A joint kinetic analysis of rugby place kicking technique to understand why kickers achieve different performance outcomes

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Abstract

We aimed to identify differences in kicking leg and torso mechanics between groups of rugby place kickers who achieve different performance outcomes, and to understand why these features are associated with varying levels of success. Thirty-three experienced place kickers performed maximum effort place kicks, whilst three-dimensional kinematic (240 Hz) and ground reaction force (960 Hz) data were recorded. Kicking leg and torso mechanics were compared between the more successful ('long') kickers and two sub groups of less successful kickers ('short' and 'wide-left') using magnitude-based inferences and statistical parametric mapping. Short kickers achieved substantially slower ball velocities compared with the long kickers (20.8 ± 2.2 m/s vs. 27.6 ± 1.7 m/s, respectively) due to performing substantially less positive hip flexor (normalised mean values = 0.071 vs. 0.092) and knee extensor (0.004 vs. 0.009) joint work throughout the downswing, which may be associated with their more front-on body orientation, and potentially a lack of strength or intent. Wide-left kickers achieved comparable ball velocities (26.9 ± 1.6 m/s) to the long kickers, but they were less accurate due to substantially more longitudinal ball spin and a misdirected linear ball velocity. Wide-left kickers created a tension arc across the torso and therefore greater positive hip flexor joint work (normalised mean = 0.112) throughout the downswing than the long kickers. Whilst this may have assisted kicking foot velocity, it also induced greater longitudinal torso rotation during the downswing, and may have affected the ability of the hip to control the direction of the foot trajectory.

Keywords (up to 5): football, inverse dynamics, kick, mechanics, three-dimensional

1. Introduction

Forty-five percent of the total points scored in 582 international rugby union matches (2002-2011) came from place kicks (Quarrie and Hopkins, 2015). If the success percentages of the two competing teams had been reversed, the results would have switched in 14% of these matches (Quarrie and Hopkins, 2015). Although other factors affect the outcome of a match, place kick performance is clearly important. Understanding place kicking technique is therefore crucial for improving kickers' performance levels and, ultimately, team success.

Despite the value of successful place kicking in rugby, there are relatively few in-depth investigations of place kicking technique. Previous research has typically examined how technique influences ball velocity, focussing on describing the motion of the kicking leg (Aitchison and Lees, 1983; Sinclair et al., 2014; Zhang et al., 2012), with peak knee extension velocity identified as the sole significant predictor ($R^2 = 0.48$; Sinclair et al., 2014). The support foot position has also been investigated and found to be highly consistent for individuals within a group of professional place kickers (0.03 ± 0.07 m behind and 0.33 ± 0.03 m lateral to the tee; Cockroft and van den Heever, 2016), although extreme acute alterations to this position have no effect on ball velocity (Baktash et al., 2009). Also of interest has been the applicability of common coaching cues, with evidence supporting the suggestion that players 'kick through the ball' but not the existence of a 'front-on' body position at ball contact (Ball et al., 2013).

Whilst insufficient ball velocity may lead to a place kick being unsuccessful by dropping short of the crossbar, a misdirected ball velocity vector also affects kick success by causing the ball to pass outside of the goalposts. To-date, only three studies have directly considered accuracy during rugby place kicking. Greater angular momentum of the non-kicking-side arm was identified as a feature of accurate kicking because it opposed the angular momentum of the kicking leg, and potentially minimised trunk rotation and over-rotation of the whole-body (Bezodis et al., 2007). Sinclair et al. (2017) found that, when prioritising accuracy, kickers demonstrated reduced kicking hip and knee extension velocities and subsequently a reduced linear velocity of the kicking foot in addition to greater ankle dorsiflexion and external rotation of the kicking foot. This kicking foot orientation reflected a more side-foot technique, with ball contact likely occurring closer to the metatarsals than the ankle joint. A side-foot technique has previously been reported in soccer instep kicking as a mechanism to improve kicking accuracy (Levanon and Dapena, 1998), and a more distal contact location is associated with reduced ball velocity (Peacock and Ball, 2018). Lastly, Bezodis et al. (2018) demonstrated that accurate kickers exhibited different kicking foot swing planes to inaccurate kickers but did not determine how the motion of the individual kicking leg joints influenced these swing planes. Both upper body and kicking leg mechanisms therefore require consideration when kicking for accuracy is investigated.

As a successful kick from distance requires both a fast and appropriately directed ball velocity (i.e. distance and accuracy), a performance outcome combining these two factors is necessary to truly understand the movement (Atack et al., 2018). Investigating specific technique differences between kickers who achieve different kick outcomes (i.e. long and straight versus long but wide or straight but short) would therefore enable the understanding of technique factors that are important for ensuring distance and accuracy, and provide information to enable coaches to manipulate these in kickers who are less successful for different reasons. The aim of this study was therefore to identify differences in key kinematic and kinetic features of technique between groups of place kickers who achieve different performance outcomes, and to understand why these features are associated with varying levels of success.

2. Methods

Participants

Thirty-three male place kickers (mean ± SD: age = 22 ± 4 years, mass = 86.2 ± 8.8 kg, height = 1.82 ± 0.06 m) ranging from amateur to senior international playing level provided written informed consent to participate in this study, which was approved by the lead researchers' university ethics committee prior to testing.

Procedures

After a self-directed warm-up and familiarisation, each participant performed a minimum of five place kicks, as if from their maximum range. These were performed indoors wearing moulded boots on a rubber floor, and from each participant's preferred kicking tee towards a vertical target (representative of the centre of the goal posts) suspended in a net. The global coordinate system was aligned such that the positive Y-axis represented the horizontal direction towards the centre of the target, the Z-axis was vertical, and the X-axis was the cross-product of the two. Eighty markers were used to define a 14-segment human-body model (Supplement 1) during a static trial, and 54 of these markers (including rigidly-mounted clusters on the limb segments) remained on the participant during the kicks to track their motion (240 Hz) using a Vicon$^{©}$ MX3 system (measurement accuracy of 0.0009 m). Ground reaction force (GRF) underneath the support foot was synchronously recorded (960 Hz) using a Kistler 9287BA force platform. Six circular markers were attached to the ball (Gilbert Virtuo, size 5) to track its three-dimensional translation and rotation.

Marker trajectories were labelled using Vicon© Nexus and the raw .c3d files were exported for analysis in Visual 3D (v. 5.0, C-Motion©, USA). Ball contact was identified when the kicking toe marker reached peak anterior velocity, and the start of ball flight when the anterior velocity of the ball centre first decreased after ball contact (Shinkai et al., 2009). Linear ball velocity was calculated from polynomial functions fitted to the first four frames of ball displacement during flight (first order for both horizontal directions, second order for vertical), and ball angular velocities were calculated as the first derivative of the respective ball orientations between the first and fourth frames. These data were input into a model of rugby ball flight to calculate the maximum distance that each kick could be successful from before dropping below crossbar height or passing outside one of the upright posts (Atack et al., 2018). Each kicker's attempt with the greatest maximum distance was used for subsequent analysis.

All trials were cropped at the frame prior to ball contact. Marker data were low-pass filtered at 18 Hz (determined through residual analyses; Winter, 2009) using a fourth-order Butterworth filter with endpoints padded (20 point reflection). The padded endpoints were subsequently removed, and segmental kinematics were reconstructed using an Inverse Kinematics approach (Lu and O'Connor, 1999) with three rotational degrees of freedom at all joints. Joint angular displacements were calculated using an XYZ Cardan rotation sequence (corresponding to the flexion-extension, abduction-adduction, internal-external rotation axes) (Lees et al., 2010) and joint angular velocities were calculated with the proximal segment as both the reference segment and resolution coordinate system. The GRF data were also filtered at 18 Hz (Bezodis et al., 2013) and combined with the kinematic and segmental inertia data (de Leva, 1996) in an inverse dynamics analysis to determine the kicking hip and knee joint kinetics prior to ball contact. The joint kinetics were normalised for comparison between participants (Hof, 1996), with height substituted for leg length. Pelvis and thorax orientations about the global z-axis were also calculated, and the rotation of the thorax relative to the pelvis was determined using an XYZ Cardan rotation sequence (Brown et al., 2013). All variables measured in the medio-lateral direction and about the longitudinal axis were inverted for left-footed kickers. As there were no differences in the downswing durations of the kickers (Table 1), all time-histories were normalised to 101 samples using an interpolating cubic spline from the top of the backswing (the highest vertical position of the kicking foot centre of mass) to ball contact.

Data Analysis

The kickers were grouped based on performance outcome. Initially, kickers who achieved a maximum distance greater than 32 m (the average place kick distance in international matches[1]) were identified and termed 'long' kickers (n = 18). Those kickers who achieved a maximum distance less than 32 m were sub-divided into short (n = 4), wide-left (n = 8) or wide-right (n = 1) groups based on their reason for failure. Two kickers were excluded as they were within 4.0% (the accuracy of the ball flight model; Atack et al., 2018) of the 32 m threshold. The wide-right group was removed as only a single kicker was classified in this category. For each group, mean ± standard deviations were calculated for all variables.

Technique variables of the long kickers were compared to those of the two less successful groups. To compare discrete variables, effect sizes (Cohen, 1988) were calculated with 90% confidence intervals, and magnitude-based inferences were derived using a smallest important effect size of 0.2 (Batterham and Hopkins, 2006). If the confidence intervals did not cross both -0.2 and 0.2, the effect was considered substantial. Time-histories were compared using 1D statistical parametric mapping with an α-level of 5% (Pataky, 2012). All group differences discussed subsequently were found to be either substantial or significant.

3. Results

The short and wide-left kickers achieved comparable maximum distances, both shorter than the long kickers (Table 1). The short kickers exhibited lower resultant ball and kicking foot velocities compared with the long kickers but there was no difference in the resultant ball velocities achieved by the long and wide-left kickers (Table 1).

*** Table 1 near here ***

For all kickers, a knee extensor moment was dominant for the majority of the downswing before becoming flexor dominant during approximately the final 20% (Figure 1b). This extensor moment was initially associated with knee flexion and thus negative extensor power (K1, Figure 1c). During phase K1, the long kickers did more negative knee extensor work than the short kickers, but there was no clear difference between the long and wide-left kickers (Table 1). A positive extensor power phase then occurred from approximately -60% as the knee extended (K2, Figure 1c), before a negative flexor power phase initiated just prior to ball contact when the knee moment became flexor dominant (K3, Figure 1c). The long kickers did more positive knee extensor work (K2) and negative knee flexor work (K3) than both the wide-left and short kickers (Table 1).

*** Figure 1 near here ***

For all kickers, the hip flexed throughout the downswing (Figure 1d). This was accompanied by a resultant flexor moment for the majority of the downswing and thus positive hip flexor power (Figure 1e,f). The flexor moment was greatest at the top of the backswing before reducing until late in the downswing where a small increase in the flexor moment was observed in all groups at around -20% of the phase (Figure 1e), before a rapid reduction prior to ball contact (Figure 1e). The long kickers did less positive hip flexor work than the wide-left kickers, but more than the short kickers (Table 1).

All the kickers orientated their pelvis and thorax segments towards the kicking leg side (when viewed from above) throughout the downswing (Figure 2a,b). There was no difference in pelvis orientation between the long and wide-left kickers but the long kickers demonstrated greater pelvis retraction than the short kickers at the top of the backswing (Figure 2a). The long kickers' thorax was orientated further towards the kicking leg side (i.e. more ‘retracted’) for the first 70% of the downswing compared with the wide-left kickers’ and for the complete downswing compared with the short kickers’ (Figure 2b). The comparable pelvis orientations and different thorax orientations between the long and wide-left kickers meant that the wide-left kickers had a larger pelvis-thorax separation angle than the long kickers throughout 80% of the downswing (Figure 2c).

*** Figure 2 near here ***

4. Discussion

We quantified kicking leg and torso mechanics during rugby place kicking and understood the techniques adopted by groups of kickers who achieve three distinctly different performance outcomes. When compared with the long kickers, the short kickers demonstrated a more front-on thorax and pelvis orientation and performed less positive work at the hip and knee joints during the downswing, resulting in reduced foot and ball velocities, and consequently a shorter maximum distance. The wide-left kickers achieved comparable foot and ball velocities to the long kickers but adopted a more front-on thorax orientation and a hip-dominant technique in which they performed greater positive work at the hip and less at the knee, leading to an inappropriately directed ball velocity vector, greater longitudinal ball spin and subsequently an inaccurate kick.

The general hip and knee joint kinematic patterns were consistent across all groups and similar to those reported for amateur kickers (Zhang et al., 2012). This is the first study to determine joint kinetics during rugby place kicking; the reductions in the hip flexor moment during the downswing are consistent with studies of soccer instep kicking (Lees et al., 2009; Nunome et al., 2002), but the second smaller peak just prior to ball contact appears unique to rugby place kicking. Previous research has identified inappropriate filtering methods through impacts as a potential source of error in data close to the impact (Nunome et al., 2006); however, as data during ball contact were not included in the current processing, this was unlikely to be an influencing factor. One possible explanation for this second peak is the additional requirement of a high ball launch angle which is typically not required in soccer instep kicking (approximately

30 ± 4° compared with 14.1 ± 0.5°; Holmes et al., 2006 and Alcock et al., 2012a, respectively). The joint kinetics used to achieve kicks with different launch angles have not been directly investigated in any football codes, but future experimental studies could investigate the role of the hip joint in achieving these launch angles.

The faster kicking foot velocity of the long kickers compared with the short kickers likely explains the faster ball velocity based on the established relationship between these in other football codes (Ball, 2008; De Witt and Hinrichs, 2012; Nunome et al., 2006). Given the proximal-to-distal transfer of energy down the kicking leg (Putnam, 1991) and the strong positive relationship between knee extension and foot velocity (Sinclair et al., 2014), the slower foot velocity of the short kickers is likely due to the reduced positive hip flexor and knee extensor joint work performed throughout the downswing. Whilst this may be due to reduced strength capabilities, these short kickers may also lack maximal intent and choose not to perform as much lower body work as they could in order to maintain a straight ball flight - this mechanism has been previously shown to be adopted within place kickers when prioritising accuracy, as evidenced through reduced kicking leg joint angular velocities (Sinclair et al., 2017). Furthermore, the more front-on pelvis of the short kickers throughout the downswing may be a further mechanism which inhibited their performance as pelvic protraction is a known feature of high velocity kicking (Lees et al., 2009). Coaches who work with kickers who lack distance could consider technical interventions to alter approach angle and therefore pelvis orientation, or technical or conditioning programmes to increase hip flexor and knee extensor work.

As there was no difference in ball velocity magnitude between the long and wide-left kickers, the wide-left kickers' poorer performance was due to the misdirected initial ball flight and greater longitudinal ball spin. Over the entire downswing, the wide-left kickers performed more positive hip flexor work and less positive knee extensor work than the long kickers. Whilst this is the first study to quantify the work done by the kicking leg joints of accurate and inaccurate kickers in any football code, two different techniques based on kicking leg kinematics have been identified in Australian Rules football punt kicking (Ball, 2008) which are supported, and partly explained, by the current kinetic results. Ball (2008) observed a negative relationship (r = -0.90) between knee angular velocity and thigh angular velocity at ball contact across a cohort of 28 professional players and separated the kickers into two groups (‘thigh’ and ‘knee’) based on their individual ratio of knee angular velocity to thigh angular velocity. These groups achieved comparable kicking foot velocities but relied on different techniques to do so (Ball, 2008). The joint work data reported in the current study provide a kinetic mechanism which supports and explains the existence of different kicking strategies and extends this theory by associating a knee-dominant technique with more accurate kicking. Greater knee dominance could also be beneficial for enabling the multi-articular hip joint to be more involved in the control of the direction of the kicking foot as suggested in a study of soccer instep versus curve kicking (Alcock et al., 2012b), but further research is warranted to directly explore this potential mechanism.

One aspect which appears to play an important role in the different techniques adopted by the long and wide-left kickers is the torso motion in the transverse plane. Both groups exhibited a comparable pelvis orientation throughout the downswing, but the wide-left kickers’ thorax was more front-on for the first 70%. This larger relative pelvis-thorax angle at the top of the backswing corresponds to a 'tension arc' mechanism which has previously been discussed in soccer instep kicking (Shan and Westerhoff, 2005). This mechanism corresponds to a large pelvis-thorax angle at the top of the backswing which is thought to create a greater muscular stretch across the torso. When released during the downswing, this enables kickers to achieve faster kicking foot velocities (Shan and Westerhoff, 2005). The ‘tension arc’ mechanism could therefore explain the wide-left kickers’ greater positive hip flexor work compared with the long kickers, with a greater initial stretch of the hip flexors leading to enhanced force production during the subsequent contraction. However, although a ‘tension arc’ may be beneficial for increasing foot velocity (Shan and Westerhoff, 2005), our results suggest that this may not be a beneficial mechanism for kick accuracy. The release of the torso stretch in the current study appeared to cause the thorax of the wide-left kickers to longitudinally rotate towards the kicking leg during the downswing (through approximately 20°), whereas the long kickers' displayed less rotation (<10°). As a minimal amount of thorax angular momentum about the longitudinal axis at ball contact is associated with more accurate rugby place kicking (Bezodis et al., 2007), use of the 'tension arc' may have negatively affected the wide-left kickers' accuracy through both the aforementioned reliance on hip flexor work and also thorax rotation affecting the control of their whole-body angular momentum. If the ‘tension arc’ release does affect foot velocity (Shan and Westerhoff, 2005) then it could also affect the direction of this vector in addition to its magnitude. Analysis of the kicking foot vector at ball contact indicated that the long kickers’ vector was directed further towards the right-hand-side of the target (26° from the centre compared with 24° for the wide-left kickers). These foot velocity vectors become progressively straighter (towards the target) during the ball contact phase, and are slightly to the left of the target by the end of ball contact (Bezodis et al., 2018). The long kickers’ more laterally oriented foot velocity at initial ball contact may be required because of the shallower inclination of their kicking foot swing planes (Bezodis et al., 2018), and therefore helps to facilitate their ball launch directions being slightly to the right of the target (Table 1), although higher-speed analysis of the foot-ball impact is required to confirm this. Adjustments to the orientation of the wide-left kickers' thorax at the top of the backswing, to be less front-on, may help to encourage a change in the joint work strategies as there will be less stretch across the torso and therefore less contribution from the stretch-shortening cycle to the positive work done by the hip flexors. A torso orientation more closely aligned to pelvis orientation has been associated with greater accuracy in elite National Rugby league kickers (Ball et al., 2013), providing further support for this suggestion; however, the efficacy of such an intervention requires investigation and the effect on ball velocity magnitude also requires consideration.

The participants in this study were all regular place kickers at playing levels ranging from University to full senior international and were therefore considered to be proficient kickers. All data collection was undertaken in a laboratory to reduce the sources of error in our joint kinetic calculations, which therefore reduced the ecological validity of the study. However, the performance outcomes achieved by the kickers in our study were comparable to those recorded in outdoor studies (Holmes et al., 2006) and in international matches (Quarrie and Hopkins, 2015). Additional factors such as location of the kick on the pitch or match-related pressures which can influence kick success (Pocock et al., 2018) were controlled for in the current study and could be considerations for future research.

This study identified important differences in kicking leg and torso mechanics between successful (long) kickers and less successful (either wide-left or short) kickers throughout the downswing of a rugby place kick. The short kickers did less positive joint work than the long kickers and subsequently achieved slower kicking foot and ball velocities. This may have been due to their more front-on orientation or a lack of strength or maximal intent. The wide-left kickers were able to achieve comparable ball velocities to the long kickers but were not able to appropriately control the direction and spin of the initial ball flight. This may have been because the wide-left kickers used a more hip-dominant technique through the creation of a ‘tension arc’ across the torso, whereas the long kickers adopted a knee-dominant technique. The knee-dominant technique may have enabled the long kickers to better control the kicking foot path through adjustments at the hip joint, whilst the greater longitudinal rotations of the wide-left kickers’ thorax also further negatively affected their accuracy.

5. Conflict of interest

There are no conflicts of interest to declare.

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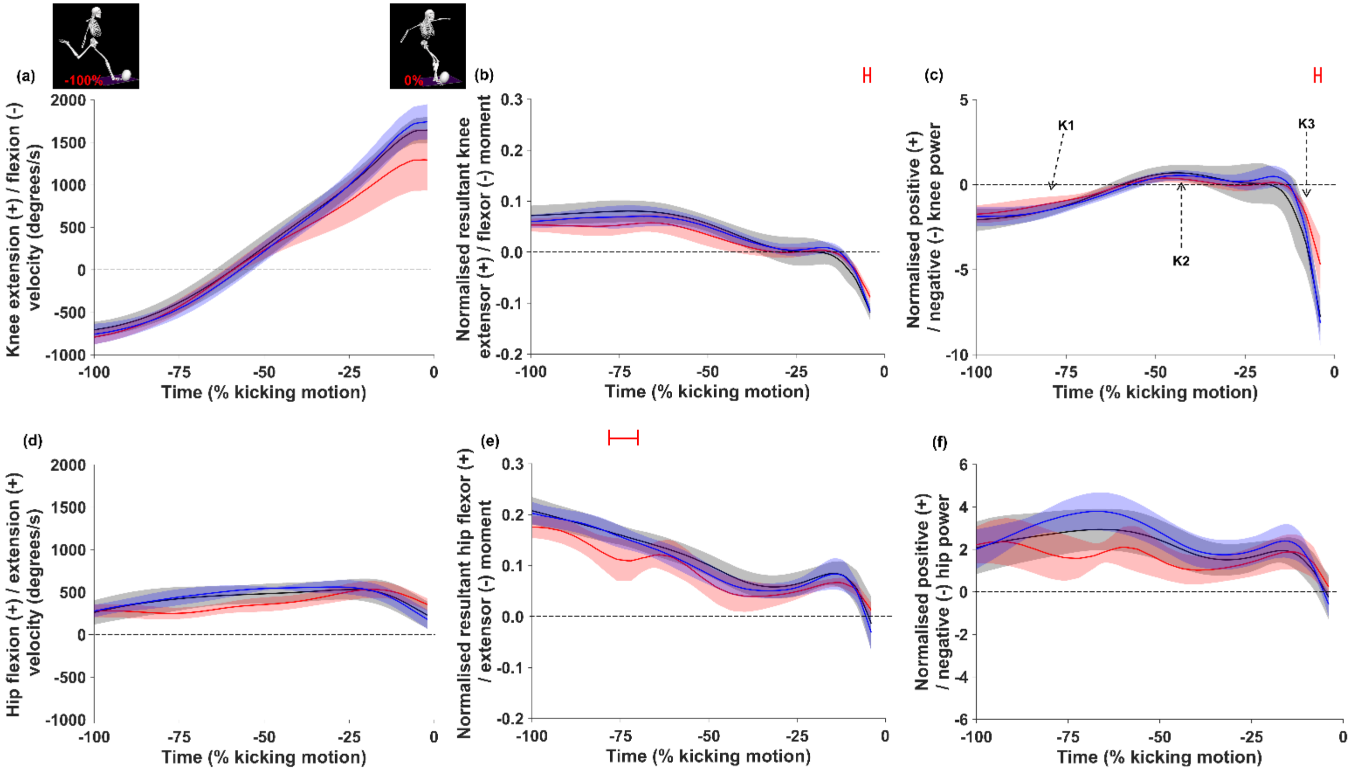


Figure 1. Mean ± SD knee and hip flexion-extension angular velocities (a,d), resultant joint moments (b,e), and joint powers (c,f) from the top of the backswing (-100%) to ball contact (0%) for the long (black), wide-left (blue) and short (red) kickers. Red bars above the figures indicate regions where the short kickers were significantly different from the long kickers ($p<0.05$).

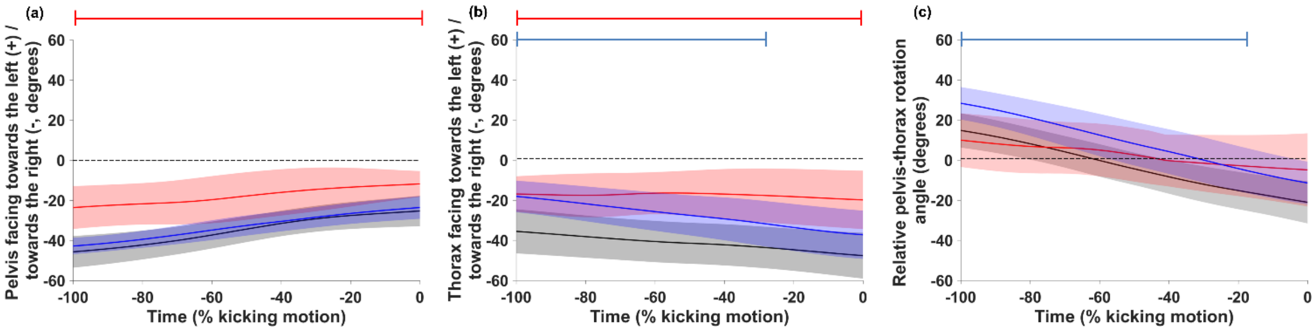
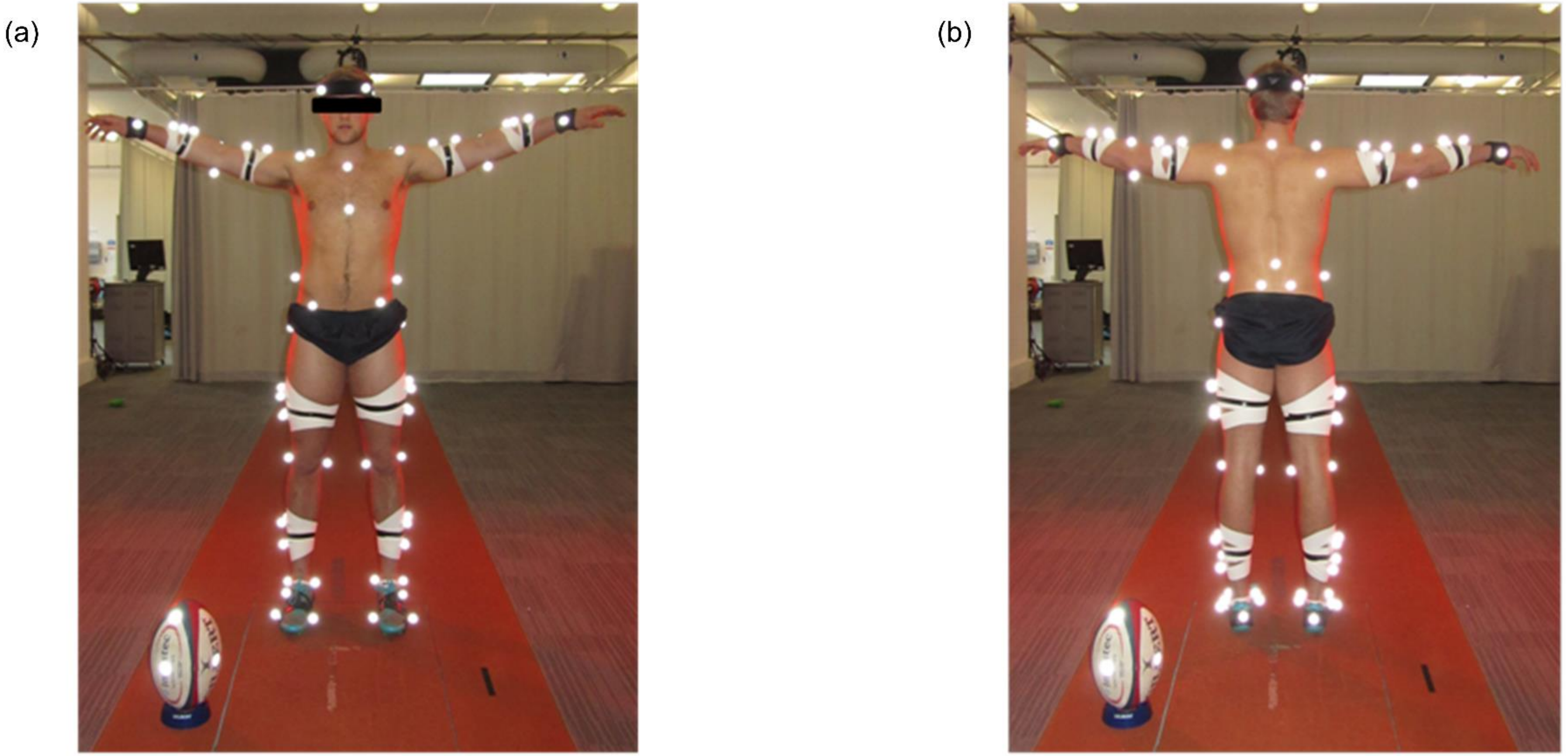


Figure 2. The pelvis (a), thorax (b), and relative pelvis-thorax (c) orientations about the longitudinal axis (mean ± SD cloud) from the top of the backswing (-100%) to ball contact (0%) for the long (black), wide-left (blue) and short (red) kickers. Bars above the figures indicate regions where the wide-left (blue) and short (red) kickers were significantly different from the long kickers ($p<0.05$)



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Supplement 1. The marker setup viewed from (a) the front, (b) the rear.

Table 1. Selected discrete variables, including performance outcome and initial ball flight characteristics, kicking foot kinematics and kicking leg joint work, for each of the three groups (mean ± SD) and the magnitude-based inferences for the group comparisons.

	Long	**Wide-left**	**Short**	**Long vs. wide-left kickers Effect size ± 90% CI**	**Long vs. short kickers Effect size ± 90% CI**
Ball Flight					
Maximum distance (m)	39.3 ± 4.9$^{\Delta}$	25.9 ± 3.2$^{\dagger\Delta}$	27.3 ± 3.8$^{\dagger\Delta}$	1.63 ± 0.37	1.61 ± 0.49
Resultant velocity (m/s)	27.6 ± 1.7$^{\Delta}$	26.9 ± 1.6$^{\Delta\Delta}$	20.8 ± 2.2$^{\dagger\Delta}$	0.42 ± 0.78	1.95 ± 0.45
Lateral direction (°)*	1 ± 3	-1 ± 2$^{\dagger\Delta}$	2 ± 3†	0.49 ± 0.61	-0.70 ± 0.90
Longitudinal spin (°/s)	288 ± 206	746 ± 466†	473 ± 394$^{\Delta}$	-1.13 ± 0.79	-0.68 ± 1.12
Kicking Foot					
Resultant velocity (m/s)	20.3 ± 1.0†	19.7 ± 0.9†††	17.0 ± 1.5†††	0.61 ± 0.77	3.01 ± 0.83
Medio-lateral velocity (m/s)	8.8 ± 1.5	7.8 ± 1.6†	5.4 ± 2.5†	0.63 ± 0.78	2.00 ± 0.90
Forward velocity (m/s)	18.1 ± 1.1†	17.8 ± 0.8††	15.8 ± 0.9††	0.30 ± 0.72	2.07 ± 0.86
Vertical velocity (m/s)**	-2.5 ± 1.1	-3.0 ± 1.2†	-2.1 ± 0.6†	0.48 ± 0.69	-0.31 ± 0.98
Normalised Joint Work					
Total negative knee extensor (K1)	-0.026 ± 0.005	-0.026 ± 0.006	-0.020 ± 0.008†	0.05 ± 0.77	-0.97 ± 0.93
Total positive knee extensor (K2)	0.009 ± 0.008	0.004 ± 0.004†	0.004 ± 0.002†	0.74 ± 0.69	0.74 ± 0.97
Total negative knee flexor (K3)	-0.016 ± 0.008	-0.009 ± 0.010†	-0.008 ± 0.004†	-0.73 ± 0.69	-0.99 ± 1.00
Total positive hip flexor	0.092 ± 0.018	0.112 ± 0.020†	0.071 ± 0.032†	-1.05 ± 0.79	1.01 ± 0.93
Event Duration					
Downswing (s)	0.107 ± 0.014	0.109 ± 0.012	0.102 ± 0.008	-0.18 ± 0.70	0.36 ± 0.92

† Denotes a substantial effect compared with the long kickers.

* A negative lateral direction indicates that the ball was initially travelling towards the left-hand-side of the goalposts, with a positive value directed towards the right-hand-side.

** A negative vertical velocity indicates that the foot was travelling down towards the ground.

K1, K2, K3 denote phases of negative and positive knee joint work, depicted in Figure 1.