Velocity and Acceleration before contact in the Tackle

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1. Introduction

A major characteristic of Rugby Union is frequent bodily collisions between two or more players. These physical collisions are generally referred to as the tackle (Hendricks & Lambert, 2010; Gabbett & Ryan, 2009; Gabbett & Kelly, 2007).The tackle contest can be identified when an opposing player, not in possession of the ball (tackler), contacts a player in possession of the ball (ball-carrier) in an attempt to prevent further progression of the ball towards the tackler's try-line. The tackle places a range of physiological, and to an extent, psychological demands on players (Takarada, 2003; Deutsch, Kearney, & Rehrer, 2007; Passos et al., 2009; Passos et al., 2008; Brault, Bideau, Craig, & Kulpa, 2010; Passos, Araujo, Davids, & Shuttleworth, 2011). Players' are expected to meet these demands on average about 10 to 25 times per a match depending on playing position (Deutsch et al., 2007; Quarrie & Hopkins, 2008). Players' capacity to fulfil these expectations, in addition to winning the tackle contest, has a significant influence on the outcome of the match (Gabbett, 2009; Gabbett & Ryan, 2009; Gabbett & Kelly, 2007; Gabbett, 2008; Wheeler, Askew, & Sayers, 2010).

The nature of two or more bodies colliding at such a high frequency exposes players to muscle damage and a high risk of injury (Hendricks & Lambert, 2010). It therefore comes as no surprise that tackle related injuries account for up to 61% of all injuries during a rugby match (Hendricks & Lambert, 2010). These findings, coupled to a need to further understand the complex dynamics of the tackle contest (whether for injury prevention, performance gains or research purposes), has triggered an increase in the number of studies done on the tackle in recent times. Work on the tackle range across disciplines such as identifying risk factors for injury (Quarrie & Hopkins, 2008; Fuller et al., 2010; Wilson, Quarrie, Milburn, & Chalmers, 1999; Garraway et al., 1999; McIntosh, Savage, McCrory, Frechede, & Wolfe, 2010), analysing techniques and their association with physiological and performance variables (Gabbett, 2009; Gabbett & Ryan, 2009; Gabbett & Kelly, 2007; Gabbett, 2008), identifying factors that may predict success in contact (Wheeler et al., 2010; Wheeler & Sayers, 2009), and understanding the governing dynamics of tackler/ball-carrier interactions (Brault et al., 2010; Passos et al., 2008; Passos et al., 2009; Passos et al., 2011; Passos, Araujo, Davids, Gouveia, & Serpa, 2006; Mouchet, 2005; Watson et al., 2010; Sekiguchi et al., 2011; Meir, 2005; Correia, Araujo, Craig, & Passos, 2011). To conduct these studies, researchers commonly make use of video analysis to analyse the tackle in real match situations, or study the tackle under controlled conditions.

Due to the complex and dynamic nature of the tackle, multiple factors may contribute to a player's ability to win the contest and prevail injury free. For example, research suggests that the velocity at which players (whether ball-carrier or tackler) enter the contact in the tackle may be one such contributing factor (Quarrie & Hopkins, 2008; Fuller et al., 2010; McIntosh et al., 2010). Velocity estimations at which players enter the tackle have been reported for both real match situations and under controlled conditions (Gabbett, 2009; Passos et al., 2008; Pain, Tsui, & Cove, 2008; Gabbett & Kelly, 2007; Gabbett & Ryan, 2009; Wheeler & Sayers, 2010; Walsh, Young, Hill, Kittredge, & Horn, 2007; Grant et al., 2003; Wheeler et al., 2010; Garraway et al., 1999; McIntosh et al., 2010; Fuller et al., 2010; Quarrie & Hopkins, 2008). However, in real match situations these estimations of velocity have been subjectively described compared to controlled conditions where actual velocity measurements were recorded (Garraway et al., 1999; McIntosh et al., 2010; Fuller et al., 2010; Quarrie & Hopkins, 2008). In controlled settings, velocities range from 1.5 $m.s^{-1}$ to 4.5/4.6 $m.s^{-1}$ for the tackler, and from 1.5 $m.s^{-1}$ to 7.7 $m.s^{-1}$ for the ball-carrier (Gabbett &

Kelly, 2007; Pain et al., 2008; Passos et al., 2008; Gabbett & Ryan, 2009; Gabbett, 2009; Grant et al., 2003; Walsh et al., 2007; Wheeler & Sayers, 2010) (Table 1). The range of these velocity measurements for both ball-carrier and tackler can be explained of course by the different study designs, aims and level of players studied. Nonetheless, the common factor among these studies is that they are all conducted in controlled settings. With the use of video analysis, speed or velocity before the tackle has also been subjectively described in real match situations. These descriptive measurements have proven to be effective in characterizing different velocities as risk factors for injury and prerequisites for success in contact (Garraway et al., 1999; McIntosh et al., 2010; Fuller et al., 2010; Quarrie & Hopkins, 2008).

Acceleration, or the ability to increase velocity over a set period, is also an important factor when entering a tackle. This is largely dependent on the starting velocity of players (Duthie, Pyne, Marsh, & Hooper, 2006). From a tackler's perspective, starting velocity can be influenced by the defensive strategy employed whereas from a ball-carrier's perspective, the velocity at which the ball is received (Wheeler et al., 2010). In controlled settings, tackler accelerations into contact under different fatigue states have been reported (Gabbett, 2008). The acceleration of the tackler decreased from 3.8 $m.s^{-2}$ during rest conditions, to 1.5 $m.s^{-2}$ under conditions of severe fatigue (Gabbett, 2008).

Video tracking, an extension of video analysis, in combination with computer generated algorithms is a fairly accurate method to calculate linear distance over time (Edgecomb & Norton, 2006; Barris & Button, 2008). This method relies predominately on ground markings as reference points to reconstruct a two-dimensional scaled version of a playing field (Edgecomb & Norton, 2006; Brewin & Kerwin, 2003). A major advantage of this approach is that it is independent of camera angle to the plane of motion (Alcock, Hunter, & Brown, 2009; Kwon & Casebolt, 2006). Therefore, it is possible to reconstruct playing fields where it is not always possible to place the camera perpendicular to the plane of motion (Alcock et al., 2009; Brewin & Kerwin, 2003). Moreover, it is possible to reconstruct playing fields from televised footage as knowledge of camera set-up is not required (Alcock et al., 2009). This method has been used in football, Australian Rugby Football, Rugby League and Rugby Union (Carling, Bloomfield, Nelsen, & Reilly, 2008; Mallo, Veiga, Lopez de, & Navarro, 2010; McIntosh, McCrory, & Comerford, 2000; Correia et al., 2011). McIntosh et al. utilized this method to compare concussive head impacts in Australian Rugby Football, Rugby League and Rugby Union (McIntosh et al., 2000). One such comparison was players' velocity before the impact. Australian Rugby Football players averaged 7 $m.s^{-1}$ (range 0.2 – 13.8), Rugby League 6 $m.s^{-1}$ (range 3.0 - 11.4) and Rugby Union 5 $m.s^{-1}$ (range 3.5 – 7.7) (McIntosh et al., 2000). Although this study reported velocity before contact, it did not differentiate between the type of contact (i.e. tackle, ruck, collision), nor did it indicate the role of the players in the contact (i.e. ball-carrier or tackler). To our knowledge, velocity and acceleration of the ball-carrier and tackler before contact in real match tackle situations has yet to be reported. Therefore the purpose of this study was to determine the velocity and acceleration of the ball-carrier and tackler before contact using the method described above.

Table 1: Velocity Measurements for Ball-carrier and Tackler in Controlled Conditions

Authors	Year	Aim	Playing Level	Velocity (m.s^{-1})	
Tackler					
(Gabbett & Kelly, 2007)	2007	Assess the tackling proficiency of collision-sport athletes and the effects of increased line-speed on tackling proficiency	Sub-elite	Enforced Line-speed 3.8 Self-paced 3.2	
(Pain et al., 2008)	2008	In vivo determination of the effect of shoulder pads on tackling forces in rugby	Not reported	<u>Without pads</u> Shoulder Run 4.5 Shoulder Crouch 3.2 Hip Run 4.6 Hip Crouch 2.4	<u>With Pads</u> Shoulder Run 4.4 Shoulder Crouch 3.5 Hip Run 4.4 Hip crouch 2.8
(Passos et al., 2008)	2008	Information-governing dynamics of attacker-defender interactions	Junior (aged 11-12)	Try 2 Unsuccessful 1.5 (Tackle Break) Successful 1.5 (Tackle completed)	
(Gabbett & Ryan, 2009)	2009	Investigate the relationship between tackling technique and playing level, experience, match performance and injury risk.	1st Grade National and State-based	<u>1st Grade</u> 2.8(2.4-3.5)#	<u>State-based</u> 2.8(1.8-3.2)#
(Gabbett, 2009)	2009	Correlate tackling ability to physiological and anthropometric variables	1st Grade	Best tacklers 3.2	Worst tacklers 3.1
Ball-carrier					
(Grant et al., 2003)*	2003	Effect of ball carrying method on sprint speed (over 20m with a 10m rolling start)	Amateur	Two-handed 7.6 Left-arm carry 7.7	Right-arm carry 7.7
(Walsh et al., 2007)*	2007	Effect of ball-carrying technique and experience on sprinting	University	Beginners (10m) 5.4 (under one arm) 5.2 (in both hands) Experienced 5.3 (under one arm) 5.3 (in both hands)	Beginners (20m) 7.7 (under one arm) 7.6 (in both hands) Experienced 7.6 (under one arm) 7.6 (in both hands)
(Passos et al., 2008)	2008	Information-governing dynamics of attacker-defender interactions	Junior (aged 11-12)	Try 5 Unsuccessful 2(Tackle Break) Successful 1.5(Tackle completed)	
(Wheeler & Sayers, 2010)	2010	Differences in agility running technique between reactive (R) and pre-planned (PP) conditions	National and International	Pre-change of direction phase Pre-planned 5.89 Reactive 5.71	Change of direction phase Pre-planned 5.22 Reactive 5.25

*Studies not done in tackle situations
mean (range in parenthesis)

2. Methods

Nine rugby union matches from Super 14 (3 matches) – an elite international competition consisting of full-time professional rugby players from provincial franchises in Australia, South Africa and New Zealand; Varsity Cup (2 matches) – a highly competitive national university competition consisting of semi-professional players; and Under 19 Currie Cup 2010 (4 matches) - competition consisting of highly trained school boy players were analysed for this study. Televised recordings were used and self-recorded video footage was used for Varsity Cup matches.

Front-on and side-on tackles which occurred during each match were then coded for using Sportscode Elite (Version 6.5.1, Sportstec, Australia). For the laws of rugby, a tackle occurs *'when a ball-carrier (a player carrying the ball) is held by one or more opponents and is brought to ground'* (International Rugby Board, 2008). The opposition player that goes to ground with the ball-carrier is referred to as the *'tackler'* (International Rugby Board, 2008)*'*. For research purposes, other definitions for the tackle have been employed. Quarrie and Hopkins defined the tackle *'when ball-carrier was contacted (hit and/or held) by an opponent without reference to whether the ball-carrier went to ground'* (Quarrie & Hopkins, 2008). Similarly, in a more recent study, Fuller et al identified a tackle to be *'any event where one or more tacklers attempted to stop or impede the ball-carrier whether or not the ball-carrier was brought to ground'* (Fuller et al., 2010). Since the tackle definitions for the aforementioned studies are fairly similar, both were considered during coding. In addition, front-on and side-on tackles were distinguished using the description by Quarrie and Hopkins (Quarrie & Hopkins, 2008). The video footage of the tackle event had to fulfil the following visibility criteria i) Visual of 4 locations with known distances represented by the lines on the field, ii) Clear running path of the ball-carrier and primary tackler pre-tackle (at least for 0.5 seconds), iii) Camera had to remain fixed over this period. The reasons for these criteria will become evident later in this section. Tackle events that fulfilled these criteria (10 tackles x 3 competitions x 2 types of tackles = 60 tackles) were subsequently imported into Dartfish Teampro (Version 4.0.9.0 Switzerland).

Using Dartfish Analyser, a timer was set to zero at the point of contact between the ball-carrier and primary tackler. The ball-carrier and tackler were then retracted for 0.5 seconds (25 frames) from the point of contact. This period is considered the pre-tackle phase (Fuller et al., 2010). Thereafter, the ball-carrier and tackler were tracked back to the point of contact for the 0.5 seconds. Ball-carriers were generally tracked from mid-section (hip area) and tacklers on the upper body. A line was then drawn with the software through the tracked path of both the ball-carrier and tackler, and divided into 0.1 second intervals (Five 0.1 second intervals, six markings) (Figure 1). An image of the analysed tackle, with the marked 0.1 seconds intervals, was subsequently imported into Matlab (Version 6.5, Mathworks Inc, United States of America).

An algorithm to determine the planar location of a single point determined by pixel co-ordinates within an image was developed in Matlab (Version 6.5, Mathworks Inc, United States of America). As mentioned earlier, one of the inclusion criteria for analysis of the tackle event was a visual of 4 locations with known distances represented by the lines on the field. This made it possible to enter four known x and y co-ordinates on the field. The program then created a 2D-axis (x; y) system in the plane of the field shown in the imported image from Dartfish. Once the 4 known co-ordinates were entered, and the 2D-axis system created, it was possible to obtain x; y co-ordinates of any point on the field. To obtain the co-ordinates, the analyser had to simply select any point on the field, and the algorithm would calculate the co-ordinates despite the distortion to the image created by the cmaera. For every tackle event, a new image and a new 2D-axis system was created, according to the known distances. Before a tackle was analysed, and to further validate the 2D-axis system, co-ordinates produced by the 2D-axis system had to correspond to the known distances of the playing field from the imported image. The centre of the field (on the half-way line at the mid-point between the two touchlines) was chosen as the point of origin on the field (x=0; y=0) (Figure 2).

After the validation, the co-ordinates of the marked 0.1 second intervals were obtained for both the ball-carrier and the tackler. The distance between 2 co-ordinates (x and y) was calculated and divided by 0.1 seconds to produce the average velocity ($m.s^{-1}$) over that interval. This was repeated for the five 0.1 second intervals up to the point of contact for both ball-carrier and tackler. Average acceleration over the 0.5 seconds was calculated by subtracting the final velocity by the initial velocity, and dividing it by 0.4 (only four intervals of acceleration over the 0.5 seconds).

2.1. Validation

To test the validity of our methods, velocity measurements using the methods described above were compared to criterion velocity measurements. A contact zone was created and located at 3 different points between the two 15-metre lines – 1 furthest away from the camera, 1 in the centre on the field and 1 closest to the camera. The contact zone consisted of 6 cones (placed 0.5 metres apart from each other. One Varsity cup backline player was asked to carry the ball into contact and execute a tackle in each contact zone 3 times, respectively (9 ball-carries and 9 tackles). When performing a ball-carry or tackle, the player was asked to execute with the same intensity as he would during a real match situation. In addition, an extra 2.5 metres was included before the contact zone to allow the player to gain speed and enter the contact zone at a velocity similar to what he would attain during a real match. Another Varsity Cup player provided the opposition in each case. Each contact situation was recorded using a digital camera (Sony HDV, HVR-A1E, Japan) The video footage was imported into Dartfish Teampro (Version 4.0.9.0 Switzerland).

Measurement velocity was determined using the methods described above. Criterion velocity was determined using the known distances indicated by the cones. In Dartfish Analyser, the known distances of the cones were set as reference points and recorded for the five 0.1 second intervals. As mentioned previously, a further validation was also conducted on each image by confirming that the co-ordinates produced by the 2D-axis system correspond to the known distances of the playing field.

2.2. Statistical Analysis

2.2.1. Validation

Correlation coefficients (r) were calculated to compare Criterion Velocity ($m.s^{-1}$) and Measurement Velocity ($m.s^{-1}$). Standard error of the estimate (SEE) was calculated to determined to analyse the amount of error in the measurement (Jennings, Cormack, Coutts, Boyd, & Aughey, 2010).

2.2.2. Velocity

Analysis of variance was used to compare the average velocity of the ball-carrier and tackler for front-on and side-on tackles across competitions. Analysis of variance was also used to compare the velocity of the ball-carrier and tackler in different competitions at each 0.1 time to contact interval during front-on and side-on tackles. A Tukey *post-hoc* test was used to further analyse any differences found. T-tests were used to compare the average velocity, and each of the five 0.1 second intervals between ball-carrier and tackler during front-on and side-on tackles for all competitions and within each competition. All velocity data are reported as mean ± standard deviation (mean ± SD)

2.2.3. Acceleration

Analysis of variance was used to compare the mean acceleration of the ball-carrier and tackler for front-on and side-on tackles in all three competitions. T-tests were used to compare mean acceleration between ball-carrier and tackler during front-on and side-on tackles for all competitions and within each competition. All acceleration data are reported as mean ± standard deviation (mean ± SD)

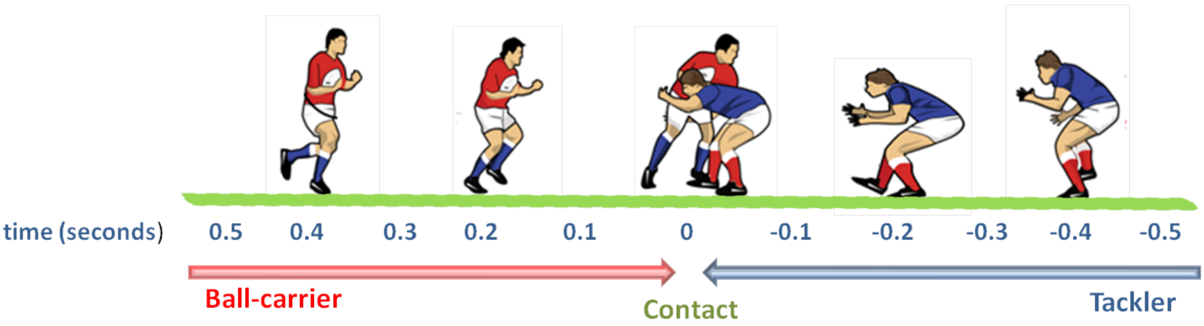

Figure 1: Graphic representation of time to contact measurement points

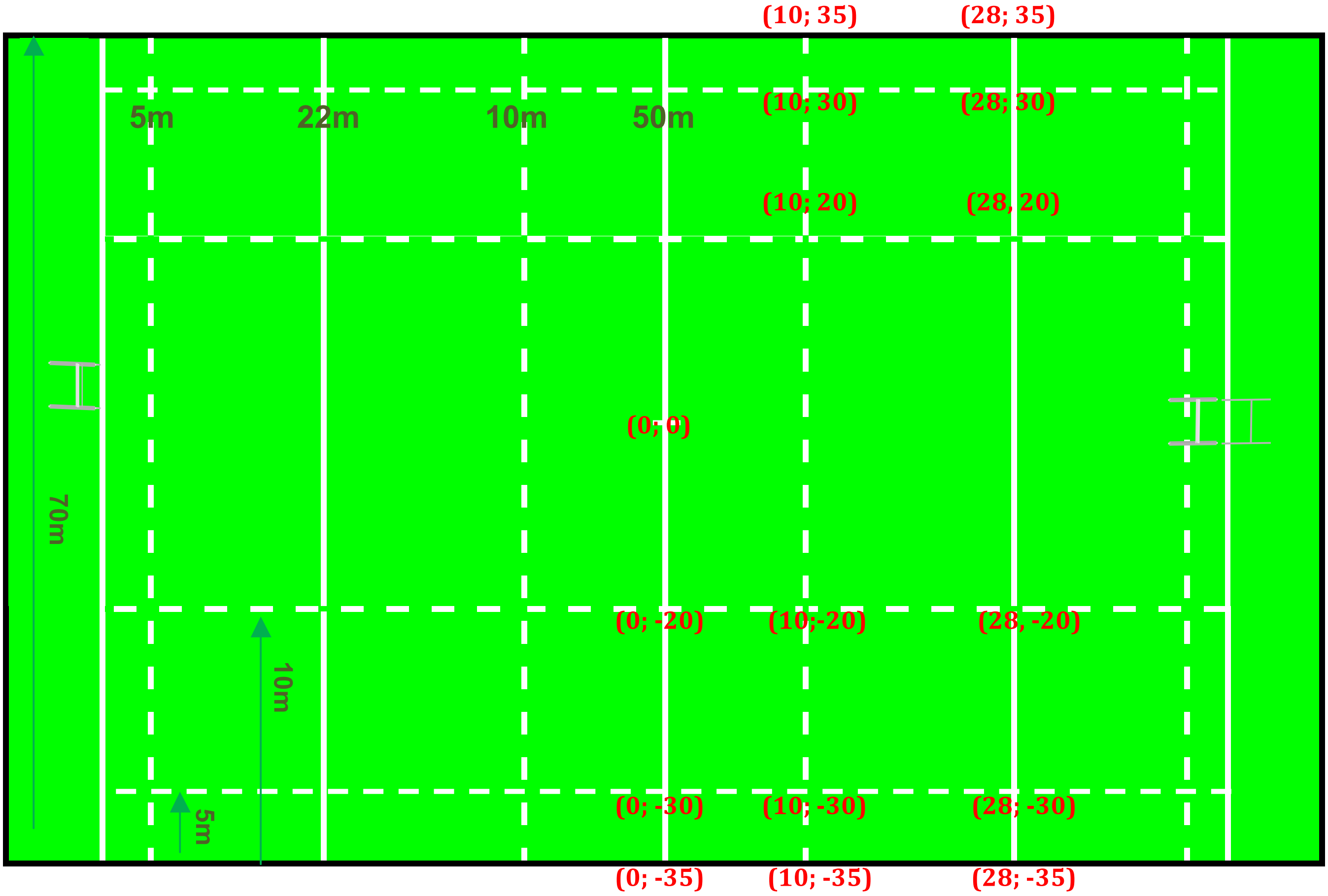

Figure 2: Graphic representation of a Rugby Field showing x and y co-ordinates determined from lines on the field. Note: This representation only shows some of the co-ordinates on one side of the field.

3. Results

3.1 Validation

Figure 3 shows an acceptable level of reproducibility between Measurement Velocity and Criterion Velocity for both ball-carrier and tackler. For the ball-carrier, higher correlation coefficients and smaller SEE values were found closer to the point of contact. For the tackler, high correlation coefficients and small SEE values are distributed over the 0.5 second pre-tackle period.

3.2 Velocity before a Front-on Tackle

During the front-on tackle the average velocity over the 0.5 second period for the ball-carrier in each respective competition were 4.8±2.9 m.s-1 (Super 14), 5.2±1.m.s-1 (Varsity Cup), and 4.9±1.7m.s-1 (Under 19). The average velocities for the corresponding tackler were 5.0±1.8m.s-1 (Super 14), 6.4±2.6m.s-1 (Varsity Cup) and 5.7±1.9m.s-1 (Under 19). No significant difference was found between the average velocities of the three competitions for both ball-carrier and tackler. Furthermore, no significant differences were found between the competitions for the ball-carrier and tackler when comparing each 0.1 time interval (Figure 4).

No significant difference was found between the average velocities of the ball-carrier and tackler overall for all competitions and within each competition. However, a significant difference between the ball-carrier and tackler was found at the 0.5 second time to contact interval, overall for all competitions and within the Varsity Cup ($p<0.05$). For the remaining time to contact points, no significant differences were found, for all competitions and within each competition.

3.3 Velocity before a Side-on Tackle

During the side-on tackle the average velocity over the 0.5 second period for the ball-carrier in each respective competition were 4.9±2.1 m.s-1 (Super 14), 5.8±1.8m.s-1 (Varsity Cup), and 4.7±1.3m.s-1 (Under 19). The average velocity for the corresponding tackler were, 5.4±2.2m.s^{-1} (Super 14), 5.5±2.1m.s^{-1} (Varsity Cup) and 3.9±1.1m.s^{-1}(Under 19). No significant difference was found between the average velocities of the three competitions for both ball-carrier and tackler.

A significant difference was found between the tacklers of the different competitions at the 0.5 seconds time to contact interval ($p<0.05$) (Figure 5). A Tukey Post-hoc test revealed that this significant difference was between Varsity Cup and Under 19 ($p<0.05$). No significant difference was found between the average velocities of the ball-carrier and tackler overall for all competitions and within each competition. Significant differences between the tackler and ball-carrier were found at the 0.5 second and 0.4 second time to contact intervals in the Under 19 competition($p<0.05$).

3.4 Acceleration before a Front-on and Side-on tackle

No significant differences were found between the mean accelerations of the three competitions for both ball-carrier and tackler during front-on and side-on tackles (Table 2). No significant difference was found between ball-carrier and tackler overall for all competitions. However, a significant difference was found between the mean acceleration of the ball-carrier and tackler during a front-on tackle in the Varsity Cup.

3. Results

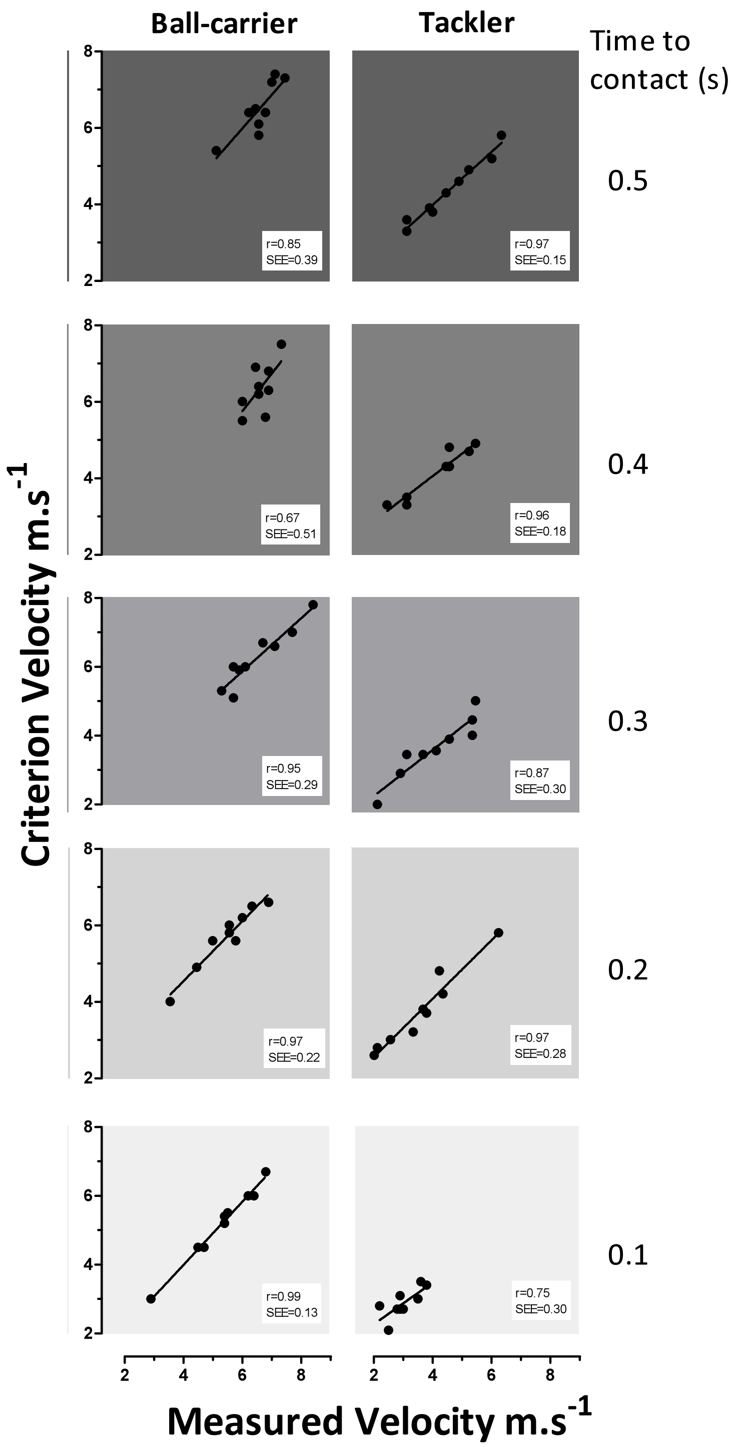

Figure 3: Relationship between Criterion Velocity and Measurement Velocity at each at each 0.1 second interval for 0.5 seconds before contact. r = Correlation Coefficient. SEE = Standard Error of the Estimate.

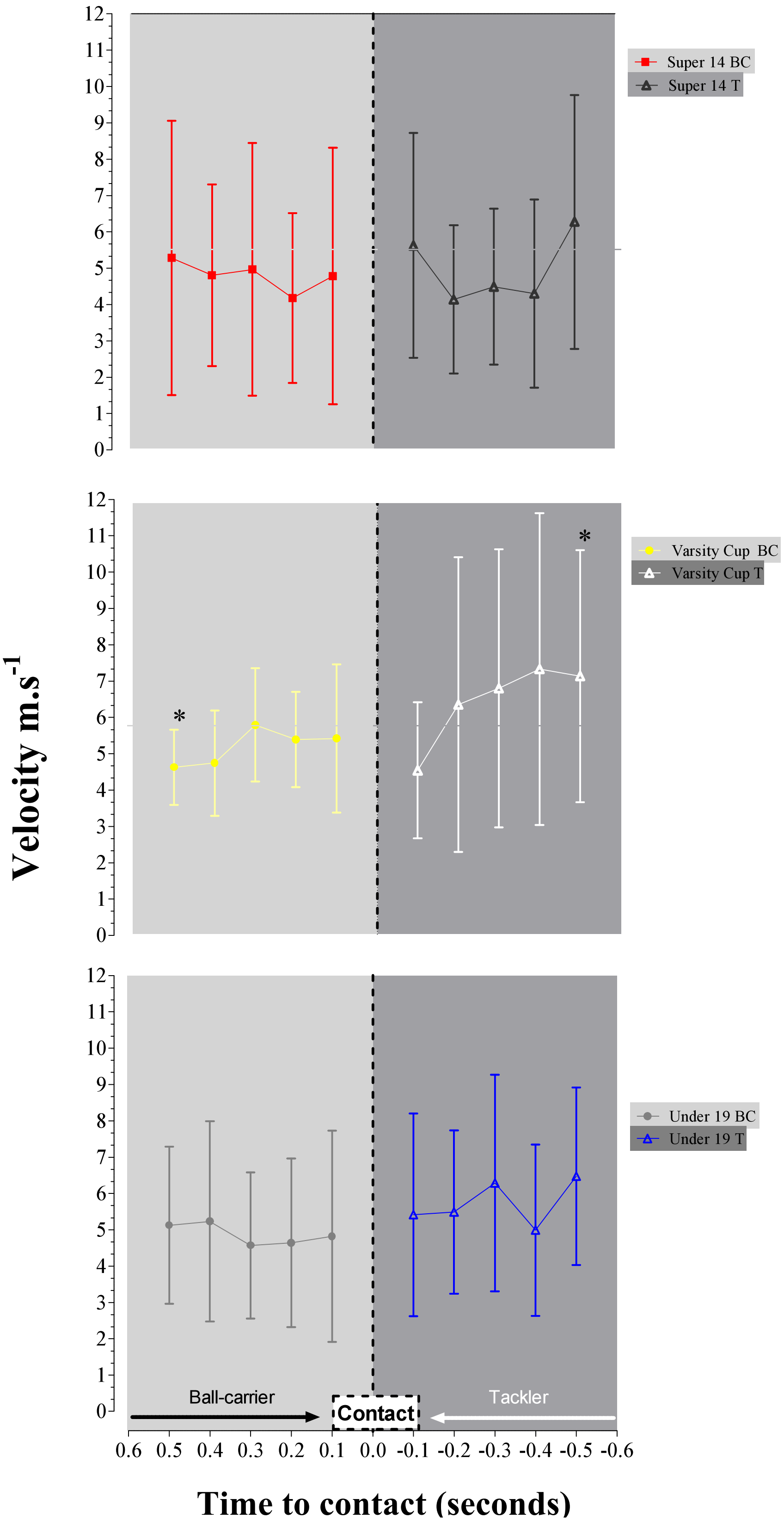

Figure 4: Ball-carrier (positive) and Tackler (negative) velocities before contact during a front-on tackle in Super 14, Varsity Cup and Under 19. Velocities measured at each 0.1 second interval for 0.5 seconds. Data reported as mean ± standard deviation. *- Ball-carrier significantly different from tackler at 0.5 seconds to contact ($p<0.05$).

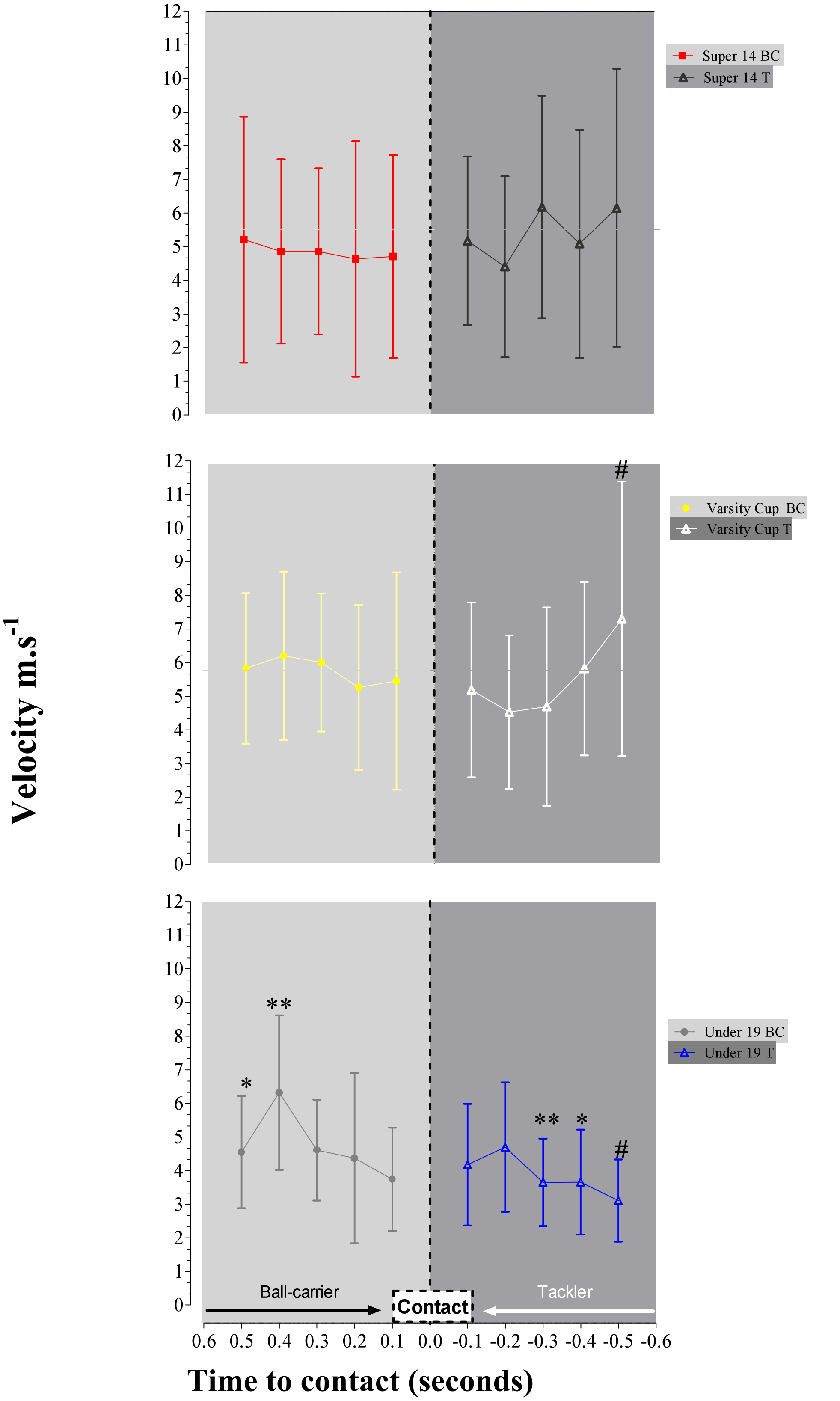

Figure 5: Ball-carrier (positive) and Tackler (negative) velocities before contact during a side-on tackle in Super 14, Varsity Cup and Under 19. Velocities measured at each 0.1 second interval for 0.5 seconds. Data reported as mean ± standard deviation. *- Ball-carrier significantliy different from tackler at 0.5 seconds to contact(p<0.05). **- Ball-carrier significantly different from tackler at 0.4 seconds to contact(p<0.05). # - Varsity Cup significantly different from Under 19 at 0.5 seconds to contact(p<0.05).

Table 2: Average acceleration for Ball-carrier and Tackler before contact during the front-on and side-on tackle in Super 14, Varsity Cup and Under 19. Data reported as mean ± standard deviation. *- Ball-carrier significantliy different from tackler(p<0.05).

	Front On				Side On			
	Ball-carrier($m.s^2$)		Tackler($m.s^2$)		Ball-carrier($m.s^2$)		Tackler($m.s^2$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Super 14	-1.24	4.88	-1.62	9.62	-1.26	8.67	-2.44	10.12
Varsity Cup	1.98*	4.95	-6.49*	10.64	-0.95	9.99	-5.28	6.30
Under 19	-0.76	8.56	-2.65	8.84	-2.02	6.24	2.67	3.59

4. Discussion

This is the first study to objectively report the velocity and acceleration of both ball-carrier and tackler in real match situations. Moreover, these velocities and accelerations were revealed for front-on and side on tackles. The velocity and accelerations within these two types of tackles were further compared across three competitions. When entering a front-on tackle, no significant differences were found between the competitions for both the ball-carrier and tackler when comparing the average velocity, average acceleration, and the velocity at each time to contact interval. This was also evident during the side-on tackle (except for the tackler at the 0.5 seconds to contact interval where a difference was found between Varsity Cup and Under 19). Intuitively, one would expect the pre-tackle velocities to differ across the three competitions. However, a possible explanation for the lack of differences is that the velocity at which players enter the tackle is not a good indicator of the level play. This explanation is supported by the velocity measurements for the ball-carrier and tackler in controlled conditions where players at national and international level do not differ substantially from sub-elite, amateur or junior levels (Table 1) (Gabbett & Kelly, 2007; Pain et al., 2008; Passos et al., 2008; Gabbett & Ryan, 2009; Gabbett, 2009; Grant et al., 2003; Walsh et al., 2007; Wheeler & Sayers, 2010). An alternative explanation may be that the three competitions used in this study did not differ enough to note any pre-tackle velocity disparities. All three competitions consist of fairly high level players, with considerable experience and quality training habits.

As mentioned earlier, due to the complex and dynamic nature of the tackle multiple factors may contribute to a player' ability to win the tackle contest and prevail injury free, and that one such factor may be velocity (Quarrie & Hopkins, 2008; Fuller et al., 2010; McIntosh et al., 2010). Be that as it may, the relative contribution and precedence of a high pre-tackle velocity compared to the other factors that players need to consider before a tackle may be relatively low. Proper technique for example, is considered imperative when entering contact whether ball-carrier or tackler (McKenzie, Holmyard, & Docherty, 1989; Sayers & Washington-King, 2005; Gabbett & Ryan, 2009; Wheeler & Sayers, 2009; Wheeler et al., 2010; Gabbett & Kelly, 2007; Gabbett, 2009; Gabbett, 2008; Wheeler & Sayers, 2010; Hendricks & Lambert, 2010). Well-trained players are generally aware of this, and would not easily sacrifice good technique to increase their velocity before a tackle (Gabbett & Ryan, 2009; Hendricks & Lambert, 2010). When tackling in matches however, players sometimes forfeit proper technique for a high pre-tackle velocity by diving into contact (Hendricks & Lambert, 2010). Hendricks and Lambert suggest that this technique, which may disadvantage players, can be attributed to rugby players trying to mimic the American football spear tackle and training inappropriately with a tackle bag (Hendricks & Lambert, 2010).

When comparing the velocities between ball-carriers and tacklers before contact in front-on and side-on tackles, significant differences were found at the furthest points from contact – 0.4 and 0.5 seconds away from contact. As contact approaches, these differences between the ball-carrier and tackler were found to be insignificant. Furthermore, for both front-on and side tackles, the ball-carriers' velocity along each time to contact interval seemed relatively stable compared to the variability in the tacklers' time to contact intervals. These results suggest that when tacklers enter the pre-tackle phase at a velocity considerably different to that of the ball-carrier (whether higher or lower), a counterbalance reaction is initiated. Tacklers achieve this counter balance during the last moments in the pre-tackle phase by adjusting their velocity accordingly. This finding supports studies by Passos et al. on the governing dynamics between attacker (ball-carrier) and defender (tackler) interactions (Passos et al., 2008). According to Passos et al., in a 1 versus 1 attacker-defender situation, two potential control parameters that may affect the outcome of an attacker-defender situation in rugby union are interpersonal distance and relative velocity (Passos et al., 2008). The outcome in this study was characterised by whether or not contact was made between the attacker and defender. In the cases where contact was made (analogous to all the tackles in this study), a critical period from 4 metres of interpersonal distance to contact (0 metres interpersonal distance) was found. Within this period, contact was predictable when the defender was able to adjust his velocity so that the relative velocity is reduced and maintained below 2 $m.s^{-1}$(Passos et al., 2008). Outside this period, relative velocity did not seem to have much effect due to players still deciding what action to take (i.e. to pass, side-step, execute the tackle, intercept etc) (Passos et al., 2008). The aforementioned study by Passos et al. however utilised junior rugby players (age 11-12) and was conducted in controlled settings; a direct comparison is therefore difficult to make. Nonetheless, applying the Passos et al. theory to our findings, a critical period - identified by a specific interpersonal distance and a definitive relative velocity range before contact may provide a rationale for our results. The significant differences outside the 0.3 second time to contact interval for front-on and side-on tackles in Varsity Cup and Under 19 players implies that these players probably reach a critical period at this stage. Within the subsequent 0.3 seconds, tacklers are able to attain a suitable relative velocity that will afford a tackle on the ball-carrier. Interestingly, no significant differences were found at each time to contact interval between the ball-carrier and tackler for front-on and side-on tackles in the Super 14 competition. The differences between ball-carrier and tackler outside the 0.3 second time to contact interval in Varsity Cup and Under 19, and absence of a significant difference at Super 14, may be indicative of the level play (compared to a entering the tackle at increasing velocities at higher levels as we discussed earlier in this section). Tacklers at an elite level may be able to make a decision quicker and therefore stabilise their velocity sooner to counter balance the velocity of the ball-carrier. In other words, the critical period, specific interpersonal distance and definitive relative velocity range, may change according to playing level and situation. Further research to substantiate this is warranted. The reduction in relative velocity, largely due to the tackler counterbalance reaction, may be explained by the tackler, and ball-carrier preparing for contact, therefore adopting the relevant technique.

The purpose of this study was to determine the velocity and acceleration of the ball-carrier and tackler before contact in real match situations. Although this was achieved, there are noteworthy limitations. Similar to most tackle velocity studies, this study generally treated the ball-carrier and tackler as single entities. Although we tried to control for this by tracking from the upper body of the tackler and mid-section of the ball-carrier, velocity measurements of individual body parts just before contact would provide much more insight into the dynamics of the tackle. For example, although a ball-carrier's velocity is 5 $m.s^{-1}$ before contact, the velocity of his fend (an effective push manoeuvre) can be 10 $m.s^{-1}$. In a tackler example, the tackler may be moving at 5.5 $m.s^{-1}$, but his shoulder velocity has he drives it into contact can be 10 $m.s^{-1}$. In controlled settings, velocity measurements of individual body parts have been reported (Pain et al., 2008; Wheeler & Sayers, 2010). With the use of 2D-axis system, another limitation of the study was the assumption that the ball-carrier and the tackler maintained a linear motion path within the 0.5 second period. Therefore subtle evasive manoeuvres by the ball-carrier, or fine technique positioning by tackler, that may have had an influence the on velocity measurement were obscured. A further limitation is the artefact introduced by the location of the two dimensional axis plane. Since the plane was positioned at field level, and the player was identified by a point above field level, at their hip or torso, the position measurements will inevitably contain a small amount of artefact dependant on how much vertical motion of the measurement point occurs during the measurement period. To correct this one would track the player's feet as they touch the ground. However, using this correction would produce highly erratic results as the position of a player's feet at any point in time is not an accurate representation of the player as a single body.

5. Conclusion

Using a valid method, this study revealed the velocities at which ball-carriers and tacklers in Super 14, Varsity Cup and Under 19 competitions enter front-on and side-on tackles in real match situations. The velocity values obtain in real match situations were comparable with studies conducted in control settings. Furthermore, differences between ball-carrier and tackler support theories on the governing dynamics between attacker (ball-carrier) and defender (tackler) interactions (Passos et al., 2008).This deeper insight into the dynamics of the tackle in real match situations suggests current training strategies for the tackle need to be modified. To effectively prepare for real match situations, coaches need to train the tackle with both the ball-carrier and tackler moving towards each other in different situations. Moreover, less emphasis should be placed on entering the contact at excessively high velocities. This will allow players to focus more on the technical aspects of the tackle – like initiating the counter balance reaction quicker and efficiently preparing for the approaching contact. As noted previously, more work is needed to further understand the critical period, interpersonal distance and relative velocity. Also understanding the specific movements and functions of major body parts before and at the point of contact in the tackle will provide valuable information that could modify the way players condition themselves for rugby matches.

Table 1: Velocity Measurements for Ball-carrier and Tackler in Controlled Conditions

Table 2: Average acceleration for Ball-carrier and Tackler before contact during the front-on and side-on tackle in Super 14, Varsity Cup and Under 19. Data reported as mean ± standard deviation. *- Ball-carrier significantliy different from tackler($p<0.05$).

Figure 1: Graphic representation of time to contact measurement points

Figure 2: Graphic representation of a Rugby Field showing x and y co-ordinates determined from lines on the field. Note: This representation only shows some of the co-ordinates on one side of the field.

Figure 3: Relationship between Criterion Velocity and Measurement Velocity at each at each 0.1 second interval for 0.5 seconds before contact. r = Correlation Coefficient. SEM = Standard Error Measurement.

Figure 4: Ball-carrier (positive) and Tackler (negative) velocities before contact during a front-on tackle in Super 14, Varsity Cup and Under 19. Velocities measured at each 0.1 second interval for 0.5 seconds. Data reported as mean ± standard deviation.

*- Ball-carrier significantliy different from tackler at 0.5 seconds to contact ($p<0.05$).

Figure 5: Ball-carrier (positive) and Tackler (negative) velocities before contact during a side-on tackle in Super 14, Varsity Cup and Under 19. Velocities measured at each 0.1 second interval for 0.5 seconds. Data reported as mean ± standard deviation.

*- Ball-carrier significantliy different from tackler at 0.5 seconds to contact($p<0.05$).

**- Ball-carrier significantliy different from tackler at 0.4 seconds to contact($p<0.05$).

- Varsity Cup significantly different from Under 19 at 0.5 seconds to contact($p<0.05$).

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