THE TRADE-OFF BETWEEN DISTANCE AND ACCURACY IN THE RUGBY UNION PLACE KICK: A CROSS-SECTIONAL, DESCRIPTIVE STUDY

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Abstract:

Little attention has been given to the rotational kinematics of the rugby union place kicking performance, especially in a field setting. The place kick is a means to score points. By maximizing the distance and accuracy a kicker is able to achieve increases in the number of point scoring opportunities available to a team. The hypothesis of this study was that there was a relationship between distance and accuracy and the rotational kinematics of place kicking performance of rugby players in the field setting. Twelve first-team university rugby players had their full body kinematics measured for five place kicks. Kick distance and accuracy were directly measured. The current study showed a positive correlation between torso (r=.76) and pelvis (r=.66) rotation with kick distance. Place kick distance (r=.24) or accuracy (r=.54) were not correlated to playing experience. Negative correlations between stance elbow flexion (r=-.78), torso rotation (r=-.74) and X-factor (r=-.79) with kick accuracy were noted. Place kick distance could potentially be maximized by improving torso and pelvic rotations. Place kick accuracy could be improved by full extension of the stance arm. The data suggests that larger torso rotations may promote kicking distance; however, they impede kicking accuracy.

Key words: *kinematics, field measurement, direct measurement*

Introduction

The place kick is a means of scoring points either as a penalty kick or by converting a try. Quarrie and Hopkins (2015) reported that an average of 45% of the points during a rugby game resulted from successful place kicks. The kicking tee is used to elevate the ball from the ground and encourage the kicker to make a clean strike against the ball. The kicker must have the ability to kick the ball over long distances as well as be accurate enough to get the ball through the up-rights, spaced 5.6 m apart. Therefore a successful rugby place kick requires accuracy and sufficient velocity to reach the necessary distance. The success of a place kick is currently thought to be reliant on both physiological factors, such as lower body strength (Zhang, Liu, & Xie, 2012), and biomechanical skill, such as the optimization of the kinetic chain (Bezodis, Trewartha, Wilson, & Irwin 2007; Zhang, et al., 2012).

Physiological improvement of muscular strength following resistance training (Manolopoulos, Katis, Manolopoulos, Kalapotharakos, & Kellis, 2013) together with a combined strength and kick coordination training intervention (Manolopoulos, Papadopoulos, & Kellis, 2006) have been shown to increase ball speed. Additionally, Australian football players that exhibit more accurate place kicks have been shown to have more muscle mass than their inaccurate counterparts (Hart, Nimphius, Cochrane, & Newton, 2013; Hart, Nimphius, Spiteri, & Newton, 2014). While muscular strength and muscle mass are essential to kicking performance, it is likely that kicking requires more than strength alone.

Kicking is a complex biomechanical action that requires the controlled and intricate coordination between the segments of the lower body, both temporally and spatially (Bezodis, et al., 2007; Kellis & Katis, 2007; Manolopoulos, et al., 2006; Naito, Fukui, & Maruyama, 2010; Shan & Westerhoff, 2005; Urbin, Stodden, Fischman, & Weimar, 2011). The kinematics of the kicking action has been studied by many researchers specifically in soccer (reviewed by Lees, Asai, Andersen, Nunome, & Sterzing, 2010) and Australian football (Hart, et al., 2014). Previous researchers that have examined the place kick in rugby have focused on kicking models and kicking performance (Bezodis, et al., 2007, Ball, Talbert, & Taylor, 2013, Sinclair, Taylor, Atkins, Bullen, Smith, & Hobbs, 2014a).

The kick distance results from the generation of maximal energy being transferred via the kinetic chain to the ball. To impart maximal velocity to the ball, the energy generated should occur in a proximal-distal fashion (Naito, et al., 2010; Shan & Westerhoff, 2005; Sinclair, et al., 2014a; Sinclair, Fewtrell, Taylor, Bottoms, Atkins, & Hobbs 2014b; Urbin, et al., 2011; Zhang et al., 2012). The initiation of the kicking sequence has previously been suggested to begin with rotation occurring at the pelvis (Kellis & Katis, 2007; Sinclair, et al., 2014b; Zhang, et al., 2012). However, recently Fullenkamp, Campbell, Laurent, and Lane (2015) showed the importance of trunk rotation in ball velocity attainment. Their finding shifts the imitation of the kinetic sequence further up to the level of the torso and needs to be investigated within the rugby context. Specifically in the rugby place kick, ball velocity has been shown to be related to peak knee extension velocity (Sinclair, et al., 2014a), but not as a result of changing the foot plant position (Baktash, Hy, Muir, Walton, & Zhang, 2009) likely due to the similar positions of foot placements across the spectrum (Cockcroft & van den Heever, 2016). Lees and colleagues (2010) mentioned the positive relationship between stride length and the resulting kick distance and attributed this relationship to energy generated by the rotation of the pelvis. While this relationship is a contributing factor, it is likely that the efficient transfer of energy between segments is more important for achieving distance with the kick (Kellis, Katis, & Vrabas, 2006). Within a rugby context longer run-ups have shown a trade-off between increased ball velocity and reduced kick accuracy (Padulo, Granatelli, Ruscello, & D'Ottavio, 2013).

The trade-off between speed and accuracy has been shown in various sporting disciplines (Sachlikidis & Salter, 2007; García, Sabido, Barbado, & Moreno, 2013), in the soccer kick (Teixeira, 1999; Asai, Carré, Akatsuka, & Haake, 2002; Kellis & Katis, 2007) and more specifically in the rugby place kick (Bezodis, et al., 2007; Padulo, et al, 2013).

The study aimed to evaluate kinematic determinants of rugby place kick distance and accuracy on a natural turf outdoor field. It was hypothesized that the rotational kinematics of the shoulder and pelvic girdles, major components in the transfer of energy in the kinetic chain, were related to the achievable distance and accuracy of the place kick. Specifically, it was expected that greater shoulder and pelvis rotations would result in further and more accurate place kicks. Following this it was hypothesized that one possible mechanism for achieving maximal distance and accuracy was muscular strength. To this end it was expected that lower body power would be related to the place kick distance and accuracy. Collectively, the study was expected to give a further biomechanical description of the rugby union place kick recorded on an outdoor field.

Methods

Participants

Twelve first-team university rugby players (age 22±3 years, mass 89±2 kg, stature 179±6 cm, playing experience 11±4 years) were recruited to take part in the study. Players were identified as those who would kick for the up-rights during a match and were all injury free at the time of the study. All tests were conducted in the evening (18:00-21:00) at a similar time to local matches. Written informed consent was received prior to the start of testing and ethical approval was granted by the University Ethics Committee (M131019).

Outcome measures and instrumentation

The place kick outcome measures were divided into two groups: outcomes (distance and accuracy) and inputs (technique and strength).

The kick distance was defined as the length from the midpoint on the halfway line to the landing position of the ball. Kicking accuracy was measured as follows: a central line was placed along the ground from the midpoint of the halfway line to the middle of the up-rights. The exact landing position of each ball that was kicked, noting whether or not it successfully passed through the up-rights, was measured perpendicularly from the central line to the nearest centimetre, using a tape measure. Accuracy was determined as the angle between the central line and the line from the centre of the field to the position of the ball. The accuracy angle was taken as the absolute angle. An angle of 0° indicated that the ball landed on the central line and achieved 100% accuracy. A larger angle indicated a greater deviation from the central target line.

As kicking performance may be dependent on lower body power, an indication of lower body power was determined using a vertical jump. The participants were instructed to crouch down in a squat position and jump as high as possible while keeping their legs fully extended. No arm swinging was permitted, and multiple jump attempts were made during the warm-up routine prior to the test. The participants were tested in three jumping conditions: dominant (kicking) leg jumps, non-dominant (support) leg jumps and two-legged jumps. Each jump procedure was repeated twice, with the average jump height being used for further analysis. Pelvic height was tracked kinematically and the lower leg power was calculated as the difference in height between the maximal jump height and standing height. A total of six vertical jumps were performed.

All kinematics (kicking technique) were recorded at 100Hz using an 18-camera system Optitrack flex:V100r2 (Natural Point Inc., Corvallis, Oregon, USA). A volume of approximately 40 m^3 was calibrated at the halfway line on a rugby pitch. Calibration and 3D tracking was performed using AMASS (C-Motion Germantown, Maryland, USA). Calibration accuracy was reported to be sub-millimetre. Raw marker trajectories were imported into MatLab 7 (Mathworks, Natick, Massachusetts, USA), where biomechanical variables were calculated using custom written algorithms (described later).

Procedure

Prior to testing, the participants warmed up in their own accustomed manner and also practised kicking the ball three times under experimental conditions. The participants performed five maximal place kicks from the midpoint on the halfway line. The accuracy constraint was to successfully kick the ball between the up-rights and over the crossbar. The distance constraint was to achieve maximal forward distance from the halfway line position. Standard training rugby balls (Gilbert XT300 inflated to the regulation pressure of between 65-68kpa) were used and the participants used their own accustomed kicking tees. Also they applied their own kicking procedure and approach angle.

Each participant performed a vertical jump test either before or after the five place kicks in a randomised manner. The five place kicks and six vertical jumps were tracked kinematically.

Data reduction

The kinematics of each kick was determined using a 42-retroreflective-marker set placed on anatomical landmarks which created a 15-segment model. Joint centres were calculated using mathematics similar to the PlugIn Gait (Gutierrez, Bartonek, Haglund-Akerlind, & Saraste, 2003; Kadaba, Ramakrishnan, & Wooten, 1990).

Back flexion was calculated as the angle between the lower back (sacrum to the tenth thoracic) vector and upper back (the tenth thoracic to seventh cervical) vector. Lateral bend angle was defined as the abduction of the torso plane relative to the pelvic plane. Neutral alignment of the torso sagittal plane relative to the pelvic sagittal plane was indicated by 0°. Arm abduction was calculated as the angle created by the separation between the upper arm vector and the torso. Head, torso and pelvic rotations were calculated as the difference between the global horizontal vector and the respective body vectors. A positive value for the rotations would indicate an open stance with the support side shoulder directed towards the up-rights. X-factor, a variable widely used in golf research (Chu, Sell, & Lephart, 2010), was defined as the difference between torso and pelvic rotations. An X-Factor value of 0 indicated that the torso and pelvic girdles were in sequence; a positive value indicated the greater rotation of the torso relative to the pelvic girdle. The elbow flexion was calculated bilaterally, as the angle of flexion between the humerus vector and the vector of the forearm. Similarly, the wrist angle was calculated bilaterally, as the angle of flexion between the forearm vector and the vector of the hand. Bilateral knee and ankle flexions were calculated as the angle of flexion between the femur vector and the vector of the shank, and the angle of flexion between the vectors of the shank and the foot, respectively. Flexion value of 0° indicated full extension of the elbows and knees and neutral head and wrist positions.

Statistical analyses

All data variables passed the Shapiro-Wilk normality test and are represented as M±SD. Pearson's correlation coefficients were run between the kicking outcomes and the biomechanical variables and vertical jump parameters in GraphPad Prism 5 (GraphPad, San Diego, California, USA). Qualitative descriptions for the strength of the relationships were defined as: r=.00-.25 little or no relationship; r=.25-.50 fair relationship; r=.50-.75 moderate to good relationship; r>.75 good to excellent relationship (Portney & Watkins, 2009). Stepwise multiple linear regressions were performed for kick distance and accuracy in MatLab 7. A significance level of $p<.05$ was applied.

Results

The average kick distance achieved was 45.35±5.27 m, with an average accuracy spread of 6.41±3.57°. Playing experience was not correlated to the accuracy (r=.54, p=.07) or the place kick distance (r=.24, p=.44).

The average two-legged vertical jump height was 0.52±0.07 m. The average support leg vertical jump height was 0.36±0.08 m, and the average kicking leg height was 0.34±0.07 m. No significant relationships were found between the two-legged vertical jump power and the distance achieved (r=-.29; p=.36) or accuracy (r=.33, p=.25) of the kicks. Furthermore, no significant relationships were found between the dominant/kicking (distance: r=-.24, p=.67; accuracy: r=-.11, p=.26) and non-dominant/support (distance: r=-.18, p=.76; accuracy: r=-.13, p=.21) single-leg vertical jump and the outcomes of the kick.

The relationships between distance and accuracy and the kinematic parameters at ball contact

Table 1. Kinematic kicking variables at ball contact and the Pearson's correlation coefficients (r) for the distance and accuracy measures

Kinematic kicking variables	M±SD	Distance (r)	Accuracy (r)
Back flexion (°)	44.6±7.7	.02	-.13
Lateral bend (°)	27.6±21.9	-.12	.20
Stance arm abduction (°)	131.3±10.2	-.03	.22
Kicking arm abduction (°)	52.0±12.7	-.36	.21
Head rotation (°)	84.5±9.4	-.16	**.60***
Torso rotation (°)	45.4±12.6	**.76***	**-.66***
Pelvis rotation (°)	28.2±9.9	**.66***	-.08
X-factor (°)	17.1±8.9	.33	**-.84***
Head flexion (°)	75.8±12.3	-.07	-.27
Stance elbow flexion (°)	22.4±9.6	.27	**-.75***
Kicking elbow flexion (°)	24.3±17.3	.05	.24
Stance knee flexion (°)	26.1±6.5	-.04	-.34
Stance ankle extension (°)	107.3±9.0	.34	.28

* Indicates statistical significance (p<.05)

are shown in Table 1. An excellent relationship was found between the kick distance and the torso rotation (r=.76) and a moderate to good relationship was identified between the kick distance and pelvic rotation (r=.66). A moderate to good negative relationship was found between the kick accuracy and the torso (r=-.66), and the head (r=.60) rotations and the stance elbow flexion (r=-.75). An excellent negative relationship was shown to exist between the kick accuracy and X-factor (r=-.84)

The resulting multiple linear regression model for kick distance was able to predict 53% of the kick distance variation (Adjusted R^2=.53; p=.005). The only significant contributor was the torso rotation (beta coefficient=.32). The multiple linear regression model for kick accuracy was able to predict 69% of the kick accuracy variation (Adjusted R^2=.69; p=.002). The significant contributors were the torso (beta coefficient=-.35) and pelvic rotation (beta coefficient=.28).

Discussion and conclusions

The primary hypothesis that the major rotational components of the kinetic chain (the shoulder and pelvic girdles) would be related to the place kick distance was confirmed. Greater shoulder and pelvis rotations were shown to be used when further place kick distances were achieved. However, more accurate place kicks were shown to have a lower degree of torso rotations, greater head rotations, lower degree of separation between the torso and pelvis and a more flexed stance elbow. While these correlations do not imply causation, they do highlight the importance of the rotational kinematics of the shoulder and pelvic girdles in the generation of kicking distance. Muscular strength was hypothesized to be a possible mechanism for achieving maximal distance and accuracy. Contrary to this hypothesis, no relationships were found between vertical jump heights and place kick distance or place kick accuracy.

Direct measure of kick distance

The mean kicking distance of 45.36 m attained in this study is in agreement with Linthorne and Stokes (2014) whose participants kicked a similar distance. Similarly, this shows that the participants were on the limit of their respective achievement thresholds. Ball and colleagues (2013) reported numerous successful attempts when the place kick was 40 m from the goal posts. While the participants' ranges may have been tested past their limits, this study showed how important the accuracy of the kick was. The likelihood of achieving a successful attempt at the goals seemed to be diminished as the distance from the goals increased (Linthorne & Stokes, 2014). By making the standard position on the halfway line, 50 m from the up-rights, we were able to test the range limits and accuracy of the kicks concurrently.

Kick distance and the kinetic chain

The current study showed a positive, good to excellent correlation between the shoulder (torso) and pelvic girdle rotations and the kick distance. One could assume that the optimal kinetic chain sequence would begin with the rotations of the torso followed by the rotation of the hips to impart optimal velocity to the leg segments. Naito et al. (2010) showed how trunk rotations could lead to greater knee extension velocities and, in effect, greater ball velocities. This, in the context of the kinetic chain, can be misleading as the trunk is not directly related to the legs. The energy generated by the trunk needs to be transferred via the pelvis to the leg. Bezodis et al. (2007) demonstrated the importance of pelvic rotation in the generation and transfer of energy and Zhang et al. (2012) showed how pelvis rotation had a small effect on overall foot velocity, thus demonstrating the transfer of energy from the trunk to the legs. Shan and Westerhoff (2005) suggested that the use of a kick preload or creating a tension arc between the trunk and pelvis could be used to generate more energy. However, this relationship between the tension arc and kick distance was not seen in the current study. Recently, Fullenkamp et al. (2015) showed the importance of the trunk rotation in attaining ball velocity. While no relationship was shown in the current study between X-factor and kick distance, the significant relationship between the X-factor and kick accuracy was presented. The kinematic variable X-factor, the separation of the torso relative to the pelvis, was similar to the trunk axial rotation used in the Fullenkamp et al. (2015) study. Surprisingly, the back flexion and the lateral bend angle at ball contact had no significant relationship with either kick distance or kick accuracy. This lack of relationships may be a result of the experienced nature of the participants within the current study. The regression model for kick distance would tend to agree that torso rotation, being the only significant inclusion, was a larger contributor than pelvic rotations, lateral bend or back flexion.

Upper body contributions

Various biomechanical parameters played a role in kick accuracy in this study. Shan and Westerhoff (2005) showed that the skilled soccer players used their upper bodies more effectively when kicking than the less skilled players. Additionally, skilled kickers were able to find the balance between segment coordination and kinetic chain optimisation (Shan & Westerhoff, 2005). The relationships found in the current study suggest that at ball contact, the difference between the torso and pelvic rotations (X-factor) should be minimized in order to achieve a more accurate kick. Furthermore, it is possible that simply minimizing the torso rotation could lead to a more accurate kick. The flexion of the stance elbow, while not directly involved with the kick, was shown to have a negative correlation with the kick accuracy. The elbow flexion of the stance arm may indirectly be related to the balance requirements of the kicker (Bezodis, et al., 2007). Less elbow flexion would increase the stance arm moment leading to a greater displacement of the kicker's centre of mass. Interestingly, no relationships were seen between the abduction of the kicking side arm and kick accuracy. Further investigation into the effects of the stance arm, balance and kick accuracy is required.

Degree of kick accuracy

The accuracy in this study was measured as the degree between the landing positions of the balls relative to the midpoint of the halfway line. A lower value indicated a more accurate kick. The margin of error for a successful kick from this distance is 3.21°. The absolute average for the sample of 12 kickers was 6.41±3.57° indicating that the majority of kick attempts, while lacking the distance, were not on target either. While many previous studies have tested accuracy and distance independently indoors, thus indirectly measuring the performance outcomes (Bezodis, et al., 2007; Zhang, et al., 2012; Sinclair, et al., 2014a), our study is the first one to test both in an outdoor setting. The regression model for kick accuracy indicated that contributions from the torso and pelvic girdle were essential in the attainment of an accurate kick.

A distance-accuracy trade-off

The positive correlations for distance and the negative correlations for accuracy would suggest that the kinematic contributors, specifically the torso rotation, would impede one another. Similar relationships have been shown by previous studies focusing specifically on the instep kick in soccer (Asai, et al., 2002; Kellis & Katis, 2007; Teixeira, 1999) and in rugby place kicking studies (Bezodis, et al., 2007; Padulo, et al., 2013). The change in ball velocity must stem from the development of power through the kinetic chain and therefore the kinematic parameters should be different. The results in the current study would suggest that some of the relationships between the kinematics, on the one hand, and distance and accuracy on the other are antagonistic. Although it would seem that the contributions from the upper body, specifically torso rotations, is the underlying determinant when distinguishing between place kick distance and accuracy. The torso rotations, which were positively correlated to the distance and negatively correlated to the accuracy spread, could be a minor contributor to the overall kick distance, with the pelvis rotation being the main contributor. However, the shoulder contribution to accuracy might be a more important relationship. The additional relationship shown between accuracy and the X-factor may in part confirm the importance of torso rotation in kick accuracy. The lack of a significant relationship between the X-factor and distance may be a result of the timing of rotations between the shoulder and pelvic girdles. The peak velocities of these girdles and their effect on kick distance and accuracy need to be investigated further.

Lower body power

Hart and colleagues (2014) suggested that muscles alone does not make an accurate or a powerful kicker, but increased muscle mass could, and should hence be a major component of an optimal kicking system. Supporting this concept is the research showing lower leg strength in soccer instep kicks to be a performance predictor for kick distance (Fousekis, Tsepis, & Vagenas 2010; Manolopoulos, et al., 2006, 2013). The lack of a significant relationship between lower body power and kick distance suggests that place kicking requires more than pure leg strength, or may be an effect of the intrinsic strength capacity exhibited by all rugby players, or the simplified nature of the vertical jump test. Other components that could predict kick performance may include balance, flexibility, proprioception and coordination. These parameters require further investigation. Furthermore, the timing of limb segments (Urbin, et al., 2011) and coordination of muscle fibre contractions (Hart, et al., 2014; Scurr, Abbott, & Ball, 2011) may prove to be contributing determinants of kicking ability for distance. While no relationship between playing experience and kick accuracy (r=.54; p=.07) was found in the current study, it is likely that skilled players have a better physiological capacity of the requirements for an accurate kick, and that this capacity develops with experience.

Limitations

A limitation of the current study was the speed of the kinematic system. The small amateur sample of players is another limitation of the study as the results may not be generalizable to more skilled players who may use other strategies to generate distance and accuracy. The outdoor setting, whilst providing representative data, had constraints regarding mobility of equipment and required the use of simple field tests. Further studies could utilize more robust strength and flexibility tests.

In conclusion, the current study showed how distance could be maximized by improving the rotations of the torso and pelvis segments, whereas accuracy of the kick could be improved by full extension of the stance arm. Biomechanical parameters that promote kick distance, specifically torso rotation, may impede kick accuracy.

Possible applications for practitioners

Our data suggests that larger torso rotations may promote place kick distance, but may impede place kick accuracy.

To achieve further place kick distances, a larger rotation of the shoulder and the pelvic girdles prior to ball contact should be encouraged.

Place kick accuracy could be improved by fully extending the stance arm and by maximizing the separation between the shoulder and pelvic girdles prior to ball contact.

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