Defining movement strategies in Soccer instep kicking using the relationship between pelvis and kick leg rotations

Simon Augustus[1], Penny E. Hudson[2], and Neal Smith[2]

[1]Department of Applied and Human Sciences, Kingston University, London, UK.

[2]Chichester Institute of Sport, University of Chichester, West Sussex, UK.

Corresponding author:

Simon Augustus

Department of Applied and Human Sciences, Kingston University, Penrhyn Road, Kingston upon Thames, London, UK, KT1 2EE.

Tel: +44 020 8417 5302

E-mail: siaugustus@icloud.com

Twitter: @SimonAugustus04

Abstract

Growing evidence suggests skilled ball kickers use distinct pelvis and kick leg strategies to achieve successful performance. However, since the interaction between different strategies remains unexplored, the aims of this study were to: a) examine relationships between pelvis and kick leg rotations in male players performing Soccer instep kicks and b) classify different 'types' of kickers based on the observed movement strategies. Twenty semi-professional players performed kicks for maximal speed and accuracy, and kick leg and pelvis kinematics were analysed using 3D motion capture (1000 Hz). A strong relationship was found between change in pelvis transverse angular velocity and thigh-knee angular velocity ratio upon ball contact ($r = 0.76$, $p < 0.001$), and participants were categorised by their location on kick leg (thigh-knee) and pelvis (maintainer-reverser) continuums. Knowledge of a player's preferred strategy can inform departure from 'one size fits all' technical and conditioning training practices towards more individualised approaches. For example, pelvis maintainer-thigh dominant kickers might benefit from focus towards the concentric capabilities of the hip flexors, whereas reverser-knee dominant kickers might benefit from developing the ability to decelerate the pelvis and thigh to induce motion-dependent angular acceleration of the lower leg towards the ball.

Word count = 3305

Keywords: football, thigh, knee, training, inter-individual.

Introduction

Instep kicking is an important variation of the kicking skill in Soccer as it is the most commonly performed when shooting at goal (Kellis & Katis, 2007; Lees et al., 2010a). Furthermore, since 30 - 50% of matches are either drawn or decided by a single goal (Reade et al., 2021), successful execution of the instep kick can directly affect the outcome of a match. From a biomechanical perspective, maximising ball speed and accuracy have been considered advantageous as they increase the chances of scoring (Dörge et al. 2002). To inform coaching of the skill, Biomechanists have thus extensively documented: a) patterns of kick leg proximal-to-distal sequencing that characterise skilled ball kicking (Dörge et al., 2002; Putnam, 1991; Nunome et al, 2002, 2006) and b) group-derived kinematic parameters associated with fast and accurate performance (Apriantono et al., 2006; De Witt & Hinrichs, 2002; Kellis et al, 2006). However, group-based analyses have been criticised as they can mask important sources of inter-individual variability (Bates et al., 2004) and it has been questioned whether training recommendations derived from 'on average' findings are useful when applied at an individual level (Glazier & Mehdizadeh, 2018). Since a player's movement strategy will emerge from a unique set of anthropometric, genetic, learning, task and environmental factors (Thelen, 1995), a more productive approach might be to first identify players' preferred movement strategies, then prescribe technical or conditioning practices based on these profiles (Augustus et al., 2021a).

Growing evidence supports that skilled ball kickers use distinct but equally functional movement strategies to achieve successful performance (Atack et al., 2019; Augustus et al., 2021; Ball, 2008). Ball (2008) observed a strong negative relationship (r = -0.90) between kicking thigh and knee angular velocities at ball contact in 28 professional Australian Football League (AFL) punt kickers. He suggested a trade-off between these parameters, and that players lie on a continuum between 'thigh' (relatively more thigh than knee angular velocity at ball contact) and 'knee' (relatively more knee than thigh angular velocity at ball contact) dominance. Importantly, however, when he split the kickers into these classifications, there was no discernible difference in performance in terms of foot and ball speeds. He suggested that different movement cues and conditioning should be used for each group but did not provide guidelines to achieve this. Atack et al. (2019) noted a similar phenomenon in 33 experienced Rugby place kickers. Despite a negligible effect on ball speeds, they showed thigh dominant kickers performed more concentric hip flexor work during the downswing, whereas knee dominant kickers performed more concentric knee extensor work. They concluded the former might benefit from focussing training towards the hip flexors and the latter towards the knee extensors.

Most recently, Augustus et al. (2021a) identified different pelvic rotation strategies in semi-professional Soccer players. They showed a trade-off between 'reversing' or 'maintaining' pelvis transverse angular velocity before ball contact. The former exhibited a fast peak velocity (kick side hip towards the ball) of ~300 °/s that 'reversed' to ~ 0 °/s by ball contact, and the latter by a slower peak (~ 150 °/s) that was 'maintained' to ball contact. Since pelvis transverse rotation about the support leg precedes kick leg proximal to distal sequencing (Augustus et al., 2021b; Inoue et al., 2014), they suggested 'maintainers' corresponded to Ball's (2008) 'thigh' dominant kickers (i.e., greater contributions from proximal segments) and 'reversers' to 'knee' dominant kickers (i.e., greater contributions from distal segments). Unfortunately, they did not present kick leg kinematic or performance data (e.g. foot and ball speeds) from these two groups, so associations between kick leg thigh-knee and pelvis maintainer-reverser strategies remain unclear. If a relationship exists between kick leg and pelvis strategies, it could enable departure from flawed 'one size fits all' training practices towards more individualised approaches (Glazier & Mehdizadeh, 2018). By classifying players based on their preferred movement strategies, coaches could tailor training practices for different 'types' of kicker.

The aims of this study were twofold. First, to assess relationships between kick leg (thigh-knee continuum) and pelvis rotation (maintainer-reverser continuum) strategies in semi-professional Soccer players performing instep kicks for maximal speed and accuracy. Second, to classify different 'types' of kickers based on these relationships. It was hypothesised that: a) like AFL punts kickers (Ball, 2008), soccer players would perform instep kicks on a continuum between kick leg thigh and knee dominance, b) despite differences in pelvis and kick leg kinematics, kicking performance (i.e. ball speeds and accuracy) would not be different between pelvis reversers and maintainers, and c) there would be a strong positive relationship between kick leg (thigh-knee) and pelvis (maintainer-reverser) strategies.

Materials and methods

Participants

Twenty male Soccer players volunteered for the study (mass 79.0 ± 7.5 kg, height 1.80 ± 0.10 m, age 23.8 ± 4.0 years; >10 years playing experience). All were injury free, aged 18-35 years, preferred to kick with the right foot and affiliated to a semi-professional club (Steps 1- 7) in the English FA national league. Ethical approval was granted by the University's local ethics committee, and participants completed written informed consent prior to data collection.

Data Collection & Modelling

After self-directed warm up (~10 mins including jogging, dynamic stretches and kicks of increasing effort), participants wore tight fitting lycra shorts and standardised Soccer shoes (Spoiler Futspeed, Nomis, Australia) to kick a FIFA approved size 5 ball (800 Hpa; Mitre Monde, UK) with the instep of their preferred foot as 'fast and accurately' towards a target (circle with 0.5 m radius) on a catching net 4 m from the ball. Kicks were performed in a carpeted laboratory with minimum three minutes rest between trials. The first five accurate kicks (i.e. only those that hit the target) were included for analysis.

Kicking motions were captured by a 10-camera, opto-electronic 3D motion analysis (Vicon T40S, Oxford, UK) at 1000Hz. Reflective markers defined the position and orientation of seven segments (bilateral feet, shanks, thighs and pelvis) using a direct kinematic (six degrees of freedom at each joint) approach (Augustus et al., 2021a,b). Segment coordinate systems were defined at the proximal end of each segment. Positive Z pointed along the long axis of the segment, X to the right, and Y anteriorly. For shanks and thighs these were defined at the location of functional knee and hip joint centres, respectively (Schwartz & Rozumalski, 2005). For the pelvis, this was determined using calibration markers placed bilaterally on the greater trochanters and iliac crests (Seay et al., 2008). Following static calibration, segment motion was tracked using triad marker clusters (CAST technique; Cappozzo et al., 1995) and six semi-hemispherical markers were attached to the anterior face of the ball to define its geometric centre (Inoue et al., 2014).

Data Analysis

Marker trajectories from kicking trials were exported to Visual 3D (V6, C-Motion, USA), where kicking foot and shank markers were low-pass filtered using a time-frequency, fractional Fourier filter (FrFF; Augustus et al., 2020a). The FrFF filters trajectories in consecutive Fourier domains to raise the cut-off frequency near the time of impact and derive valid kinematics during both swing and foot-to-ball contact (Augustus et al., 2020b). The cut-off frequencies were 18 Hz and between 150 – 300 Hz for swing and ball contact phases, respectively. Markers attached to all other segments were low-pass filtered using a conventional fourth-order, dual-pass Butterworth digital filter (cut-off frequency = 18 Hz, determined by residual analysis).

Pelvis transverse angular velocity was defined as the pelvis segment angular velocity about the global vertical axis (Baker, 2001), kicking thigh angular velocity (flexion/ extension) the thigh segment relative to the global medio-lateral axis, and kicking knee angular velocity (flexion/ extension) the shank angular velocity relative to the thigh (Lees et al., 2010b). Thigh segment and knee joint angular velocities (rather than hip and knee joint) were selected to enable calculation of thigh-knee angular velocity ratios as described by Ball (2008). Foot and ball velocities were the resultant magnitudes of foot and ball centre of mass (CoM) velocities at the frames immediately before (ball acceleration > 200 m/s^2) and after (ball acceleration < 200 m/s^2) ball contact, respectively (Augustus et al., 2020b).

Participants were sorted by their percentage change between peak pelvis transverse angular velocity and the corresponding values at ball contact. The 10 participants with the greatest percentage change (mean value from 5 trials) were classified as 'reversers' and the ten with smallest percentage change as 'maintainers'. As per Ball (2008), it is acknowledged these groupings were arbitrary and a continuum of pelvic strategies were likely to exist. Kicking stride length (vector magnitude displacement between kicking foot CoM position at take-off to support foot CoM position at touchdown), approach angle (angle of approach displacement vector relative to global medio-lateral axis) and approach velocity (vector magnitude of whole-body CoM velocity in frame before support foot touchdown) were also calculated as known moderators of pelvic and kick leg kinematics (Andersen & Dörge, 2011; Augustus et al., 2021a; Inoue et al., 2014; Lees & Nolan; 2002; Scurr & Hall, 2009). The mean values from participant's five kicks were used for further analyses.

Statistical Analyses

Following normality checks (Shapiro-Wilks = $P < 0.05$), Bonferroni adjusted independent t-tests assessed differences in discrete parameters between the groups (No. of comparisons = 10, $\alpha = 0.005$, effect sizes (d) = small > 0.2, medium > 0.5 and large > 0.8; Cohen, 1988). To compare pelvis, thigh and knee angular velocities across the entire kicking motion, Bonferroni adjusted ($N = 3$; $\alpha = 0.017$) independent t-test statistical parametric mapping (SPM1D V0.4; Pataky, 2012) was also conducted on time-normalised ensemble average curves between kicking foot take off (KFTO; 0 %) and start of ball contact (BCS; 100 %). The average instances of maximal kicking hip extension (MHE), support foot touchdown (SFTD), maximal kicking knee flexion (MKF) and the instance the kicking knee extended past 90° (K90) are shown on the curves to aid interpretation. Finally, Pearson's correlations explored relationships between pelvis and kick leg rotation strategies ($N = 4$, $\alpha = 0.013$, 0 - 0.2 = no correlation, 0.2 - 0.4 = weak, 0.4 - 0.7 = moderate, 0.7 - 1.0 = strong; Fallowfield et al., 2005). Discrete statistical tests were conducted using JASP software (V0.12, University of Amsterdam, Netherlands).

Results

Ball (26.2 ± 2.1 vs 25.8 ± 1.3 m/s, d = 0.2) and foot velocities (18.8 ± 1.2 vs 18.1 ± 0.8 m/s, d = 0.5) were not significantly different between reversers and maintainers, but distinctly different pelvis transverse and kick leg thigh and knee rotation strategies were adopted at BCS (Table 1). The SPM analyses revealed maintainers were transversely rotating the pelvis faster than reversers between 94 -100% of the kick ($p = 0.006$; Figure 1) and flexing the thigh significantly faster than reversers between 95 - 100% of the kick ($p = 0.012$; Figure 1). Conversely, reversers were extending the knee significantly faster than maintainers between 96 - 100% of the kick ($p = 0.014$; Figure 1). These differences were despite almost identical approach characteristics (Table 1).

Table 1 near here **Figure 1 near here**

Thigh flexion velocities showed a significant strong negative correlation with knee extension velocities at ball contact ($r = -0.85$, $p < 0.001$). Percentage change in pelvis transverse angular velocity showed significant and strong negative ($r = -0.75$, $p < 0.001$) and positive ($r = 0.70$, $p < 0.001$) relationships with thigh and knee angular velocities at ball contact, respectively. There was a significant strong positive correlation between percentage change in pelvis transverse angular velocity and thigh to knee angular velocity ratios at ball contact ($r = 0.76$, $p < 0.001$). Scatterplots for each relationship are shown in Figures 2 and 3.

Figure 2 near here

Discussion and implications

Relationships between kick leg and pelvis rotation strategies

The first aim of this study was to assess relationships between kick leg (thigh-knee continuum) and pelvis rotation (maintainer-reverser continuum) strategies in semi-professional Soccer players performing instep kicks for maximal speed and accuracy. Similar to AFL punt kickers (Ball, 2008), soccer players exhibited a strong negative relationship between kick leg thigh and knee angular velocities at ball contact (Figure 2). The hypothesis that kicks would be performed on a continuum between thigh and knee dominance was thus accepted. However, this relationship was slightly weaker than as reported by Ball (2008) (r = -0.85 vs -0.90, respectively). His AFL punt kickers used faster thigh (313 ± 185 °/s) and slower knee angular velocities (1364 ± 253 °/s) than the current cohort (Table 1), indicating a greater propensity towards thigh dominance. This was not surprising given Soccer kicking generally involves more non-sagittal plane motion (Lees & Nolan, 2002; Levanon & Dapena, 1998; Blair et al., 2018) and foot-to-ball contact tends to occurs towards the anterior-medial rather than the anterior dorsal aspect of the foot (Nunome et al, 2014).

While this finding supports that different coaching recommendations should be used for thigh and knee dominant kickers (Atack et al. 2019; Ball, 2008), this study also highlights that pelvis motion should also be considered when prescribing training practices. Greater changes in pelvis transverse angular velocity were strongly associated with faster knee extension velocities (r = 0.70) and slower thigh flexion velocities (r = -0.75) at ball contact. This confirmed that for Soccer players, it is appropriate to extends Ball's (2008) classifications to include that pelvis reversers generally correspond to knee dominance, and pelvis maintainers to thigh dominance (Figure 2). That is, reverser-knee dominant kickers tend to use greater contributions from the distal segments to generate foot velocities at foot-to-ball contact, whereas maintainer-thigh kickers use greater contributions from the more proximal segments.

It should be noted, however, that when classified into these discrete groups, pelvis, thigh and knee angular velocities only diverged as the kicking knee extended past 90° (Figure 1). This suggests changes in movement strategy only manifested later in the kicking action and future research might investigate pelvis and kick leg co-ordination patterns to understand how and when different movement strategies emerge during the kick. Furthermore, despite the existence of different pelvis and kick leg strategies, there were no appreciable differences in terms of the foot and ball velocities between the groups (Table 1). The second hypothesis that overall kicking performance would not be different between groups was therefore accepted. This contributes to evidence that different movement strategies can be used to achieve successful performance (Atack et al., 2019; Augustus et al., 2021a; Ball, 2008), and is an important finding in two respects. First, it corroborates that a single optimal technique is unlikely to exist for fast and accurate Soccer instep kicking. If the Soccer biomechanics community does not account for the individual nature of kicking motions then future attempts to understand skilled performance will remain flawed (Bates et al., 2004; Glazier & Mehdizadeh, 2018). Second, knowledge of the different strategies used to perform instep kicking can inform departure from 'one-size fits all' approaches to training towards more individualised approaches.

Classification of pelvis and kick leg strategies

The second aim of this study was to classify different 'types' of kickers based on the relationship between kick leg and pelvis rotations. Given the strong associations between kick leg and pelvis strategies (Figure 2), each participant adopted a strategy that can be represented by their location on each kick leg (thigh-knee) and pelvis (maintainer-reversers) continuums. Figure 3 conceptualises this interaction as a quadrant model that identifies different 'types' of kickers based on the position an individual occupies on the scatterplot. The horizontal (x) axis indicates a player's relative pelvis maintainer-reverser dominance (i.e. percentage change in pelvis transverse angular velocity between peak and ball contact), the vertical (y) axis their relative kick leg thigh-knee dominance (i.e. ratio between thigh and knee angular velocity at ball impact) and by intersecting the axes at the pooled mean value for each variable (x = 66.85% and y = 0.95), the interaction between the two continuums indicates the quadrant they fall into.

** Figure 3 near here**

Most participants were classified as either reverser-knee (N = 7, top right) or maintainer-thigh dominant (N = 9, bottom left) kickers. However, since only 58% of variance was accounted for by this relationship, several participants also fell within either reverser-thigh (N = 3; bottom right), or maintainer-knee (N = 1; top left) classifications (Figure 3). From a practical perspective, researchers and practitioners could first identify players occupying each quadrant (i.e. the 'types' of kicker), then apply training practices that are appropriate for those groups. Pelvis maintainer-thigh kickers might benefit from focussing training towards: a) the concentric capabilities of the hip flexors (Atack et al., 2019; Augustus et al., 2021b) and b) co-ordinated formation and release of a 'tension arc' between the torso, pelvis and thigh (Shan & Weterhoff, 2005). Conversely, reverser-knee dominant kickers might focus on: a) concentric knee extensor strength (Atack et al., 2019) and b) the ability to decelerate the pelvis and thigh during the downswing and induce motion-dependent angular acceleration of the lower leg towards the ball (Putnam, 1991; Nunome et al, 2002, 2006). Those identified as maintainer-knee, reverser-thigh or towards the centre of the plot (i.e. closer to mean values) might benefit from a more balanced approach to training. It is important to add, however, that these recommendations should not be considered as exhaustive nor prescriptive. They are instead intended as a foundation upon which other researchers and practitioners can build upon to optimise training of kicking skills. Future research should add to the model by assessing common characteristics exhibited by each 'type' of kicker, and assess the efficacy of the proposed (or other) training practices. It may also be beneficial to investigate other factors that could determine a player's tendency towards particular strategies (e.g. anthropometrics, strength or flexibility). This information may prove particularly helpful for guiding development of effective kicking actions in developing players.

Finally, we acknowledge that the quadrant model has some limitations that should be considered. First, the presented classification boundaries were arbitrarily selected based on strategies observed in the current participants (i.e. using mean values on each continuum). We therefore urge caution when using these boundaries with separate cohorts. Future work must examine pelvis and kick leg strategies in larger samples and across different populations to ensure boundary locations (and thus training prescription) can be made appropriate for each intended application. For example, different movement strategies likely exist across Football codes (Ball, 2008), playing levels (Lees & Nolan, 2002), in females (Boyne et al., 2021), and in younger players (Katis et al., 2015). Second, factors such as intra-individual variation (Lees & Rahnama, 2013), maturation (Vieira et al., 2018) and task complexity (Teixeira, 1999) will influence a kicker's preferred movement strategy and thus could change the position they occupy on the model. It is conceivable that a player could move both within and between the quadrants to occupy a larger 'space' of the model that is representative of different within-player strategies. Future research should investigate how and when kickers adapt their movement strategies so that training practices can be further optimised for such variation.

Conclusions

The relationship between kick leg and pelvis transverse rotations can be used to identify distinct but equally functional movement strategies in fast and accurate Soccer instep kicking. Semi-professional players performed kicks on two continuums between kick leg (thigh-knee) and pelvis (reverser-maintainer) dominance, and the interaction between the two strategies can be used to classify different 'types' of kicker. Knowledge of an individual's preferred strategy can inform departure from flawed 'one size fits all' training practices towards more individualised approaches. The proposed quadrant model is thus intended as a foundation upon which researchers and practitioners can build upon to optimise coaching of ball kicking skills. For example, those identified as maintainer-thigh kickers might focus on developing the concentric capabilities of the hip flexors whereas reverser-knee kickers might benefit from developing the ability to decelerate the pelvis and thigh and induce motion-dependent angular acceleration of the lower leg towards the ball.

Disclosure and funding statement

The authors report no conflict of interest. No funding was received for this study.

References

Andersen, T. B., & Dörge, H. C. (2011). The influence of speed of approach and accuracy constraint on the maximal speed of the ball in Soccer kicking. *Scandinavian Journal of Medicine and Science in Sports*, *21*, 79–84. https://doi.org/10.1111/j.1600-0838.2009.01024.x

Apriantono, T., Nunome, H., Ikegami, Y., & Sano, S. (2006). The effect of muscle fatigue on instep kicking kinetics and kinematics in association football. *Journal of Sports Sciences*, *24*, 951–960. https://doi.org/10.1080/02640410500386050

Atack, A. C., Trewartha, G., & Bezodis, N. E. (2019). A joint kinetic analysis of rugby place kicking technique to understand why kickers achieve different performance outcomes. *Journal of Biomechanics*, *87*, 114–119. https://doi.org/10.1016/j.jbiomech.2019.02.020

Augustus, S., Hudson, P. E., & Smith, N. (2021a). The effect of approach velocity on pelvis and kick leg angular momentum conversion strategies during football instep kicking strategies during football instep kicking. *Journal of Sports Sciences*, *in press*. https://doi.org/10.1080/02640414.2021.1929008

Augustus, S., Hudson, P. E., Harvey, N., & Smith, N. (2021b). Whole-body energy transfer strategies during football instep kicking: implications for training practices. *Sports Biomechanics*, *in press*. https://doi.org/10.1080/14763141.2021.1951827

Augustus, S., Mithat Amca, A., Hudson, P. E., Smith, N. (2020a). Improved accuracy of biomechanical motion data obtained during impacts using a time-frequency low-pass filter. *Journal of Biomechanics*, *101*, 1-5. https://doi.org/10.1016/j.jbiomech.2020.109639

Augustus, S., Mithat Amca, A., Hudson, P. E., & Smith, N. (2020b). Choice of low-pass filter influences practical interpretation of ball kicking motions: the effect of a time-frequency filter method. *Sports Biomechanics*, *in press*. https://doi.org/10.1080/14763141.2020.1805507

Baker, R. (2001). Pelvic angles: a mathematically rigorous definition which is consistent with a conventional clinical understanding of the terms. *Gait and Posture*, *13*, 1–6. https://doi: 10.1016/s0966-6362(00)00083-7

Ball, K. (2008). Biomechanical considerations of distance kicking in Australian Rules football. *Sports Biomechanics*, *7*, 10–23. https://doi.org/10.1080/14763140701683015

Bates, B. T., James, C. R., & Dufek, J. S. (2004). Single-subject analysis. In N. Stergiou (Ed.), *Innovative analyses of human movement: analytical tools for human movement research* (pp. 3–28). Human Kinetics.

Blair, S., Duthie, G., Robertson, S., Hopkins, W., & Ball, K. (2018). Concurrent validation of an inertial measurement system to quantify kicking biomechanics in four football codes. *Journal of Biomechanics*, *73*, 24–32. https://doi.org/10.1016/j.jbiomech.2018.03.031

Boyne, M., Simms, C., van Dyk, N., Farrell, G., Farrell, E., McHugh, C., Wall, J., Mockler, D., & Wilson, F. (2021). It's not all about power: a systematic review and meta-analysis comparing sex-based differences in kicking biomechanics in soccer. *Sports Biomechanics*, *in press*. https://doi.org/10.1080/14763141.2021.1981426

Cappozzo, A., Catani, F., Della Croce, U., & Leardini, A. (1995). Position and orientation in space of bones during movement: anatomical frame definition and determination. *Clinical Biomechanics (Bristol, Avon)*, *10*, 171–178. https://doi: 10.1016/0268-0033(95)91394-t

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Academic Press.

De Witt, J. K., & Hinrichs, R. N. (2012). Mechanical factors associated with the development of high ball velocity during an instep Soccer kick. *Sports Biomechanics*, *11*, 382–390. https://doi.org/10.1080/14763141.2012.661757

Dörge, H. C., Anderson, T. B., Sorensen, H., & Simonsen, E. B. (2002). Biomechanical differences in Soccer kicking with the preferred and the non-preferred leg. *Journal of Sports Sciences*, *20*, 293–299. https://doi.org/10.1080/026404102753576062

Fallowfield, J. L., Hale, B. J., & Wilkinson, D. M. (2005). *Using Statistics in Sport and Exercise Science Research*. Lotus Publishing.

Glazier, P. S., & Mehdizadeh, S. (2018). Challenging Conventional Paradigms in Applied Sports Biomechanics Research. *Sports Medicine, 49,* 171-176. https://doi.org/10.1007/s40279-018-1030-1

Inoue, K., Nunome, H., Sterzing, T., Shinkai, H., & Ikegami, Y. (2014). Dynamics of the support leg in Soccer instep kicking. *Journal of Sports Sciences*, *32*, 1023–1032. https://doi.org/10.1080/02640414.2014.886126

Katis, A., Kellis, E., & Lees, A. (2015). Age and gender differences in kinematics of powerful instep kicks in soccer. *Sports Biomechanics*, 14, 287-299. https://doi.org/10.1080/14763141.2015.1056221

Kellis, E., & Katis, A. (2007). Biomechanical characteristics and determinants of instep Soccer kick. *Journal of Sports Science and Medicine*, *6*, 154–165.

Kellis, E., Katis, A., & Vrabas, I. S. (2006). Effects of an intermittent exercise fatigue protocol on biomechanics of Soccer kick performance. *Scandinavian Journal of Medicine and Science in Sports*, *16*, 334–344. https://doi.org/10.1111/j.1600-0838.2005.00496.x

Lees, A., Asai, T., Andersen, T. B., Nunome, H., & Sterzing, T. (2010a). The biomechanics of kicking in Soccer: a review. *Journal of Sports Sciences*, *28*, 805–817. https://doi.org/10.1080/02640414.2010.481305

Lees, A., Barton, G., & Robinson, M. (2010b). The influence of Cardan rotation sequence on angular orientation data for the lower limb in the Soccer kick. *Journal of Sports Sciences*, *28*, 445–450.

Lees, A. N., & Nolan, L. (2002). Three-dimensional kinematic analysis of the instep kick under speed and accuracy conditions. In A. Murphy, T. Reilly, & W. Spinks (Eds.), *Science and Football IV*. Routledge.

Lees, A., & Rahnama, N. (2013). Variability and typical error in the kinematics and kinetics of the maximal instep kick in soccer. *Sports Biomechanics*, *12*, 283–292. https://doi.org/10.1080/14763141.2012.759613

Levanon, J., & Dapena, J. (1998). Comparison of the kinematics of the full-instep and pass kicks in soccer. *Medicine & Science in Sports & Exercise*, *30*, 917–927. https://doi: 10.1097/00005768-199806000-00022

Nunome, H., Asai, T., Ikegami, Y., & Sakurai, S. (2002). Three-dimensional kinetic analysis of side-foot and instep Soccer kicks. *Medicine and Science in Sports and Exercise*, *34*, 2028–2036. https://doi.org/10.1249/01.MSS.0000039076.43492.EF

Nunome, H., Ball, K., & Shinkai, H. (2014). Myth and fact of ball impact dynamics in football codes. *Footwear Science*, *6*, 105–118. https://doi.org/10.1080/19424280.2014.886303

Nunome, H., Ikegami, Y., Kozakai, R., Apriantono, T., & Sano, S. (2006). Segmental dynamics of Soccer instep kicking with the preferred and non-preferred leg. *Journal of Sports Sciences*, *24*, 529–541. https://doi.org/10.1080/02640410500298024

Pataky, T. C. (2012). One-dimensional statistical parametric mapping in Python. *Computer Methods in Biomechanical and Biomedical Engineering*, *15*, 295–301. https://doi.org/10.1080/10255842.2010.527837

Putnam, C. A. (1991). A segment interaction analysis of proximal-to-distal sequential segment motion patterns. *Medicine and Science in Sports and Exercise*, *23*, 130–144. https://doi.org/10.1249/00005768-199101000-00019

Reade, J. J., Singleton, C., & Brown, A. (2021). Evaluating strange forecasts: The curious case of football match scorelines. *Scottish Journal of Political Economy*, *68*, 261–285. https://doi.org/10.1111/sjpe.12264

Schwartz, M. H., & Rozumalski, A. (2005). A new method for estimating joint parameters from motion data. *Journal of Biomechanics*, *38*, 107–116. https://doi.org/10.1016/j.jbiomech.2004.03.009

Scurr, J. C., & Hall, B. (2009). The effects of approach angle on penalty kicking accuracy and kick kinematics with recreational Soccer players. *Journal of Sports Science and Medicine*, *8*, 230–234.

Seay, J., Selbie, W. S., & Hamill, J. (2008). In vivo lumbo-sacral forces and moments during constant speed running at different stride lengths. *Journal of Sports Sciences*, *26*, 1519–1529. https://doi.org/10.1080/02640410802298235

Teixeira, L. A. (1999). Kinematics of kicking as a function of different sources of constraint on accuracy. *Perceptual and Motor Skills*, *88*, 795–798.

Thelen, E. (1995). Motor development: A new synthesis. *American Psychologist*, 50, 79–95. https://doi.org/10.1037/0003-066X.50.2.79

Vieira, L. H. P., Cunha, S. A., Moraes, R., Barbieri, F. A., Aquino, R., Oliveira, L. de P., Navarro, M., Bedo, B. L. S., & Santiago, P. R. P. (2018). Kicking

Performance in Young U9 to U20 Soccer Players: Assessment of Velocity and Accuracy Simultaneously. *Research Quarterly for Exercise and Sport*, *89*, 210–220. https://doi.org/10.1080/02701367.2018.1439569

Tables (with captions)

Table 1. Mean ± SD values and comparisons between reverser and maintainer groups. AV = angular velocity, BC = ball contact. Larger thigh: knee ratios indicate trend towards knee dominance.

	Reversers	Maintainers	p-value	Effect Size (d)
Ball velocity (m/s)	26.2 ± 2.1	25.8 ± 1.3	0.600	0.2 - small
Foot velocity (m/s)	18.8 ± 1.2	18.1 ± 0.8	0.241	0.5 - medium
% change pelvis transverse AV	93 ± 15	40 ± 17	< 0.001*	3.2 - large
Pelvis transverse AV BC (°/s)	-3 ± 45	148 ± 51	< 0.001*	3.1 - large
Thigh flexion AV BC (°/s)	46 ± 84	186 ± 73	< 0.001*	1.8 - large
Knee extension AV BC (°/s)	1894 ± 77	1768 ± 87	0.003*	1.5 - large
Thigh: knee AV ratio BC	0.98 ± 0.04	0.91 ± 0.03	< 0.001*	1.8 - large
Kicking stride length (m)	1.5 ± 0.1	1.5 ± 0.1	0.997	0.0 - negligible
Approach angle (°)	26 ± 6	27 ± 7	0.593	0.2 - small
Approach velocity (m/s)	3.4 ± 0.4	3.4 ± 0.2	0.898	0.3 - small

* indicates significantly different between groups ($p < 0.005$)

Figure Captions

Figure 1. Mean ± SD pelvis transverse, thigh (flexion/ extension) and knee (flexion/extension) angular velocities for maintainers and reversers between kicking foot take off (KFTO) and ball contact (BCS). Arrows and p-values on each plot indicate locations of SPM significant differences. KFTO = kicking foot take off, MHE = maximum kicking hip flexion, SFTD = support foot touchdown, MKF = maximum kicking knee flexion, K90 = kicking knee angle 90°, BCS = ball contact start.

Figure 2. Scatterplots showing relationships and coefficient of determinations (R^2) between kick leg and pelvis rotation strategies for the 20 players. The plots also show the players identified as either pelvis reversers or maintainers.

Figure 3. Quadrant model showing the relationship between pelvis maintainer-reverser (x-axis) and kick leg thigh-knee continuums (y-axis). Quadrants were arranged by placing the x and y intercepts at the pooled mean values for percentage change in pelvis transverse angular velocity (x = 66.85%) and thigh to knee ratios (y = 0.94). The quadrant into which each players falls indicates their preferred movement strategy. Top left = maintainer-knee, top right = reverser-knee, bottom left = maintainer-thigh and bottom right = reverser-thigh.