THE ENERGY TRANSFERRED BETWEEN LOWER-BODY SEGMENTS BY SUCCESSFUL AND LESS SUCCESSFUL MALE RUGBY PLACE KICKERS

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The purpose of this study was to understand how energy is transferred during a rugby place kick and how it differs between successful and less successful kickers. Senior male kickers (n=33) performed maximal range place kicks which were analysed using 3D motion capture (240 Hz), enabling segment powers to be determined. Energy was transferred out of the support leg throughout the backswing and early downswing, adding to the energy at the pelvis, which was subsequently transferred out as the kick knee extended towards the ball. Kickers who were limited by range, transferred less energy out of the support leg and into their kick foot, likely leading to a reduced kick foot and therefore, ball velocity. Appropriate support leg action appears important for achieving greater range in rugby place kicking.

KEYWORDS: football, kinetics, power, statistical parametric mapping.

INTRODUCTION: Previous studies have highlighted the importance of place kicking in determining the outcome of International Rugby Union matches (Quarrie & Hopkins, 2015) as well as the reduction in kick success when kicks are taken further from and at greater angles to the goalposts (Pocock et al., 2018). Therefore, it is important to understand differences in kicking technique between more successful kicks and those that are limited by range or accuracy. The kickers' approach to the ball (Atack et al., 2022) and their kicking leg joint mechanics (Atack et al., 2019b) are associated with kicking range, whilst upper-body rotation has been linked to inaccurate kicks (Atack et al., 2019b). However, kicking requires the coordinated action of both active and passive forces to transfer energy through the linked segment system to the kick foot (as demonstrated in soccer, Augustus et al., 2021). It is, therefore, important to understand not just the differences in individual joint mechanics, but how the coordinated action of multiple segments contributes to kick performance. Given kickers can transfer energy from their approach to the kick leg, through support leg action (as seen in soccer; Augustus et al., 2017), analysis of the energy transfer between the lower limbs is warranted. The aim of this study was a) to determine how energy is transferred during a rugby place kick and b) to identify differences between successful and less successful kickers.

METHODS: Thirty-three male place kickers (mean ± SD: age = 22 ± 4 years, mass = 86.2 ± 8.8 kg, height = 1.82 ± 0.06 m; playing level: amateur to senior international) provided informed consent to participate in the study, which was approved by the local ethics committee. Following a warm-up and familiarisation kicks, participants performed five maximum range place kicks towards a vertical target (representing the centre of the goal posts) suspended in a net in a laboratory. A Vicon© MX3 motion capture system recorded the position of individual and rigidly-mounted cluster markers attached to 14 body segments (240 Hz, see Atack et al., 2019b for full marker setup) as well as six circular markers attached to the ball (Gilbert Virtuo, size 5), whilst ground reaction forces (GRFs) were synchronously recorded underneath the support foot using a Kistler 9287BA force platform (960 Hz).
Marker trajectories were labelled in Vicon© Nexus before the raw .c3d files were analysed in Visual 3D (v.2021, C-Motion©, USA). Ball contact (BC) was identified as the frame in which the kick toe marker reached peak anterior velocity, and ball flight started when the anterior velocity of the ball first decreased after BC. The success of each kick was determined as the maximum distance from which it would have passed between the goalposts, predicted by a mathematical

model (Atack et al., 2019a). The kick with the greatest maximum distance taken by each kicker was used for subsequent analysis and cropped to the frame prior to BC.

Marker trajectories and GRFs were filtered at 18 Hz (determined by residual analysis) using a fourth-order zero-lag Butterworth filter with 20 reflected padding points at each end. Segmental kinematics were reconstructed using Inverse Kinematics, permitting unconstrained 3D joint rotations but no translations. Four further events were then defined: kick foot-take-off (KFO), kick foot CM was first 0.1 m above the floor; support foot contact (SFC), vertical GRF first >10 N; top of the backswing (TB), greatest vertical kick foot CM position; maximum kick knee flexion (MKF), greatest kick knee flexion angle.

Segment kinematics, GRFs and inertia data were combined in an inverse dynamics analysis to determine lower limb and pelvis kinetic parameters. Following the methods of Augustus et al. (2021), 'joint powers' were calculated as the scalar product of joint forces and corresponding joint centre linear velocities, and 'muscle powers' were the scalar product of joint moments and corresponding segment angular velocities. 'Segment power' (SP) was the sum of the 'joint' and 'muscle powers' at both the distal and proximal segment ends, indicating the net energy inputted to or outputted from the segment ('joint' and 'muscle powers' from both hip joints as well as the thorax-pelvis joint were included in the pelvis SP). SPs were normalised to the participants' body mass and height (Bezodis et al., 2010), and time histories were normalised to 101 points from KFO to BC. The net total energy transferred into/out of the segments was also computed from KFO to SFC and from SFC to BC as the integral of SP.

Kickers were grouped based on the outcome of their best kick, with successful kickers being those who achieved a maximum distance >32 m ($n = 18$), those who were unsuccessful from 32 m were grouped based on their reason for failure (limited range, $n = 4$; inaccurate to the left, $n = 8$). Two kickers were excluded as their maximum distance was within the accuracy tolerance of the model, whilst two others were also omitted (one kicker was inaccurate to the right and one successful group kicker had incomplete data from KFO-SFC). Mean ± standard deviations were calculated for both continuous and discrete data for each group. Group differences were investigated using a one-way ANOVA and independent t-tests if a significant main effect was found, with statistical parametric mapping used for continuous data ($p<0.05$).

RESULTS: The SP time-histories and net energy transferred data both indicate that energy was transferred out of the support leg segments (Figure 1, Figure 3a,c) and added to the pelvis (Figure 1, Figure 2) and kick leg segments (Figure 1, Figure 3b,d) during the backswing (KFO-SFC). Following SFC, there was a net energy transfer out of the support leg and pelvis segments (Figure 1). More specifically, as the kick hip began to initiate the downswing (TB), energy continued to be transferred from the support leg (Figure 3a,c,e) and was added to the kick leg (Figure 3b,d,f) up to MKF. As the kick knee then extended down to BC, energy was transferred out of the pelvis (Figure 2) and the kick leg segments (Figure 3b,d) until just prior to BC, when energy was transferred into all kick leg segments (Figure 3b,d,f).

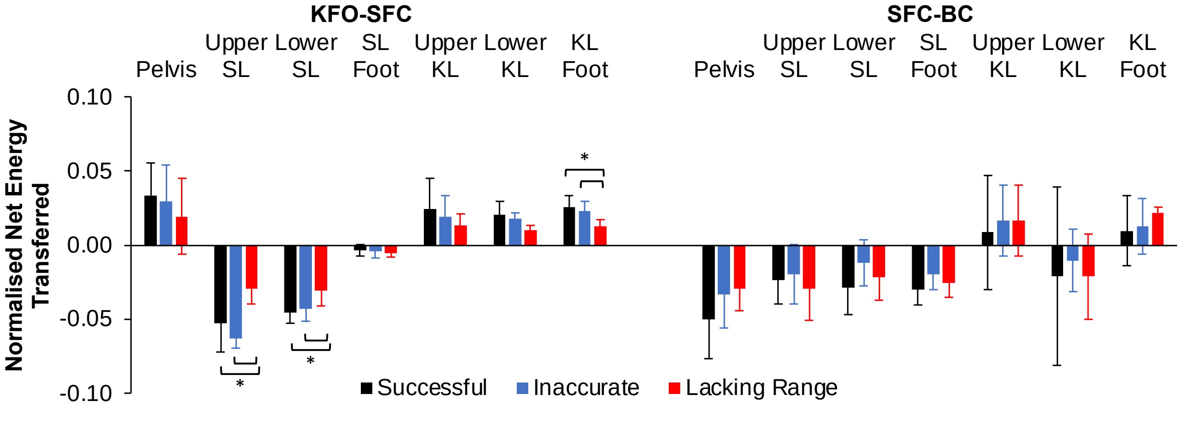

Figure 1: Net energy transferred into (+) / out of (-) the pelvis, kick leg (KL) and support leg (SL) segments between kick foot-off (KFO) and support foot contact (SFC) and between SFC and ball contact (BC). * indicates the limited range kickers were significantly different to the other groups ($p < 0.05$)

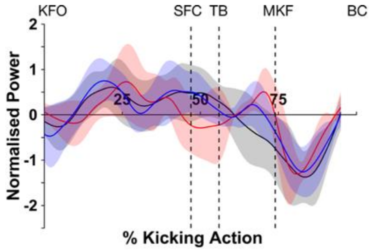

Figure 2: Normalised pelvis power from kick foot off (KFO, 0%) to ball contact (BC, 100%) of successful (black), inaccurate (blue) and limited range (red) place kickers (mean ± sd clouds). The mean time that support foot contact (SFC), top of the backswing (TB) and maximum kick knee flexion (MKF) occurred is indicated by dashed vertical lines.

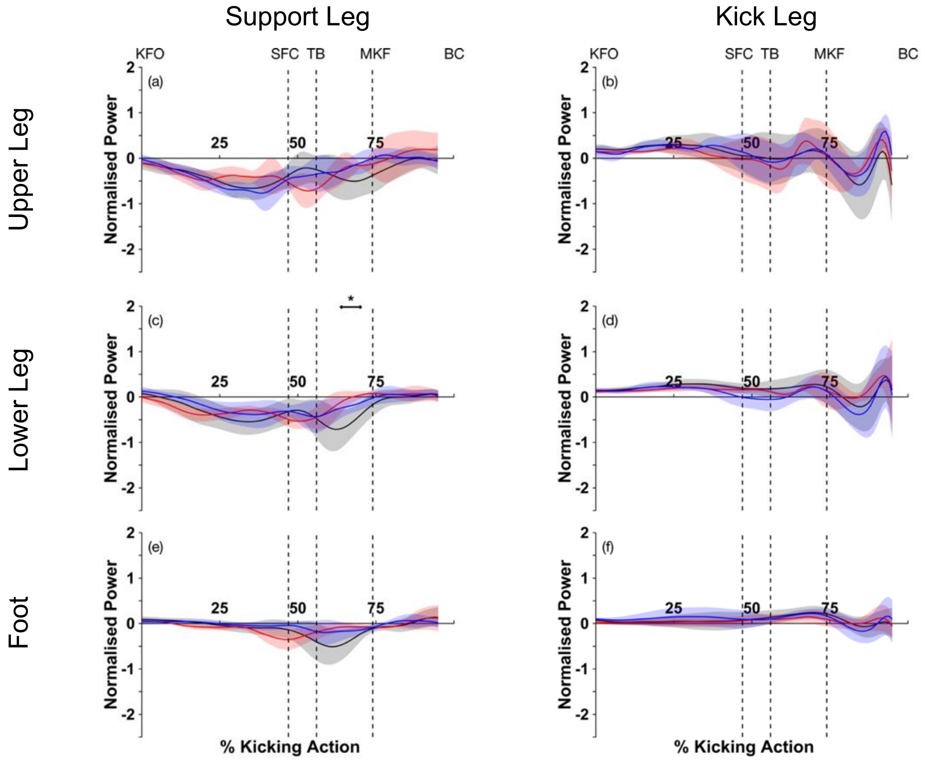

Figure 3: Normalised segment powers from kick foot off (KFO, 0%) to ball contact (BC, 100%) of the support leg (a,c,e) and kick leg segments (b,d,f) of successful (black), inaccurate (blue) and limited range (red) place kickers (mean ± sd clouds). The mean time that support foot contact (SFC), top of the backswing (TB) and maximum kick knee flexion (MKF) occurred is indicated by dashed vertical lines. * indicates where a significant difference was identified between the successful and limited range place kickers ($p < 0.05$).

No differences were seen in the SP time-histories between KFO and SFC when comparing the kicker groups (Figures 2 and 3). However, the limited range kickers had a significantly reduced net energy transfer out of their support leg segments and into their kick foot compared with the other kickers in this phase (Figure 1). Limited range kickers also transferred significantly less energy out of their lower support leg during the initial downswing (64-70% of the kicking action) compared with the successful kickers (Figure 3c). No differences were seen between groups in the net energy transferred into/out of the segments from SFC-BC (Figure 1).

DISCUSSION: This study investigated the energy transferred between lower limb segments during a rugby place kick and sought to identify differences between successful and less successful kickers. Throughout the backswing, and up to the point of MKF, energy was primarily transferred out of the support leg and into the pelvis and kick leg. As the kick knee then extended to contact the ball, minimal energy was transferred in or out of the support leg, but there was a large transfer out of the pelvis and the proximal kick leg segments. During the backswing, limited range kickers transferred significantly less energy out of their support leg

segments and into their kick foot which then impacted the ball with a reduced velocity (~3 m/s slower; Atack et al., 2019b) compared with both the successful and inaccurate kickers.
The outflow of energy from the lower support leg during the downswing of the place kicks was comparable to that seen in soccer instep kicks (Augustus et al., 2021). However, whilst energy was also transferred out of the upper support leg in the place kicks, energy was added to this segment in instep kicks. Additionally, although energy was added to the pelvis in both kick types over this time, the magnitude was larger in the place kicks. This indicates that place kickers transfer energy out of the support leg earlier than soccer kickers, supported by the greater energy outflow from the upper support leg and inflow to the pelvis following SFC by the soccer kickers. An earlier transfer of energy out of the support leg may enable place kickers to create a more stable base about which the kick leg can swing, which is associated with greater accuracy (Kellis et al., 2004), as is required in place kicks compared with maximal instep kicks.
The greater amount of energy transferred out of the support leg during the backswing by both the successful and inaccurate kickers compared with those who were limited by range indicates differences in how the kickers approach the ball. Support leg mechanics prior to SFC have not previously been reported, however, faster approach velocities were seen in longer place kicks (Atack et al., 2023). Further, the time when the limited range kickers transferred significantly less energy out of their lower support leg, early in the downswing, corresponds to a period of support knee flexion and hip extension (Atack et al., 2023). Given the previously reported association between kick foot velocity and total energy transferred out of the upper support leg to the pelvis in soccer (Augustus et al., 2021) as well as the impact of raising the support hip on passive energy transfer to the kick leg (Augustus et al., 2017), it is suggested that the support leg action following SFC was inadequate in the limited range place kickers. Further research is needed to establish if this is due to reduced muscular strength or technical factors, investigating the relative contributions of active and passive forces to these energy transfer strategies may provide further insight.

CONCLUSION: When performing rugby place kicks, the support leg primarily transferred energy to the pelvis throughout the backswing and early downswing. Energy was subsequently transferred out of the pelvis as the kick knee extended towards the ball. Kickers who were limited by range transferred less energy out of the support leg and into the kick foot prior to SFC and in the early downswing. Kickers may benefit from greater support hip extension and therefore, energy transfer between the lower limbs in order to maximise kicking range.

REFERENCES

Atack, A., Trewartha, G., & Bezodis, N.E. (2019a). Assessing rugby place kick performance from initial ball flight kinematics: development, validation and application of a new measure. *Sports Biomechanics*, 18(5), 457-469.

Atack, A.C., Trewartha, G., & Bezodis, N.E. (2019b). A joint kinetic analysis of rugby place kicking technique to understand why kickers achieve different performance outcomes. *Journal of Biomechanics*, 87, 114-119.

Atack, A.C., & Bezodis, N.E. (2023). Biomechanical analysis of elite female rugby place kickers. *ISBS Proceedings Archive*, 41(1), Article 7.

Augustus, S., Mundy, P., & Smith, N. (2017). Support leg action can contribute to maximal instep soccer kick performance: an intervention study. *Journal of Sports Sciences*, 35(1), 89-98.

Augustus, S., Hudson, P.E., Harvey, N., & Smith, N. (2021). Whole-body energy transfer strategies during football instep kicking: implications for training practices. *Sports Biomechanics.*

Bezodis, N.E., Salo, A.I.T., & Trewartha, G. (2010). Choice of sprint start performance measure affects the performance-based ranking within a group of sprinters: which is the most appropriate measure? *Sports Biomechanics*, 9(4), 258-269.

Kellis, E., Katis, A., & Gissis, I. (2004). Knee biomechanics of the support leg in soccer kicks from three angles of approach. *Medicine and Science in Sports and Exercise,* 36(6), 1017-1028.

Pocock, C., Bezodis, N.E., Davids, K., & North, J.S. (2018). Hot hands, cold feet? Investigating effects of interacting constraints on place kicking performance at the 2015 Rugby Union World Cup. *European Journal of Sport Science*, 18 (10), 1309-1316.

Quarrie, K. L., & Hopkins, W. G. (2015). Evaluation of goal kicking performance in international rugby union matches. *Journal of Science and Medicine in Sport*, 18(2), 195-198.