A BIOMECHANICAL ANALYSIS OF THE KICKING LEG DURING A RUGBY PLACE KICK

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The successful performance of rugby place kicks is often important in determining the outcome of a match. This study aimed to further the understanding of rugby place kicking technique by quantifying and explaining kicking leg joint mechanics. Three-dimensional joint kinematics and kinetics were calculated using an inverse dynamics analysis. Whilst ankle motion was negligible, the knee flexed until around 50% of the kicking phase before extending towards ball contact. A resultant hip flexor moment was largely dominant throughout; it initally reduced extension before initiating flexion near support foot contact. Whilst these patterns were broadly similar to soccer kicking, peak magnitudes of angular velocity and resultant moment appeared to differ from soccer kicking and, along with the mechanics about other joint axes, these require further investigation.

KEY WORDS: football, kinematics, kinetics, lower-limb, soccer.

INTRODUCTION: Place kicks in rugby union provide an opportunity for teams to score points when either a penalty is awarded or a try is scored. The importance of successful place kicking was demonstrated by Quarrie and Hopkins (2014) who found that 45% of the total points scored in international rugby union matches between 2002 and 2011 were from place kicks. Furthermore, realistic changes in the kickers' success percentages could have changed the outcome of over 80 international matches during this period.

Despite the clear value of accurate rugby place kicking, few researchers have investigated the technique. Two specific three-dimensional (3-D) analyses have considered the effects of different stance foot positioning (Baktash et al., 2009) and the role of the non-kicking side arm (Bezodis et al., 2007), but the mechanics of the kicking leg remain unexplored. In contrast to this, the kicking leg mechanics are well documented in soccer instep kicking (e.g. Lees & Rahnama, 2013; Lees et al., 2009) and have been used to understand the skill in the context of successful performance. Obtaining similar information for the rugby place kick would be useful for informing the development and monitoring of training programmes designed to improve place kicking performance. Therefore, the purpose of this study was to quantify and explain the kicking leg joint mechanics during rugby place kicking.

METHODS: Thirteen competitive rugby place kickers (mean ± *s* age: 20 ± 2 years, height: 1.82 ± 0.07 m, body mass: 84.2 ± 9.5 kg) playing at levels ranging from community to age group international volunteered to participate in this study. All participants provided written informed consent and the protocol was approved by the local research ethics committee.

Kinematic data were collected (240 Hz) in a laboratory within an approximate 4.4 m × 6.0 m × 2.0 m capture volume using 10 or 11 cameras (MX3 and MX3+, Vicon©, UK). Eighty retro-reflective markers were attached to participants to determine a 14-segment model from a static trial standing in the anatomical position. Fifty-four of these markers (including rigid clusters on the upper and lower arm and leg segments) remained on the participants to track segmental motion during place kick trials. Ground reaction forces (GRFs) underneath the support foot were synchronously recorded (960 Hz) using a force platform (9287BA, Kistler Instruments Ltd., Switzerland). The platform was covered so it was flush and consistent with the surrounding rubber surface. All participants wore their own moulded boots and each participant's personal kicking tee was positioned to ensure that their support foot landed near the centre of the force platform. A net was positioned 2.0 m in front of the kicking tee. Suspended from the top of the net was a target to represent the centre of the posts. Six circles of reflective tape (25 mm in diameter) were attached to a ball (Gilbert Virtuo, size 5) to determine the motion of the centre of the ball. The global coordinate system was aligned such that the y-axis represented the horizontal direction from the kicking tee to the target, the z-axis was vertical, and the x-axis was the cross-product of the two. Following a self-selected warm-up, including submaximal and maximal familiarisation kicks, participants were asked to kick as if from their maximum range until five or six trials were collected. Participants were allowed sufficient self-selected rest between kicks. Marker position data were reconstructed using Vicon© Nexus (v. 1.8, UK).

Kicking foot take-off (KFO) from its last ground contact before ball contact (BC) was identified as the frame when the marker on the fifth metatarsal-phalangeal joint was greater than 0.1 m above the ground. Support foot contact (SFC) was identified as the frame in which the vertical GRF first increased, and subsequently remained, above 10 N. Ball contact was identified as the frame in which the resultant displacement of the centre of the ball was first greater than, and subsequently remained above, the determined measurement precision (0.9 mm). The marker trajectories and raw GRF data prior to BC were exported to Visual3D (v. 5.0, C-Motion©, USA). Gaps in the marker trajectory data ($n \leq 10$ samples) were interpolated with a cubic spline using three data points either side of the gap. All marker and GRF data were padded by reflection ($n = 20$ points) at both ends and filtered using a fourth order zero-lag Butterworth filter with the same cut-off frequency (18 Hz) to prevent potential artefacts in the subsequently determined joint kinetics (Bezodis et al., 2013).

The 14-segment model was reconstructed from the marker data using a global optimisation approach (Lu & O'Connor, 1999) which permitted 3-D rotations at all joints but no relative segmental translation. Inertia parameters were obtained from de Leva (1996) to define the properties of the body segments. Hip, knee and ankle joint angular displacements were calculated relative to the proximal segment at each joint using an XYZ Cardan rotation sequence and joint angular velocities were calculated with the proximal segment of the joint used as the both the reference segment and resolution coordinate system. Full hip and knee extension were defined as 0°, and the ankle angle from each participant's static trial was defined as 0°. Resultant joint moments and powers were resolved into the joint coordinate system through an inverse dynamics analysis. All joint mechanics were time-normalised to 101 points across the kicking phase (from SFC to BC) and data prior to SFC (termed the late approach phase) were normalised using the same scale factor. Initial ball velocity was calculated in each direction by fitting a polynomial to the first four frames of recorded ball flight (first order for the horizontal displacements and second order for vertical displacement) and resultant ball velocity was determined. Kick accuracy was quantified as the angle between the resultant ball velocity vector and the y-axis when projected onto the x-y plane. To allow comparison with previous studies, discrete values were normalised using the recommendations of Hof (1996) and the data for left-footed kickers was adjusted to correspond with the convention defined for right-footed kickers. For all continuous and discrete variables, mean values were calculated from all trials for each participant, and the mean ± *s* across all participants was subsequently determined.

RESULTS: Initial resultant ball velocity was 27.6 ± 1.9 m/s and kick accuracy was 3.2 ± 1.6°. The absolute duration of the kicking phase (from SFC to BC) was 0.13 ± 0.01 s and following time normalisation KFO was identified as occurring at 233 ± 13% prior to BC. Time-histories of the flexion-extension kicking leg joint mechanics are presented in Figure 1. The ankle plantar flexed slightly during the late approach phase of the kick before dorsiflexing during the kicking phase but the resultant joint moment magnitude was minimal throughout (Figure 1a,d). During the late approach phase, the knee joint flexed and continued to do so until around 50% of the kicking phase from which point extension was observed until BC (Figure 1e). A resultant knee extensor moment was evident throughout the first two-thirds of the kicking phase before it became flexor dominant prior to BC and the knee flexors absorbed energy (Figure 1h,k). The hip joint extended until just before SFC where a large resultant flexor moment was observed which initiated hip flexion (Figure 1c,i). This resultant hip flexor moment continued throughout the kicking phase, generating energy as the hip joint continued to flex (Figure 1c,i,l). A second peak in the resultant hip flexor moment occurred during the final 20% of the kicking phase, after which a rapid reduction in the resultant hip flexor moment was observed (Figure 1i).

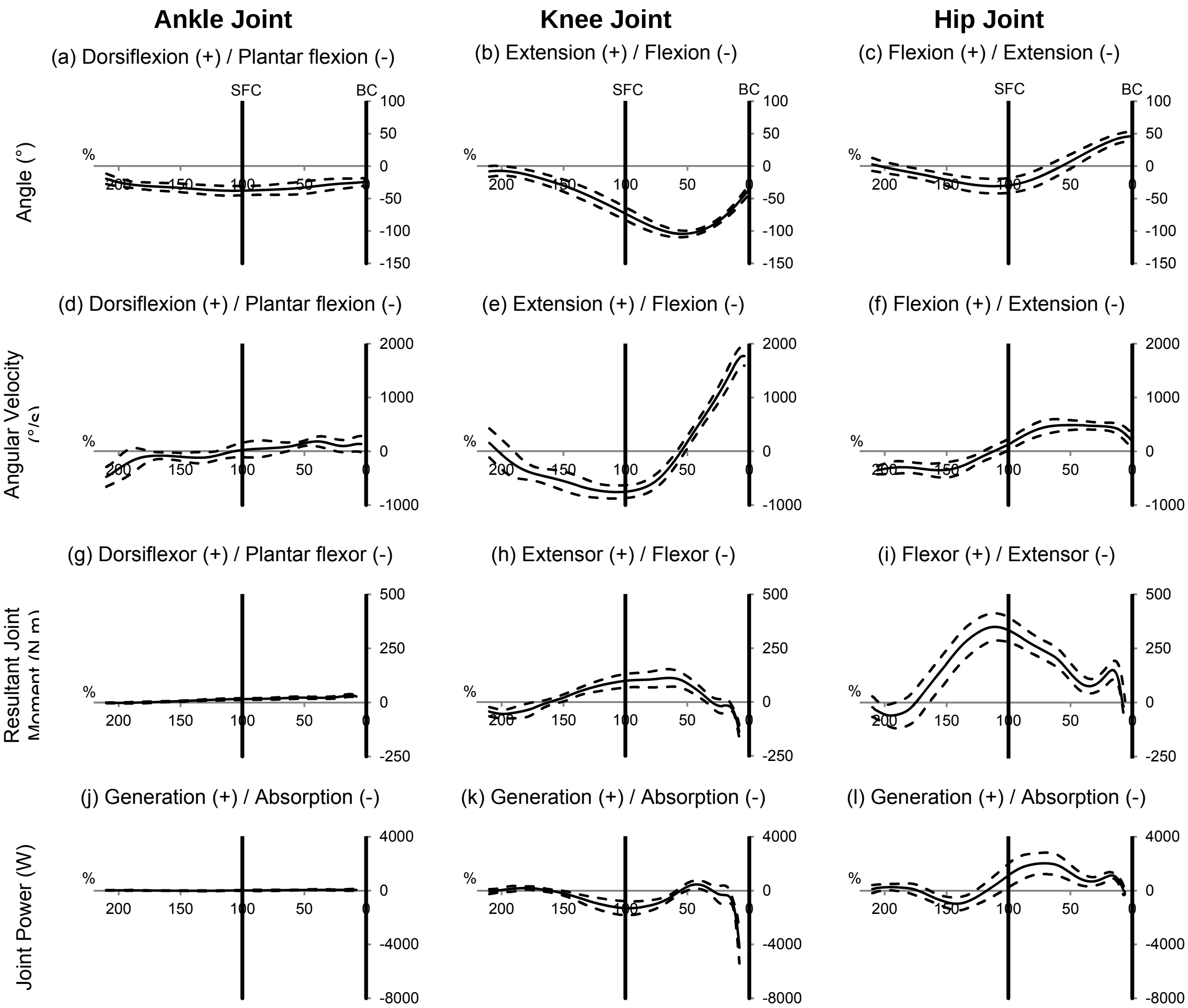

Figure 1a-l. Time histories of flexion-extension kicking leg joint mechanics (mean ± *s*).

DISCUSSION: This study presents typical flexion-extension joint mechanics of the kicking leg during rugby place kicks. The mean ball velocity recorded in this study is larger than that recorded previously in rugby place kicking (Baktash et al., 2009; Bezodis et al, 2007), likely due to the higher playing level of kickers in this study.

In the present study, the kicking leg hip joint extended until just before SFC. Prior to SFC, a large resultant hip flexor moment was observed, which caused a phase of energy absorption by the hip flexors and reduced the extension velocity. This resultant hip flexor moment continued, causing the hip to flex throughout the kicking phase up to BC. A sudden reduction in the resultant flexor moment was observed just before BC alongside a reduction in the angular velocity of the hip. This pattern in hip joint mechanics was similar to that reported by previous studies investigating soccer instep kicks. However, a consistent additional peak was seen in the resultant hip flexor moment during the final 20% of the kicking phase that has not previously been reported and may be of interest in future investigations. Whilst the normalised peak hip flexion velocities (208 ± 35) were similar to soccer instep kicking (198 ± 35; Lees & Rahnama, 2013), the normalised peak resultant flexor moments were over 50% larger in the current study (0.27 ± 0.05 compared to 0.17 ± 0.03).

The knee flexed throughout the late approach phase and continued flexing until around 50% of the kicking phase. From before SFC, this flexion was accompanied by a resultant extensor moment and thus energy absorption by the knee extensors. This decelerated flexion at the knee before initiating the extension which continued up to BC. Towards the end of this period of knee extension a resultant knee flexor moment, and thus energy absorption by the knee flexors, was observed. This motion was similar to that reported by Lees and Rahnama

(2013). Two potential reasons for a resultant knee flexor moment prior to BC in soccer kicking have been proposed (Lees et al., 2009). Firstly, it is suggested to be a protective mechanism, preventing full extension of the knee at maximum velocity. Secondly, a more flexed knee may allow greater external rotation of the shank relative to the thigh (albeit relatively small due to the joint constraints) and therefore a more desirable orientation of the foot at BC for a controlled foot-ball contact. As no single definitive explanation exists, the reason for this resultant flexor moment requires further investigation. Peak knee extension velocity and peak resultant knee extensor moment were over 40% and 80% larger, respectively, than those recorded previously for soccer kicking by Lees & Rahnama (2013; normalised peak velocity of 765 ± 80 compared to 522 ± 91 and normalised peak resultant moment of 0.09 ± 0.03 compared to 0.05 ± 0.01). Proximal-to-distal sequencing in peak hip and knee joint angular velocities was observed, with peak hip flexor velocity recorded soon after SFC and peak knee extension velocity just before BC, and the importance of this sequencing in maximising the velocity of a distal segment is well documented.

The ankle was in a relatively plantar flexed position throughout; it plantar flexed further during the late approach phase before dorsiflexing slightly prior to BC. This pattern was similar to that observed by Lees and Rahnama (2013), however, the peak ankle dorsiflexion velocity was twice as great in soccer kicking (normalised peak velocity of 165 ± 72 compared to 79 ± 106). Resultant ankle moment and power were negligible during the kicking phase up to BC.

One explanation for the differences seen in the peak joint angular velocities and resultant joint moments in this study compared to those investigating soccer instep kicking may be the different demands of the two skills. The accuracy constraints inherent to rugby place kicking are rarely the focus of instep kicking studies where participants are typically required to strike the ball as fast as possible. The smaller peak ankle angular velocity recorded in this study may be necessary in order to ensure a more controlled foot-ball contact. However, ball velocity is still an important performance determinant in rugby place kicking, and the larger peak resultant hip moment and peak knee angular velocity relative to soccer instep kicking may be a strategy to allow high linear foot velocities to be maintained at BC.

CONCLUSION: The joint mechanical profiles presented in this study depict the general movement patterns of the kicking leg prior to BC in a rugby place kick. The movement patterns observed are broadly similar to those previously reported for the instep kick in soccer but with potentially more emphasis on velocity generation from proximal joints. These differences may be due to the greater accuracy constraints imposed on place kickers and therefore the need for a more controlled foot-ball contact; additional consideration of kicking leg joint rotations about other axes may help to further this understanding.

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