant
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26 Direct Head Impact occurrence were identified. Significant Direct Head Impact Tackles generally had
27
28 at least one player entering the Tackle at speed. The majority of Significant Direct Head Impacts due
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30 to a Tackle occurred in the second half of the game, with the majority of Upper Body Tackle related
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32 Significant Direct Head Impacts occurring in the last quarter of the game. Difference in player mass
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34 was statistically significant for Significant Direct Head Impacts related to Upper Body Tackles, with
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36 the Ball Carrier on average weighing 12 kg more than the Tackler. For Upper Body Tackles and Lower
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38 Body Tackles, Tackler head placement in front of the Ball Carrier was the most important factor for
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40 Significant Direct Head Impact occurrence and this was potentially affected by Tackler foot planting
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42 for Upper Body Tackles and Ball Carrier change in direction for Lower Body Tackle related Significant
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44 Direct Head Impacts.
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Declaration of Interest statement

The authors report no declarations of interest

For Peer Review Only

6. References

1. McCrory P, Meeuwisse WH, Aubry M, Cantu B, Dvořák J, Echemendia RJ, Engebretsen L, Johnston K, Kutcher JS, Raftery M. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *British Journal of Sports Medicine* 2013;47(5):250-258.
2. Giza CC, Kutcher JS, Ashwal S, Barth J, Getchius TS, Gioia GA, Gronseth GS, Guskiewicz K, Mandel S, Manley G. Summary of evidence-based guideline update: Evaluation and management of concussion in sports Report of the Guideline Development Subcommittee of the American Academy of Neurology. *Neurology* 2013;80(24):2250-2257.
3. RFU. England Professional Rugby Injury Surveillance Project. 2015. Available online at: http://www.englandrugby.com/mm/Document/General/General/01/30/80/08/EnglandProfessionalRugbyInjurySurveillanceProjectReport2013_2014_Neutral.pdf accessed 10 December 2015.
4. Cross M, Kemp S, Smith A, Trewartha G, Stokes K. Professional Rugby Union players have a 60% greater risk of time loss injury after concussion: a 2-season prospective study of clinical outcomes. *British Journal of Sports Medicine* 2015;bjsports-2015-094982. Available online at: <http://bjsm.bmj.com/content/early/2015/12/01/bjsports-2015-094982.full> accessed 11 December 2015.
5. Bathgate A, Best JP, Craig G, Jamieson M. A prospective study of injuries to elite Australian rugby union players. *British Journal of Sports Medicine* 2002;36(4):265-269.
6. Bird Y, Waller AE, Marshall SW, Alsop J, Chalmers D, Gerrard D. The New Zealand Rugby injury and Performance Project: V. Epidemiology of a season of rugby injury. *British Journal of Sports Medicine* 1998;32(4):319-325.
7. Shuttleworth-Edwards AB, Noakes TD, Radloff SE, Whitefield VJ, Clark SB, Roberts CO, Essack FB, Zoccola D, Boulind MJ, Case SE. The comparative incidence of reported concussions presenting for follow-up management in South African Rugby Union. *Clinical Journal of Sport Medicine* 2008;18(5):403-409.
8. Kemp SP, Hudson Z, Brooks JH, Fuller CW. The epidemiology of head injuries in English professional rugby union. *Clinical Journal of Sport Medicine* 2008;18(3):227-34.
9. Fuller CW, Taylor A, Raftery M. 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* 2015;49(7):478-483.
10. King D, Hume PA, Brughelli M, Gissane C. Instrumented mouthguard acceleration analyses for head impacts in amateur rugby union players over a season of matches. *The American Journal of Sports Medicine* 2015;43(3):614-624.
11. Gardner AJ, Iverson GL, Quinn TN, Makdissi M, Levi CR, Shultz SR, Wright DK, Stanwell P. A preliminary video analysis of concussion in the National Rugby League. *Brain Injury* 2015; 29(10): 1182-1185.
12. Hutchison MG, Comper P, Meeuwisse WH, Echemendia RJ. A systematic video analysis of National Hockey League (NHL) concussions, part I: who, when, where and what? *British Journal of Sports Medicine* 2013;bjsports-2013-092234. Available online at: <http://bjsm.bmj.com/content/early/2013/06/12/bjsports-2013-092234> accessed 11 December 2015
13. Andersen TE, Arnason A, Engebretsen L, Bahr R. Mechanisms of head injuries in elite football. *British Journal of Sports Medicine* 2004;38(6):690-696.
14. MacQueen AE, Dexter WW. Injury Trends and Prevention in Rugby Union Football. *Current Sports Medicine Reports* 2010;9(3):139-143 10.1249/JSR.0b013e3181df124c. Available online at: <http://journals.lww.com/acsm->

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3 csmr/Abstract/2010/05000/Injury_Trends_and_Prevention_in_Rugby_Union.8.aspx
4 accessed 12 December 2015.
- 5 15. Fraas MR, Coughlan GF, Hart EC, McCarthy C. Concussion history and reporting rates in elite
6 Irish rugby union players. *Physical Therapy in Sport* 2014;15(3):136-142.
- 7 16. Quarrie KL, Hopkins WG. Tackle Injuries in Professional Rugby Union. *The American Journal*
8 *of Sports Medicine* 2008;36(9):1705-1716.
- 9 17. Brooks JHM, Fuller CW, Kemp SPT, Reddin DB. Epidemiology of injuries in English
10 professional rugby union: part 1 match injuries. *British Journal of Sports Medicine*
11 2005;39(10):757-766.
- 12 18. Best JP, McIntosh AS, Savage TN. Rugby World Cup 2003 injury surveillance project. *British*
13 *Journal of Sports Medicine* 2005;39(11):812-817.
- 14 19. Bottini E, Poggi EJT, Luzuriaga F, Secin FP. Incidence and nature of the most common rugby
15 injuries sustained in Argentina (1991–1997). *British Journal of Sports Medicine*
16 2000;34(2):94-97.
- 17 20. Fuller CW, Sheerin K, Targett S. Rugby World Cup 2011: International Rugby Board Injury
18 Surveillance Study. *British Journal of Sports Medicine* 2012; 47(18):1184-1191.
- 19 21. Jakoet I, Noakes TD. A high rate of injury during the 1995 Rugby World Cup. *Injury*
20 1998;29:27.
- 21 22. Fuller CW, Laborde F, Leather RJ, Molloy MG. International Rugby Board Rugby World Cup
22 2007 injury surveillance study. *British Journal of Sports Medicine* 2008;42(6):452-9.
- 23 23. Alexander D, Shuttleworth-Edwards A, Kidd M, Malcolm C. Mild traumatic brain injuries in
24 early adolescent rugby players: Long-term neurocognitive and academic outcomes. *Brain*
25 *Injury* 2015;29(9):1113-1125.
- 26 24. Shuttleworth-Rdwards AB, Radloff SE. Compromised visuomotor processing speed in players
27 of Rugby Union from school through to the national adult level. *Archives of Clinical*
28 *Neuropsychology* 2008;23(5):511-520.
- 29 25. Fuller CW, Ashton T, Brooks JH, Cancea RJ, Hall J, Kemp SP. Injury risks associated with
30 tackling in rugby union. *British Journal of Sports Medicine* 2010; 44(3):159-167.
- 31 26. Altman DG. *Practical statistics for medical research*. London (England): CRC press; 1990.
- 32 27. Pagano M, Gauvreau K, Pagano M. *Principles of biostatistics*. Pacific Grove (CA): Duxbury;
33 2000.
- 34 28. Hendricks S, Micheal L. Theoretical model for the relationship between the number of
35 tackles a player engages in, tackle injury risk and performance in rugby union. *British Journal*
36 *of Sports Medicine* 2014;48(7):606-606.
- 37 29. McIntosh AS. Risk compensation, motivation, injuries, and biomechanics in competitive
38 sport. *British Journal of Sports Medicine* 2005;39(1):2-3.
- 39 30. Garraway W, Lee A, Macleod D, Telfer J, Deary IJ, Murray GD. Factors influencing tackle
40 injuries in rugby union football. *British Journal of Sports Medicine* 1999;33(1):37-41.
- 41 31. Hendricks S, O'Connor S, Lambert M, Brown J, Burger N, Mc Fie S, Readhead C, Viljoen W.
42 Contact technique and concussions in the South African under-18 Coca-Cola Craven Week
43 Rugby tournament. *European Journal of Sport Science* 2015;15(6):557-64.
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Table 1: Single Tackle variables with corresponding description.

Variable	Description
Tackler and Ball Carrier (BC) Data	
Mass	Player mass in kg
Height	Player height in m
Playing Position	Front Row; Second Row; Back Row; Scrum Half; Midfield Backs; Back Three
Pre-tackle	
Speed [25]	
Fast	Tackler/Ball Carrier was running/sprinting into tackle
Slow	Tackler/Ball Carrier was jogging/side shuffling/walking into tackle
Stationary	Tackler/Ball Carrier was standing/minimal movement into tackle
Acceleration/Deceleration	
Speeding up	Visible increase in Tackler/Ball Carrier speed before committing to the tackle
Slowing Down	Visible decrease in Tackler/Ball Carrier speed before committing to the tackle
Change in direction	Change in Ball Carrier direction once tackler has committed to the tackle
Leading with arm/shoulder	Ball Carrier leading with arm/shoulder (Applied to Upper Body Tackles only)
Upper arm raise	Ball carrier raises upper arm (Applied to Upper Body Tackles only)
Foot planting	Tackler planting foot when committing to the tackle or at the time of impact
Tackler Head Placement	
In front of BC	Head placed in front of Ball Carrier
Side of BC	Head placed to the side of Ball Carrier
Behind BC	Head placed to the side of Ball Carrier
Direction of Tackle	
Front On	Tackler & Ball Carrier directly facing ($\pm 10^\circ$) at the time of impact (Figure 1)
Side On	Tackler impacting Ball Carrier laterally from left or right hand side ($\pm 10^\circ$)
Oblique	Tackler impacting Ball Carrier between the front-on and side-on positions
Tackle	
Type of Tackle	
Upper Body Tackle	Intended primary contact being above the Ball Carrier's hip
Lower Body Tackle	Intended primary contact being at or below the Ball Carrier's hip
Number of Tacklers	Number of players tackling the Ball Carrier
Time in Game	
1 st , 2 nd , 3 rd or 4 th Quarter	0 - ≤ 20 mins, >20 - ≤ 40 mins, >40 - ≤ 60 mins, >60 - ≤ 80 mins
Head Impacted Player	
Tackler	Tackler received Significant Direct Head Impact
Ball Carrier	Ball Carrier received Significant Direct Head Impact
Impacting Player	
Tackler	Tackler impacted Ball Carrier's head
Ball Carrier	Ball Carrier impacted Tackler's head
Teammate	Tackler from own team impacted either Ball Carrier or Tackler's head
Striking Body Region	
Head	Impacting Player's head struck the Head Impacted Player's head
Shoulder	Impacting Player's shoulder struck the Head Impacted Player's head
Arm	Impacting Player's arm struck the Head Impacted Player's head
Back	Impacting Player's back struck the Head Impacted Player's head
Hip	Impacting Player's hip struck the Head Impacted Player's head
Thigh	Impacting Player's thigh struck the Head Impacted Player's head
Knee	Impacting Player's knee struck the Head Impacted Player's head
Foot	Impacting Player's foot struck the Head Impacted Player's head

Table 2: Ruck, dive and ground variables with corresponding description

Variable	Description
Ruck	
Main Cause	
Opposing player entry	Player received head impact by opposing player's entry into the ruck
Own entry	Player received head impact by their own entry into the ruck
Teammate entry	Player received head impact by their own teammate's entry into the ruck
Striking Body Region	
Head	Player's head struck the Head Impacted Player's head
Shoulder	Player's shoulder struck the Head Impacted Player's head
Knee	Player's knee struck the Head Impacted Player's head
Foot	Player's foot struck the Head Impacted Player's head
Time in Game	
1 st , 2 nd , 3 rd or 4 th Quarter	0 - ≤20 mins, >20 - ≤40 mins, >40 - ≤60 mins, >60 - ≤80 mins
Dive	
Main Cause	
Loose ball	Player received head impact by attempting to retrieve a loose ball either on the ground or in the air
Try	Player received head impact by diving forward to score a try
Striking Body Region	
Knee	Player's knee struck the Head Impacted Player's head
Foot	Player's foot struck the Head Impacted Player's head
Time in Game	
1 st , 2 nd , 3 rd or 4 th Quarter	0 - ≤20 mins, >20 - ≤40 mins, >40 - ≤60 mins, >60 - ≤80 mins
Ground	
Main Cause	
Tackle made	Player's head impacted the ground after making a tackle
Tackle Received	Player's head impacted the ground after receiving a tackle
Air contest	Player's head impacted the ground after contesting a high ball.
Time in Game	
1 st , 2 nd , 3 rd or 4 th Quarter	0 - ≤20 mins, >20 - ≤40 mins, >40 - ≤60 mins, >60 - ≤80 mins

Table 3: The Head Impacted Player, Impacting Player and Striking Body Region for Significant Direct Head Impacts related to Upper Body Tackles, [see Table 1 for definitions](#).

Variable	No of event in group (%)
Head Impacted Player	
Tackler	18
Ball Carrier	1
Impacting Player	
Tackler	1
Ball Carrier	14
Teammate	4
Striking Body Region	
Head	8
Shoulder	7
Arm	3
Back	1

Table 4: Average Ball Carrier/Tackler mass and height (with Standard Deviation) for Significant Direct Head Impact and Non Direct Head Impact Upper Body Tackles (One Tackler) with p values for unpaired t-tests on Ball Carrier and Tackler mass and height differences. Statistically significant p values are shown in bold.

	Upper Body Tackle (Single Tackle)					
	Significant Direct Head Impact (n=15)			Non Direct Head Impact (n=20)		
	Ball Carrier (SD)	Tackler (SD)	p Value	Ball Carrier (SD)	Tackler (SD)	p Value
Average Player Mass (kg)	110 (± 10)	98 (± 12)	<0.01	104 (± 11)	102 (± 12)	0.71
Average Player Height (m)	1.88 (± 0.07)	1.86 (± 0.05)	0.51	1.87 (± 0.06)	1.85 (± 0.06)	0.37

Table 5: Risk Ratios (RRs) of Significant Direct Head Impact as a function of Upper Body Tackle (one tackler) pre-tackle variables with statistically significant p values in bold.

	No of events in group (%)		RR (95% CI)	p value
	Significant Direct Head Impact (n=15)	Non Direct Head Impact (n=20)		
General				
One Player Fast	13 (87%)	10 (50%)	1.73 (1.07 to 2.80)	0.03
Type of Tackle				
Front	7 (47%)	9 (45%)	1.03 (0.50 to 2.14)	0.92
Oblique	4 (27%)	10 (50%)	0.53 (0.21 to 1.37)	0.19
Side On	3 (20%)	1 (5%)	4.00 (0.46 to 34.8)	0.21
Ball Carrier				
Position				
Front Row	4 (27%)	2 (10%)	2.67 (0.56 to 12.7)	0.22
Second Row	2 (13%)	1 (5%)	2.67 (0.27 to 26.7)	0.40
Back Row	3 (20%)	8 (40%)	0.70 (0.22 to 2.25)	0.55
Scrum Half	0 (0%)	1 (5%)	0.44 (0.02 to 10.0)	0.61
Midfield Back	4 (27%)	3 (15%)	1.78 (0.47 to 6.78)	0.40
Back three	2 (13%)	5 (25%)	0.53 (0.12 to 2.38)	0.41
Speed				
Fast	11 (73%)	9 (45%)	1.63 (0.92 to 2.89)	0.09
Slow	4 (27%)	8 (40%)	0.67 (0.24 to 1.81)	0.43
Stationary	0 (%)	3 (15%)	0.19 (0.01 to 3.38)	0.26
Acceleration/Deceleration				
Speeding up	6 (40%)	4 (20%)	2.00 (0.68 to 5.85)	0.21
Slowing down	0 (0%)	0 (0%)	0 (-)	-
Change in direction	2 (13%)	3 (15%)	0.89 (0.17 to 4.67)	0.89
Leading with arm/shoulder	8 (53%)	7 (35%)	1.52 (0.71 to 3.27)	0.28
Upper Arm Raise	8 (53%)	7 (35%)	1.52 (0.71 to 3.27)	0.28
Tackler				
Position				
Front Row	4 (27%)	6 (30%)	0.88 (0.30 to 2.60)	0.83
Second Row	0 (0%)	1 (5%)	0.44 (0.02 to 10.0)	0.61
Back Row	0 (0%)	3 (15%)	0.19 (0.01 to 3.38)	0.26
Scrum Half	0 (0%)	0 (0%)	0 (-)	0.00
Midfield Back	9 (60%)	7 (35%)	1.71 (0.83 to 3.54)	0.15
Back three	2 (13%)	3 (15%)	0.89 (0.17 to 4.67)	0.89
Speed				
Fast	4 (27%)	1 (5%)	5.33 (0.66 to 43.0)	0.12
Slow	7 (46%)	14 (70%)	0.67 (0.36 to 1.23)	0.19
Stationary	4 (27%)	5 (25%)	1.07 (0.34 to 3.31)	0.91
Acceleration				
Speeding up	1 (7%)	2 (10%)	0.67 (0.07 to 6.68)	0.73
Slowing down	7 (47%)	5 (25%)	1.87 (0.73 to 4.74)	0.19
Head Placement				
In front of BC	14 (93%)	2 (10%)	9.33 (2.49 to 35.0)	<0.01
Side of BC	1 (7%)	18 (90%)	0.07 (0.01 to 0.49)	<0.01
Foot Planting	9 (60%)	3 (15%)	4.00 (1.30 to 12.3)	0.02

Table 6: Average Ball Carrier/Tackler mass and height (with Standard Deviation) for Significant Direct Head Impact and Non Direct Head Impact cases resulting from Lower Body Tackles, with p values for unpaired t-tests on Ball Carrier and Tackler differences. Statistically significant p values are shown in bold.

	Lower Body Tackle					
	Significant Direct Head Impact (n=12)			Non-head Impact (n=20)		
	Ball Carrier (SD)	Tackler (SD)	p Value	Ball Carrier (SD)	Tackler (SD)	p Value
Average Player Mass (kg)	100 (± 11)	100 (± 13)	0.91	108 (± 11)	100 (± 13)	0.05
Average Player Height (m)	1.87 (± 0.07)	1.83 (± 0.04)	0.10	1.90 (± 0.08)	1.84 (± 0.06)	0.02

Table 7: Risk Ratios (RRs) of Significant Direct Head Impact as a function of Lower Body Tackle pre-tackle variables with statistically significant p values in bold.

	No of event in group (%)		RR (95% CI)	p value
	Significant Direct Head Impact (n=12)	Non Direct Head Impact (n=20)		
General				
One Player Fast	11 (92%)	11 (55%)	1.67 (1.08 to 2.57)	0.02
Type of Tackle				
Front	3 (25%)	7 (35%)	0.71 (0.23 to 2.25)	0.57
Oblique	5 (42%)	10 (50%)	0.83 (0.37 to 1.85)	0.66
Side On	4 (33%)	3 (15%)	2.22 (0.60 to 8.28)	0.23
Ball Carrier				
Position				
Front Row	2 (17%)	4 (20%)	0.83 (0.18 to 3.88)	0.82
Second Row	2 (17%)	3 (15%)	1.11 (0.22 to 5.73)	0.90
Back Row	1 (8%)	6 (30%)	0.28 (0.04 to 2.04)	0.21
Scrum Half	0 (0%)	1 (5%)	0.54 (0.02 to 12.3)	0.70
Midfield Back	3 (25%)	4 (20%)	1.25 (0.34 to 4.66)	0.74
Back three	4 (33%)	2 (10%)	3.33 (0.72 to 15.5)	0.13
Speed				
Fast	9 (75%)	9 (45%)	1.67 (0.93 to 2.99)	0.09
Slow	3 (25%)	7 (35%)	0.71 (0.23 to 2.25)	0.57
Stationary	0 (0%)	4 (20%)	0.18 (0.01 to 3.07)	0.24
Acceleration				
Speeding up	3 (25%)	3 (15%)	1.67 (0.40 to 6.97)	0.48
Slowing down	0 (0%)	1 (5%)	0.54 (0.02 to 12.26)	0.70
Change in direction	7 (58%)	4 (20%)	2.92 (1.07 to 7.92)	0.04
Tackler				
Position				
Front Row	4 (33%)	2 (10%)	3.33 (0.72 to 15.5)	0.13
Second Row	1 (8%)	1 (5%)	1.67 (0.11 to 24.3)	0.71
Back Row	0 (0%)	6 (30%)	0.12 (0.01 to 2.03)	0.14
Scrum Half	1 (8%)	1 (5%)	1.67 (0.11 to 24.3)	0.71
Midfield Back	3 (25%)	8 (40%)	0.63 (0.20 to 1.91)	0.41
Back three	3 (25%)	2 (10%)	2.50 (0.49 to 12.9)	0.27
Speed				
Fast	5 (42%)	4 (20%)	2.08 (0.69 to 6.28)	0.19
Slow	4 (33%)	12 (60%)	0.56 (0.23 to 1.33)	0.19
Stationary	3 (25%)	4 (20%)	1.25 (0.34 to 4.66)	0.74
Acceleration				
Speeding up	1 (8%)	1 (5%)	1.67 (0.11 to 24.26)	0.71
Slowing down	3 (25%)	5 (25%)	1.00 (0.29 to 3.45)	1.00
Head Placement				
In front of BC	10 (83%)	1 (5%)	16.7 (2.43 to 114)	<0.01
Side of BC	0 (0%)	19 (95%)	0.04 (<0.01 to 0.63)	0.02
Behind BC	2 (17%)	0 (0%)	8.08 (0.42 to 155)	0.17
Foot Planting	4 (33%)	5 (25%)	1.33 (0.44 to 4.02)	0.61

Table 8: Main Causes and Striking Body Region for Significant Direct Head Impacts from ruck, dive and ground impacts.

Variable	No of event in group (%)
Ruck (n=10)	
Main Cause	
Opposing player entry	7 (70%)
Own entry	2 (20%)
Teammate entry	1 (10%)
Striking Body Region	
Head	2 (20%)
Shoulder	3 (30%)
Knee	4 (50%)
Foot	1 (10%)
Dive (n=7)	
Main Cause	
Loose ball	6 (86%)
Try	1 (14%)
Striking Body Region	
Shoulder	2 (14%)
Knee	4 (57%)
Foot	1 (29%)
Ground (n=4)	
Main Cause	
Tackle made	2 (50%)
Tackle Received	1 (25%)
Air contest	1 (25%)

Table Captions

Table 1: Single Tackle variables with corresponding description.

Table 2: Ruck, dive and ground variables with corresponding description

Table 3: The Head Impacted Player, Impacting Player and Striking Body Region for Significant Direct Head Impacts related to Upper Body Tackles, [see Table 1 for definitions](#).

Table 4: Average Ball Carrier/Tackler mass and height (with Standard Deviation) for Significant Direct Head Impact and Non Direct Head Impact Upper Body Tackles (One Tackler) with p values for unpaired t-tests on Ball Carrier and Tackler mass and height differences. Statistically significant p values are shown in bold.

Table 5: Risk Ratios (RRs) of Significant Direct Head Impact as a function of Upper Body Tackle (one tackler) pre-tackle variables with statistically significant p values in bold.

Table 6: Average Ball Carrier/Tackler mass and height (with Standard Deviation) for Significant Direct Head Impact and Non Direct Head Impact cases resulting from Lower Body Tackles, with p values for unpaired t-tests on Ball Carrier and Tackler differences. Statistically significant p values are shown in bold.

Table 7: Risk Ratios (RRs) of Significant Direct Head Impact as a function of Lower Body Tackle pre-tackle variables with statistically significant p values in bold.

Table 8: Main Causes and Striking Body Region for Significant Direct Head Impacts from ruck, dive and ground impacts.

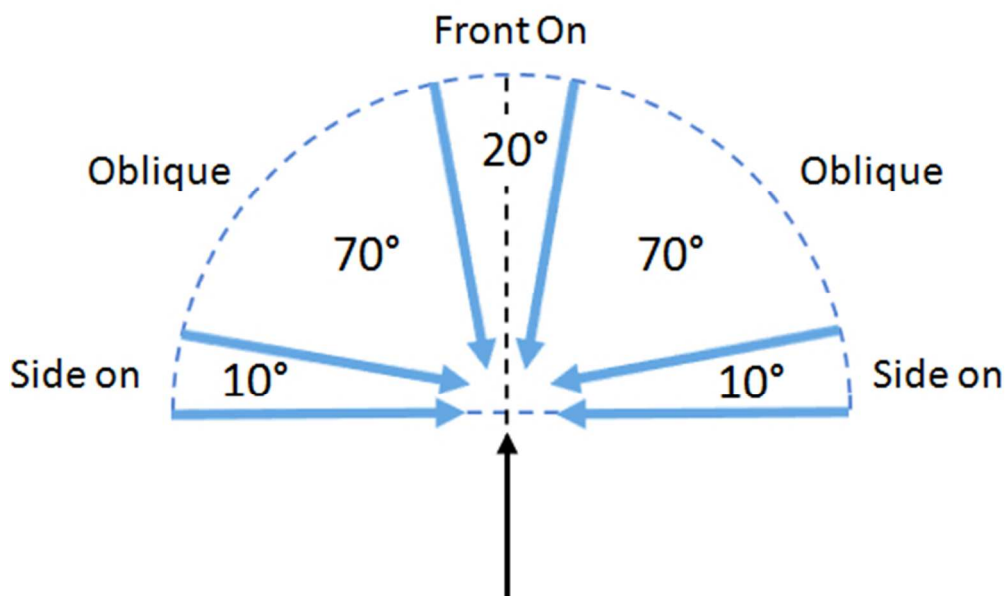


Figure 1: Angle criteria for determining the direction of tackle. Black arrow indicates estimated Ball Carrier's direction of motion; Blue arrows indicate estimated Tackler's direction of motion.
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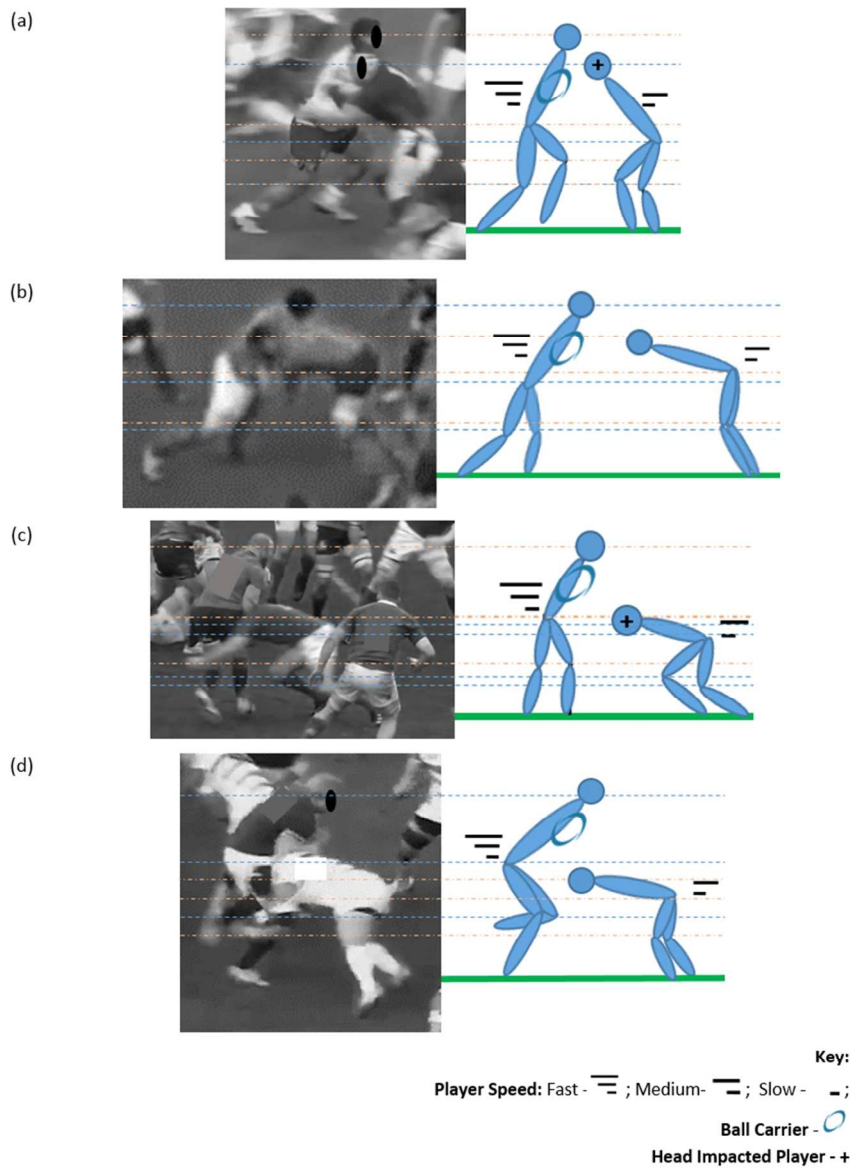


Figure 2: Representative cases of multibody model method applied to a (a) Significant Direct Head Impact from an Upper Body Tackle; (b) Non Direct Head Impact from an Upper Body Tackle; (c) Significant Direct Head Impact from a Lower Body Tackle (d) Non Direct Head Impact in a Lower Body Tackle.
224x310mm (96 x 96 DPI)

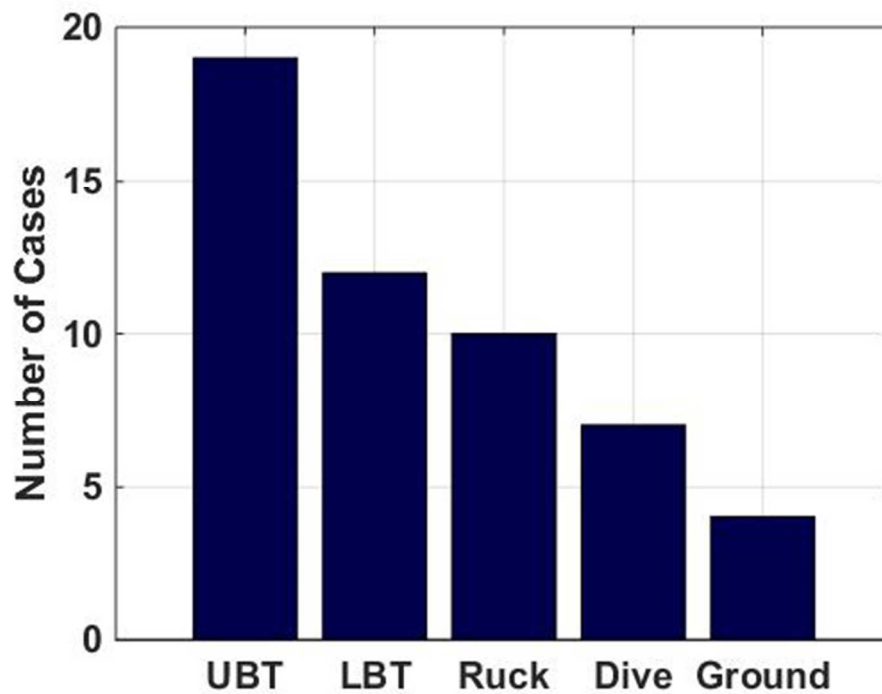


Figure 3: Categories of Significant Direct Head Impacts from all cases. UBT – Upper Body Tackle; LBT – Lower Body Tackle.

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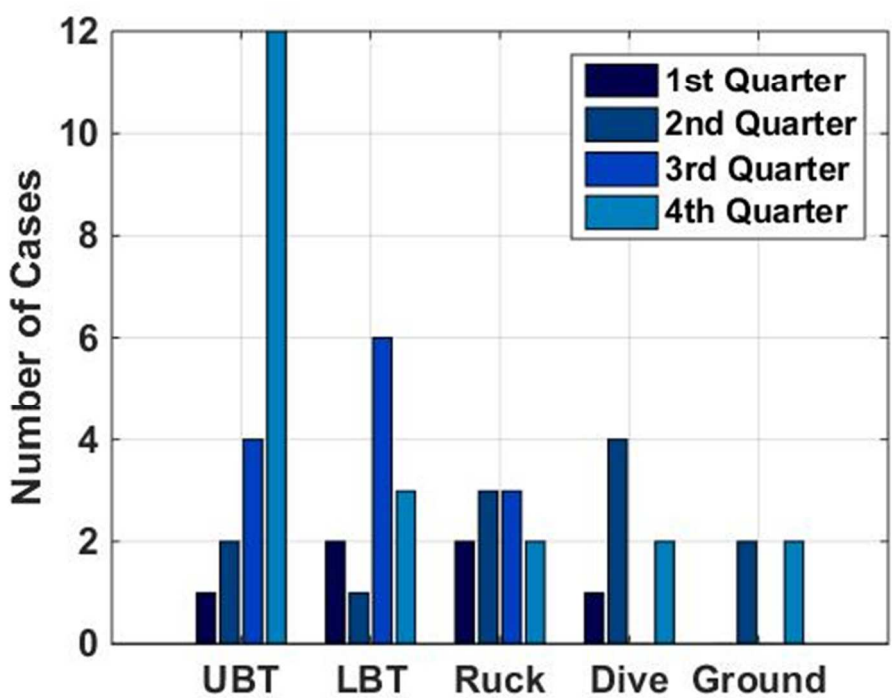


Figure 4: Quarter of the game at which Significant Direct Head Impacts occurred. UBT – Upper Body Tackle; LBT – Lower Body Tackle.
148x111mm (96 x 96 DPI)

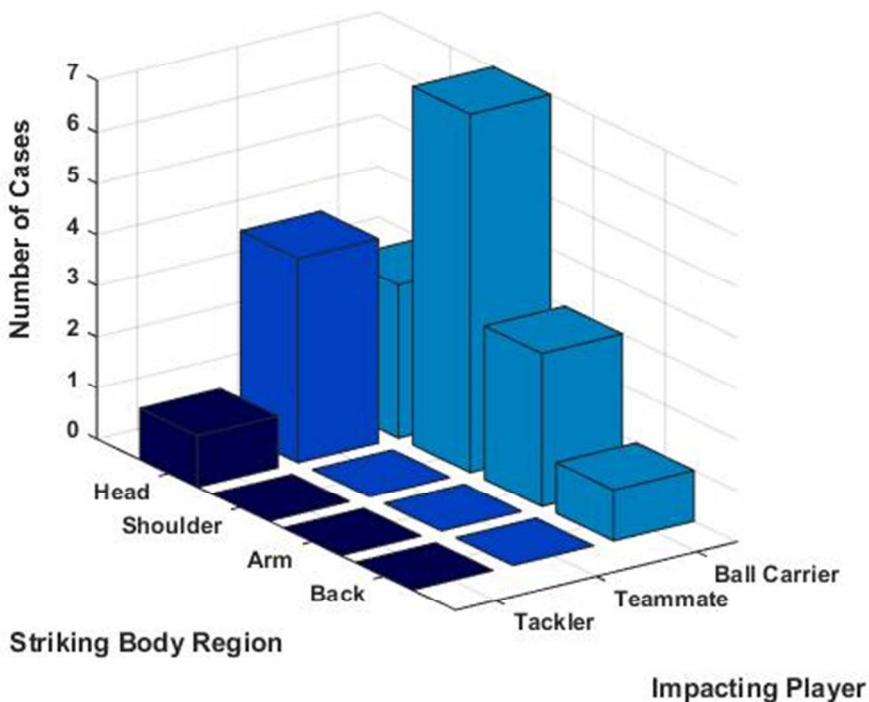


Figure 5: The number of Upper Body Tackles with Significant Direct Head Impacts based on Striking Body Region and Impacting Player.
148x111mm (96 x 96 DPI)

Review Only

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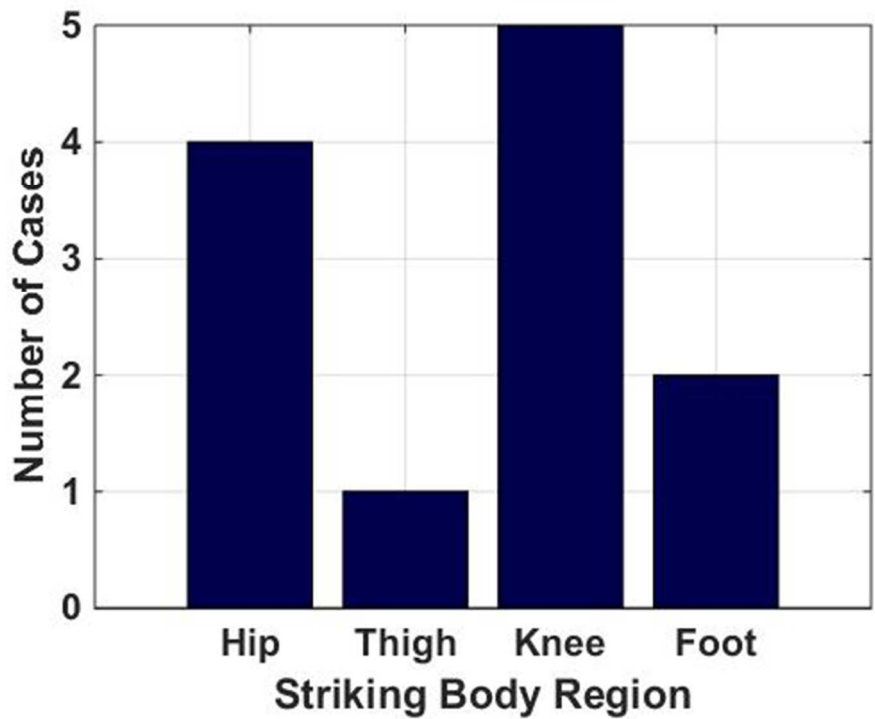


Figure 6: The number of Lower Body Tackles with Significant Direct Head Impacts based on Striking Body Region.

148x111mm (96 x 96 DPI)

Review Only

Figure Captions

Figure 1: Angle criteria for determining the direction of tackle. Black arrow indicates estimated Ball Carrier's direction of motion; Blue arrows indicate estimated Tackler's direction of motion.

Figure 2: Representative cases of multibody model method applied to a (a) Significant Direct Head Impact from an Upper Body Tackle; (b) Non Direct Head Impact from an Upper Body Tackle; (c) Significant Direct Head Impact from a Lower Body Tackle (d) Non Direct Head Impact in a Lower Body Tackle.

Figure 3: Categories of Significant Direct Head Impacts from all cases. UBT – Upper Body Tackle; LBT – Lower Body Tackle.

Figure 4: Quarter of the game at which Significant Direct Head Impacts occurred. UBT – Upper Body Tackle; LBT – Lower Body Tackle.

Figure 5: The number of Upper Body Tackles with Significant Direct Head Impacts based on Striking Body Region and Impacting Player.

Figure 6: The number of Lower Body Tackles with Significant Direct Head Impacts based on Striking Body Region.