Support Leg Action Can Contribute To Maximal Instep Soccer Kick Performance: An Intervention Study

Running Title

Support Leg Action Can Contribute to Kicking Performance

Keywords

Biomechanics; Dynamics; Technique intervention; Football; Power flow.

Disclosure Statement

The authors report no conflict of interest.

No funding was received for this study.

Abstract

This investigation assessed whether a Technique Refinement Intervention designed to produce pronounced vertical hip displacement during the kicking stride could improve maximal instep kick performance. Nine skilled players (age 23.7 ± 3.8 years, height 1.82 ± 0.06 m, body mass 78.5 ± 6.1 kg, experience 14.7 ± 3.8 years; mean ±SD) performed 10 kicking trials prior to (NORM) and following the intervention (INT). Ground reaction force (1000Hz) and three-dimensional motion analysis (250Hz) data were used to calculate lower limb kinetic and kinematic variables. Paired *t*-tests and statistical parametric mapping (SPM) examined differences between the two kicking techniques across the entire kicking motion. Peak ball velocities (26.3 ± 2.1 $m \cdot s^{-1}$ vs 25.1 ± 1.5 $m \cdot s^{-1}$) and vertical displacements of the kicking leg hip joint centre (0.041 ± 0.012 m vs 0.028 ± 0.011 m) were significantly larger (P<0.025) when performed following INT. Further, various significant changes in support and kicking leg dynamics contributed to a significantly faster kicking knee extension angular velocity through to ball contact following INT (70-100% of total kicking motion, P<0.003). Maximal instep kick performance was enhanced following INT and the mechanisms presented are indicative of greater passive power flow to the kicking limb during the kicking stride.

Introduction

The maximal instep kick is an important variation of the kicking skill in soccer, as it is the most commonly used technique when attempting a direct shot at goal. The ability to generate a fast ball velocity represents a distinct advantage for a player when shooting, as this gives goalkeepers less time to react and increases the chances of scoring (Kellis & Katis, 2007, Inoue, Nunome, Sterzing, Shinkai & Ikegami, 2014; Lees, Asai, Andersen, Nunome & Sterzing, 2010). A detailed understanding of the mechanisms that determine kicking performance are therefore important to inform coaching practices. Subsequently, the kinetic (Dorge, Andersen, Sorensen & Simonsen, 2002; Inoue *et al.*, 2014; Lees, Steward, Rahnama & Barton, 2009; Nunome, Asai, Ikegami & Sakurai, 2002; Nunome, Ikegami, Kozakai, Apriantono & Sano, 2006) kinematic (Apriantono, Nunome, Ikehami & Sano, 2006; Andersen, Dorge & Thomsen, 1999; Levanon & Dapena, 1998; Nunome, Lake, Georgakis & Stergioulas, 2006) and electromyographic (Dorge *et al.*, 1999; Katis *et al.*, 2013) characteristics of mature maximal instep kick technique have been extensively documented. However, these investigations have been mostly descriptive in nature and the practical applications are limited. Only a few studies have attempted to improve maximal instep kicking performance through resistance training programs (Manolopoulos, Katis, Manolopoulos, Kalapohtarakos & Kellis, 2013; Manolopoulos, Papadopoulos & Kellis, 2006) and to our knowledge no scientific investigations have attempted to refine kicking technique to improve performance.

Co-ordinated instep soccer kicking involves the controlled recruitment of muscular and motion-dependent (from segment interactions) joint torques and the proximal-to-distal motion of the kicking leg is well established (Nunome, Ikegami *et al.*, 2006; Putnam, 1991; Putnam, 1993). That is, the kicking leg acts as an open kinetic chain that rotates around the pelvis to maximise shank and foot velocities at ball contact

(Dorge *et al.*, 2002; Nunome, Ikegami, *et al.*, 2006). Less attention has been paid to the function of the support leg with regards to kicking performance, despite evidence to suggest the proximal-to-distal sequencing of the kick emanates from support leg action. For example, it has been shown that players who produce largest kicking hip vertical displacement generate the fastest shank angular velocities at ball contact (Inoue, Ito, Sueyoshi, O'Donoghue, & Mochinaga, 2000). That is, extension of the support leg knee and hip during the kicking stride serves to lift the kicking leg hip; creating a motion dependent moment which accelerates the kicking leg shank during its downswing (Nunome & Ikegami, 2005). More recently, it has been established that the support leg may contribute to performance by lifting the body and adding to the vertical velocity of the foot at impact (Lees *et al.* 2009) and an increasing joint reaction moment on the support leg side may decelerate the support leg hip and emphasise the forward rotation of the pelvis about the support leg hip and thigh towards the ball (Inoue *et al.*, 2014).

Clearly a kinetic link exists between the kicking and support legs during the maximal instep kick, but exactly how the support leg interacts to facilitate the co-ordinated downswing of the kicking leg during the kicking stride is still largely unknown. The question also remains whether pronounced vertical displacement of the hips (via support leg action) can be intentionally utilised to facilitate a faster kicking leg swing. However, it is logical to surmise that larger vertical displacement of the hips might be indicative of increased kicking performance since robust relationships exist between a) support knee and hip extension and shank angular velocity at ball contact (Inoue *et al.*, 2000; Nunome & Ikegami, 2005), and b) shank angular velocity at ball contact and peak ball velocity (De Witt & Hinrichs, 2012; Levanon & Dapena, 1998). The aims of the current study were therefore to: a) assess the effectiveness of a Technique

Refinement Intervention designed to produce pronounced extension of the support leg and vertical displacement of the kicking hip joint during the kicking stride; and b) highlight the dynamic interaction between support and kicking legs during the maximal instep kick. We hypothesised that kicking performance would improve (i.e. increased ball velocities) following the Intervention.

Method

Participants

Nine skilled club players (age 23.7 ± 3.8 years, height 1.82 ± 0.06 m, body mass 78.5 ± 6.1 kg; mean ± SD) volunteered for the investigation. All were regularly competing in senior amateur or semi-professional competition, had a minimum of ten years playing experience (14.7 ± 3.8 years) and were free from injury at the time of testing. All participants preferred to kick with the right foot. Informed consent was obtained prior to testing and ethical approval granted by the University's Local Ethics Committee.

Experimental Design

The participants performed 10 maximal instep kicks both prior to and immediately following the Technique Refinement Intervention (see Technique Refinement Intervention sub-section for full details). The first 10 trials were performed with the participant's normal kicking technique to establish a representative baseline of technique and performance (NORM). The 10 trials following the intervention were performed with the refined technique (INT). Ten trials were chosen per condition as 10-15 trials is optimal for reducing typical error (within-subject variation) for variables commonly used to describe maximal instep kicking (Lees and Rahnama, 2013).

Technique Refinement Intervention

The aim of the intervention was to produce pronounced extension of the support leg knee and hip and vertical displacement of the pelvis and hips during the kicking stride. The intervention incorporated aspects of Carson and Collin's (2011) Five-A model for technical refinement in skilled performers (see Table 1). The intervention was split into two distinct phases; an Awareness Phase and an Adjustment Phase. During the initial Awareness Phase, the aim was for the participant to call into consciousness the differences between NORM and INT techniques. The Adjustment Phase then aimed to modify the technique and internalise the changes to the extent that it was no longer in conscious awareness. Care was taken not to make specific reference to individual body segments or positions during the intervention process, since implicit learning techniques have been reported to be more effective than explicit techniques when refining well developed movement patterns (Carson & Collins, 2011; MacPherson, Collins & Obhi, 2009).

Intervention sessions lasted 2-4 hours, were semi-structured and an iterative process whereby participants could revisit the material provided during the Awareness Phase if required. All intervention sessions were led by the same investigator to ensure consistency in delivery and implementation of the techniques used and feedback provided. Self-report was chosen to assess when each participant's technique had been successfully adjusted as kinematic measures may not be indicative of performance when refining movement patterns (Peh, Chow and Davids, 2011). However, as outlined in Table 1, the lead investigator did qualitatively assess if the desired changes were apparent in each participant's INT technique.

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

Data Collection and Processing

All kicks were performed in a carpeted laboratory with the participants' preferred (right) foot using a FIFA approved size five ball (inflated pressure 800 hPa). After warm up participants were instructed to strike the ball as forcefully as possible into the centre of a catching net placed four metres away and approached the ball in the way most comfortable to them for the two specific kick conditions. The ball was placed so that the support (left) foot landed on a Kistler 9821B force platform (Kistler Instruments, Hook, UK) which collected ground reaction forces at 1000 Hz. The force platform was synchronised electronically with a 10-camera optoelectronic motion analysis system (250 Hz) (Vicon T40S, Vicon Motion Systems, Oxford, UK). A Casio Exilim EX-FH20 (Casio Ltd, Tokyo, Japan) digital camera (210Hz) was used to provide qualitative feedback during the intervention process. The participant wore their usual Astroturf or indoor soccer shoes and a compressive shirt, shorts and socks for all trials.

Prior to data collection, 24 passive reflective markers (12.6mm diameter) were attached to selected lower limb landmarks as shown in Figure 1. To reduce error associated with soft tissue artefact, marker clusters (consisting of three markers fixed to semi-rigid plastic) were attached to the left and right thigh and shank to determine the orientation of these segments relative to the calculated anatomical joint centres obtained following static calibration (Cappozo, Catani, Leardini, Benedetti & Della Croce, 1996). One additional marker was cut into hemispheres and placed over opposing poles of the ball so that ball velocity could be calculated. Raw marker displacements were smoothed within the Vicon Nexus software (Vicon Nexus v1.8.2, Vicon Motion Systems, Oxford, UK) using a generalized, cross-validated spline (GCVSPL) (Woltring, 1986) (30 MSE; chosen as per residual analysis (Winter, 2009)). Due to distortions of position and velocity data associated with marker trajectories through impacts (Knudson & Bahamonde, 2001; Nunome, Lake *et al.*, 2006), trajectories during the ball impact phase (one frame before and five after ball contact) were extrapolated using the same GCVSPL function.

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

Synchronised force and 3D motion data were exported to Visual 3D (v5.00.31, C-Motion, Rockville, USA) where support and kicking leg knee and hip joint powers (generation/absorption), moments (flexion/extension), reaction forces (compressive/tensile) and angular velocities (flexion/ extension) were calculated for each kicking trial. Lower limb motion was defined using a seven segment, six degrees of freedom model including the pelvis, thighs, shanks and feet. Geometrical volumes were used to represent individual segments and inertial parameters were derived from young male Caucasians (De Leva, 1996). For all segments joint co-ordinate systems were defined at the proximal joint (see Figure 2), whereby hip joint centres were estimated from the positions of the pelvic markers (Bell, Pederson and Brand, 1989) and knee and ankle joint centres were defined as the mid-point between femoral epicondyle and malleoli marker, respectively. Joint angle orientations were defined by the distal joint segment relative to the proximal using an X-Y-Z Cardan rotation sequence (Lees, Barton & Robinson, 2010). Angular velocities were computed by subtracting the absolute angular velocity vectors from that of the adjacent proximal segment. Joint reaction forces calculated within Visual 3D represented the resultant joint force (from bone, muscle and external forces) as derived by inverse dynamics and not the compressive load due to muscles acting at the joint (Selbie, Hamill & Kepple, 2014). All kinetic data were resolved to the proximal co-ordinate system and were normalised to body mass. The smoothed co-ordinates of the ball markers were exported to Microsoft Excel 2007® and the resultant velocities of the mid-point between the two markers were computed at each frame following ball contact to ascertain the peak resultant ball velocity of each kicking trial. Kicking motions were time-normalised between the instances of support foot touchdown (SFTD) (0%) and ball contact (BC) (100%) and key events and phases defined as shown in Figure 3. For discrete measures, the average value from each participant's 10 trials were used calculate a group mean per condition. Whereas time-series data from all trials per participant were included to calculate a mean curve per condition. Thus, data are expressed as mean ± SD per condition.

****Figures 2 and 3 near here****

Statistical Analyses

To assess if the intervention process had successfully refined kicking technique two-tailed paired *t*-tests were conducted using SPSS (v20; SPSS Inc., Chicago, IL). These compared the peak ball velocities and vertical (Z axis) displacements of the kicking hip joint centre from support hip low (SHLOW) to ball contact (BC) between the two kicking conditions. Overall alpha was Bonferroni adjusted to $\alpha = 0.025$ and effect sizes were calculated using Cohen's *d* (Cohen, 1988). To compare the time-normalised kinematic and kinetic waveforms, Statistical Parametric Mapping (SPM) was conducted using freely available source code (SPM1D v0.1, (Pataky, 2012)) in Python (Python v2.7.2; Enthought Python Distribution, Austin, USA). SPM allows for quantitative evaluation of differences across the entire kicking motion rather than at pre-selected discrete instances and removes the bias of analysing one-dimensional data using zero-dimensional (discrete) techniques (Pataky, Vanrenterghem and Robinson, 2015). First, a paired t-test statistical curve (SPM{t}) was calculated for each dependent variable (Robinson, Donnelly, Tsao and Vanrenterghem, 2014) across the entire kicking motion. Next, the significance of the SPM{t} supra-threshold clusters were determined topologically using random field theory (Adler and Taylor, 2009). Alpha was bonferroni adjusted to $\alpha=0.003$ to account for multiple comparisons (N=16). That is, where the SPM{t} curve exceeded the critical t-threshold at which only α% of smooth random curves would be expected to traverse, there was deemed to be a significant difference between conditions. Conceptually, a SPM paired t-test is therefore calculated and interpreted similarly to a scalar (discrete) paired t-test (Pataky, 2015).

Results

The peak ball velocities following INT (26.3 ± 2.1 m·s^{-1}) were significantly faster ($P<0.025$) than those observed during the NORM trials (25.1 ± 1.5 m·s^{-1}). Vertical displacements of the calculated kicking leg hip joint centers from SHLOW to BC were significantly larger ($P<0.025$) in the INT trials (0.041 ± 0.012 m) than in the NORM trials (0.028 ± 0.011 m). Table 2 shows detailed results of the paired t-tests. During the NORM condition the Absorption and Reversal Phases constituted 46 ± 7% and 34 ± 7% of total kicking motion, respectively; whereas these same phases lasted 41 ± 7% and 34 ± 12% when kicks were performed with the INT technique. The Extension Phase lasted 20 ± 10% during NORM compared to 25 ± 7% in the INT condition.

****Table 2 near here****

Support Leg

Figures 4 and 5 illustrate support leg joint profiles from the two conditions and subsequent statistical results. In the period immediately preceding ball contact (99%-100% of kicking motion) the support knee was extending significantly faster ($P<0.003$) during the INT trials. The support knee moment observed during the period that corresponded with peak extension (12-17%) was significantly larger during the INT condition ($P<0.003$). Similarly, compressive reaction forces at the support knee were significantly larger in the INT condition at 12-17%, 25-29% and from 49-100% of total kicking motion ($P<0.003$). No significant differences in support knee power, or support hip extension angular velocity were observed ($P>0.003$). However, support hip extension moment and compressive reaction forces were significantly larger between 12-17% and 10-16% of kicking motion during the INT trials, respectively ($P<0.003$). Finally, support hip compressive reaction force was also significantly larger (43-100%, $P<0.003$) and significantly more power was generated throughout the Reversal and Extension during the INT condition (52-100%, $P<0.003$).

Kicking Leg

Figures 6 and 7 illustrate kicking leg joint profiles from the two conditions and subsequent statistical results. Kicking hip flexion moment during the initial period of the Reversal Phase (45-60%) was significantly greater in the NORM condition ($P<0.003$). Kicking hip tensile reaction force was significantly larger between 10-96% of total kicking motion when performed with the INT technique ($P<0.003$). As the kicking motion progressed the kicking hip generated less power, and power absorption was noted in both conditions in the period immediately preceding BC (90-100% of kicking motion). During the latter part of the Reversal Phase and entire Extension

Phase until BC (70-100%), the knee was extending at a significantly faster rate when kicks were performed with the INT technique (*P*<0.003). After the kicking knee moment reversed at around 70% of total kicking motion the INT technique elicited a significantly larger flexion moment between 74-92% of the movement (*P*<0.003). Similarly, a significantly larger tensile reaction force was seen when the kicks were performed with the INT technique from 70% of motion to BC (*P*<0.003). Further, an expeditious increase in power absorption at the kicking knee is seen during the Extension Phase and power absorption is significantly larger when kicks are performed with the INT (72-93%) (*P*<0.003).

****Figures 4,5,6,7 near here****

Discussion

Effectiveness of Technique Intervention

Kicking performance was enhanced following the Technique Refinement Intervention since peak ball velocities and kicking knee angular extension velocities at BC were significantly faster during the INT condition. Furthermore, the Intervention successfully elicited significantly greater extension of the support leg knee and vertical displacement of the kicking hip joint during the kicking stride. As a robust relationship exists between ball velocity and the linear and angular velocities of the kicking foot at BC, it is widely considered that maximising these two variables is integral to performance of the maximal instep kick (DeWitt & Hinrichs, 2012; Kellis & Katis, 2007; Nunome, Ikegami *et al.* 2006; Levanon & Dapena, 1998). Further, since the kicking ankle is forced into plantar-flexion during foot-ball impact (Nunome, Lake *et* *al.*, 2006) the knee is considered the most distal joint which can facilitate faster foot velocities at BC. However, a key caveat of this relationship is that ball velocity is also dependent on the quality of foot-ball impact (Andersen *et al.*, 1999; Nunome, Lake *et al.* 2006); thus increasing foot velocity at BC is not wholly indicative of performance. Indeed, re-organisation of movement patterns can often lead to performance decrements due to ‘collapse’ of technique (Carson and Collins, 2011; MacPherson, Collins & Obhi, 2009). Had this been the case within the relatively short intervention period we speculate that it is likely foot-ball impact quality may have reduced, leading to a decrement in peak ball velocity. Conversely, we argue that because the alterations made to support leg action during the intervention process were subtle, the participants were able to produce significantly faster kicking knee extension velocities during the INT condition without compromising the dynamic stability and precise foot-ball impact mechanics needed for a successful kick (Lees *et al.*, 2009). Ultimately, the increase in kicking knee velocity observed at BC following intervention accounted for the concurrent increase in ball velocity; and as such out hypothesis that kicking performance would be improved was confirmed.

Contribution of Support Leg to Performance

The greater support leg hip and knee extension in the final Extension Phase of the kicking stride during the INT condition served to lift the support leg hip vertically and promote the downward (extension) velocity of the knee towards the ball. Previous studies have highlighted that the motion dependent extension moment at the kicking knee due to vertical hip displacement as described by Putnam (1991) is greater when support leg hip vertical acceleration is larger (Inoue *et al.*, 2014; Nunome & Ikegami, 2005). However, neither study reported kicking leg kinematic data to support the conclusion that this mechanism directly influences leg swing speed. In the present study the instance of support knee extension (EXT) and power generation was coupled with the kicking knee's increase in power absorption, tensile reaction force and extension angular velocity through to BC; indicating that the kicking shank and foot was being accelerated passively about the knee towards the ball. Further, the kicking knee was showing a larger flexion moment during the Extension Phase of the INT trials which commonly occurs to protect the kicking knee joint as it is prepared for contact (Kellis & Katis, 2007; Lees *et al.*, 2009). A backwards (flexion) moment also supports the notion that the shank cannot be accelerated via muscular forces during the Extension Phase and the speeds of the kicking knee at BC certainly exceed the inherent force-velocity capabilities of the musculature (Nunome, Ikegami *et al.*, 2006). As such, the motion-dependent interaction between the kicking thigh and shank has been identified as the dominant action by which the shank is passively accelerated during the downswing (Dorge *et al.*, 2002; Nunome, Ikegami *et al*., 2006). We argue however that it is not sufficient to illustrate the dynamics of maximal kicking performance using data from the kicking leg only, since kinetic sources originating from support leg action directly contribute to shank angular velocity during the Extension Phase. That is, when kicks were performed following the INT passive contribution to shank acceleration was exacerbated since kicking knee power absorption, tensile reaction forces and extension angular velocities were significantly larger throughout most of the Extension Phase. Thus the assumptions made previously regarding the relationship between vertical hip acceleration and passive acceleration of the shank before BC (Inoue *et al.*, 2014; Nunome & Ikegami, 2005) are confirmed. However, because the pronounced passive contribution to kicking shank extension during the INT condition begins before EXT and support knee extension velocity is only faster for a brief period before BC other kinetic sources originating from the support leg may also influence kicking leg velocity during the downswing.

The ability of the support leg knee and hip contribute to performance during the final Extension Phase might originate from the dynamics that occurred during the preceding phases. It is well established that the support knee joint is forced into flexion following SFTD to dissipate ground reaction forces (GRFs) and a large counteracting (extension) knee moment resists this flexion to ensure the body is kept stable through the movement (Inoue *et al.*, 2014; Lees *et al.*, 2009). This large extension moment is replicated in the current study irrespective of condition; but following INT, participants exhibited significantly larger peak moments and compressive reaction forces at the support knee and hip during the Reversal Phase. This suggests that participants were actively contracting the support knee extensor musculature to resist knee flexion following SFTD and thus performed the movement with a more rigid support leg (Inoue *et al.*, 2014). One benefit of actively resisting flexion may be that the support leg is able to reverse from power absorption to generation sooner in the kicking motion, maximising its potential to extend and contribute to performance in the latter phases of the kick. Indeed, the Absorption Phase duration was shorter during the INT compared to the NORM condition and the final Extension Phase was longer when performed with the INT condition.

Another benefit of actively resisting flexion following SFTD may be to minimise negative work and power absorption at the support knee to promote transfer of power through the support leg in a distal to proximal direction (i.e. from the ground to the support hip and pelvis). Indeed, compressive reaction forces at the support hip and knee were significantly larger during the INT trials for the duration of the Reversal and Extension Phases and the support hip was able to generate significantly more power during these phases following the INT. Inoue *et al.* (2014) previously noted that horizontal deceleration of the support leg hip and a large joint reaction force at the support hip following SFTD prompted the counter clockwise rotation of the pelvis about the support leg that precedes the proximal-to-distal sequencing of the kicking leg (Dorge *et al.,* 2002; Nunome, Ikegami *et al.,* 2006). However, despite presenting a more precise illustration of the dynamics interaction between the support leg and pelvis than shown here, they did not attempt to highlight how this interaction influenced kicking leg dynamics. In the present study kicking hip tensile reaction forces were significantly larger for the majority of the kicking motion (11-97%) when performed with the INT technique suggesting that the enhanced propagation of power through the closed kinetic chain of the support leg is translated across the pelvis into the open kinetic chain of the kicking leg. Further, because the greater passive power flow and extension velocity of the kicking knee observed during the INT condition occurs before the EXT event and support knee extension is only larger during the final 2% of kicking motion, kinetic sources other than the motion dependent moment due to hip vertical acceleration (Inoue *et al.,* 2014; Nunome & Ikegami, 2005) must have been contributing to the acceleration of kicking knee, shank and foot towards BC.

The current study provides preliminary evidence for the application of Technique Refinement in skilled soccer players to enhance kicking performance, however its limitations must also be considered. First, the absence of a control (sham) training group should be noted. Had a paired group been included which received non-specific instruction during the intervention (i.e. not focussed on increasing vertical hip displacement), we could be more confident that performance improvements were a result of the intervention process and the mechanisms presented rather than learning effects. Second, only the immediate effect of the INT was measured thus further study is needed to examine its longitudinal applications. Specifically, the present data provides preliminary support for use of the ‘Awareness’ and ‘Adjustment’ aspects of the Five-A Model (Carson & Collins, 2011) for technical refinement of kicking but it is not known whether subsequent ‘Automation’ and ‘Assurance’ aspects can be incorporated as part of a more extensive intervention process. Finally, due to the experimental nature of the study no accuracy or situational constraints (e.g. moving ball, opposing players) were introduced to the kicking task. Thus the findings are currently limited to ‘set-piece’ situations where production of a fast ball velocity is the main goal of the kick.

Conclusions

Preliminary evidence is presented to suggest that maximal instep kick technique can be refined through coaching interventions to elicit enhanced performance (i.e. faster ball velocity). Greater active contraction and extension of the support leg musculature during the kicking stride may facilitate power flow across the pelvis and passive acceleration of the lower leg to maximise foot linear and angular velocities at ball impact. This knowledge might influence coaching practices by: a) providing a basis from which to generate effective kicking interventions and b) highlighting the benefits of strengthening the support leg when training to improve kicking performance. Further, since support leg action can alter lower limb dynamics during kicking and contribute significantly to performance, it is not sufficient to illustrate the dynamics of maximal kicking using data obtained exclusively from the kicking leg.

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Tables and Captions

Table 1. Detailed overview of procedures and techniques implemented during the Technique Refinement Intervention.

Awareness Phase	
Procedure	**Techniques used (from Carson and Collins, 2011)**

1. Provided a brief overview and participants informed study aimed to refine their kicking technique. 2. Showed video clips of elite performers using the desired technique. Emphasis placed on a long final kicking stride and low to high translation of centre of mass and momentum throughout the kicking stride and follow through, resulting in both feet leaving the ground. 3. Visual 3D animation from a previous performer using the desired technique (same level of experience as participant) used to further highlight these points and for slow motion example. 4. Global kicking cue presented: **‘Approach the ball with increasing step length, displace your body weight from low to high during the kicking stride, strike the ball as forcefully as possible and follow through fully, leaving the ground and landing again on the kicking leg’**	• Contrast/Awareness drills. • Mental and physical contrast of the current followed by new technique, aided by video. • Introduction of a holistic rhythm-based cue. • Continuous discussion with investigators as to the solution for new technique.
Adjustment Phase	
Procedure	**Techniques used (from Carson and Collins, 2011)**
1. Participant begins to practice and discover the refined technique. 2. Verbal feedback provided ad hoc by researcher in relation to cues. 3. Qualitative feedback provided using Casio Exilim® Digital camera (210Hz) and Quintic Biomechanics (v21 Quintic Consultancy Ltd, Sutton Coldfield, UK) to allow participant to further refine technique. 4. Participant self-rates each practice kick (1 being poorest and 10 being perfect) on three questions: a) How well do you think you produced the best possible ball contact? b) How well do you think you performed co-ordinated kicking motion? c) How well do you think you performed the kick in relation to ‘cues’ given beforehand? 5. When participant was consistently scoring >8 on all three questions for 5 consecutive practice kicks and the researcher was confident the desired changes had been made successfully, the participant proceeded to perform the 10 intervention trials.	• Contrast/awareness drills (NORM vs. INT). • Investigator and video feedback. • Confirmatory video analysis. • Self-rating scale for performance of new technique.

Table 2. Paired *t*-test results comparing discrete measures of performance between the NORM and INT conditions.

	p- Value	Mean Difference	Effect Size (Cohen’s *d* **)	95% Confidence Interval	
				Lower	Upper

Peak Ball Velocity ($m \cdot s^{-1}$)	*p* <0.001*	1.2 $m \cdot s^{-1}$	0.58	0.7 $m \cdot s^{-1}$	1.7 $m \cdot s^{-1}$
Vertical Displacement of Kicking Hip Joint Centre (m)	*p* <0.001*	0.012 m	0.89	0.009 m	0.015 m

* Denotes significant difference between INT and NORM conditions, *P*<0.025.
** *d* = 0.2 – 0.5, small effect. d= 0.5- 0.8, medium effect. d>0.8, large effect.

Figure Captions

Figure 1. Reflective marker placements. The trochanter, femoral epicondyle, malleoli and kicking foot 2^{nd} metatarsal markers were removed following static calibration.

Figure 2. Definition of lab and joint co-ordinate systems. At each joint Z = interval/ external rotation, Y= abduction/ adduction and X = flexion/ extension.

Figure 3. Definition of kicking motion key events and phases. Support foot touchdown (SFTD) was the instance the force plate began to measure a vertical force (25 N threshold), support hip joint low (SHLOW) the instance the calculated support hip joint centre was at its lowest displacement in the global Z (vertical) plane, support knee extension (EXT) the instance the support leg knee began to exhibit an extension angular velocity and ball contact (BC) was one frame before the ball markers showed a clear onset of forward movement. Subsequently, Absorption Phase occurred between SFTD and SHLOW, Reversal Phase between SHLOW and EXT and Extension Phase between EXT and BC.

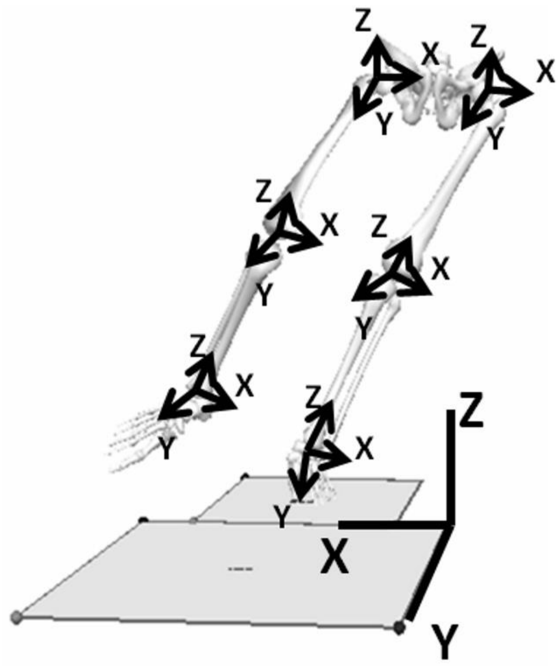
Figure 4. Mean ± SD support knee joint angular velocities (a), moments (b), reaction forces (c) and powers (d) observed during the NORM (bold) and INT (dashed) conditions between SFTD (0%) and BC (100%). Below each joint parameter curve is the corresponding SPM{t} output. Shaded areas and *p*-value labels indicate SPM{t} threshold (dotted horizontal line) has been exceeded and there is a significant difference between conditions (α = 0.003). Vertical dashed lines indicate average SHLOW and EXT events across all trials. Ext = Extension, Flex = Flexion.

Figure 5. Mean ± SD support hip joint angular velocities (a), moments (b), reaction forces (c) and powers (d) observed during the NORM (bold) and INT (dashed) conditions between SFTD (0%) and BC (100%). Below each joint parameter curve is the corresponding SPM{t} output. Shaded areas and *p*-value labels indicate SPM{t} threshold (dotted horizontal line) has been exceeded and there is a significant

difference between conditions (α = 0.003). Vertical dashed lines indicate average SHLOW and EXT events across all trials. Ext = Extension, Flex = Flexion.

Figure 6. Mean ± SD kicking hip joint angular velocities (a), moments (b), reaction forces (c) and powers (d) observed during the NORM (bold) and INT (dashed) conditions between SFTD (0%) and BC (100%). Below each joint parameter curve is the corresponding SPM{*t*} output. Shaded areas and *p*-value labels indicate SPM{*t}* threshold (dotted horizontal line) has been exceeded and there is a significant difference between conditions (α = 0.003). Vertical dashed lines indicate average SHLOW and EXT events across all trials. Ext = Extension, Flex = Flexion.

Figure 7. Mean ± SD kicking knee joint angular velocities (a), moments (b), reaction forces (c) and powers (d) observed during the NORM (bold) and INT (dashed) conditions between SFTD (0%) and BC (100%). Below each joint parameter curve is the corresponding SPM{*t*} output. Shaded areas and *p*-value labels indicate SPM{*t}* threshold (dotted horizontal line) has been exceeded and there is a significant difference between conditions (α = 0.003). Vertical dashed lines indicate average SHLOW and EXT events across all trials. Ext = Extension, Flex = Flexion.


Z
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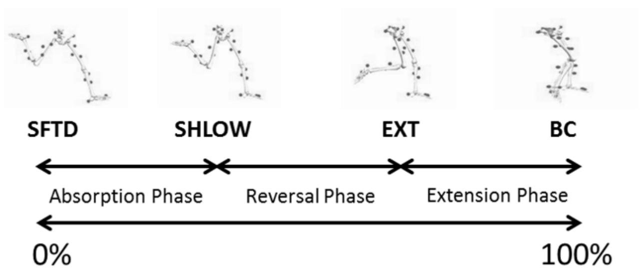
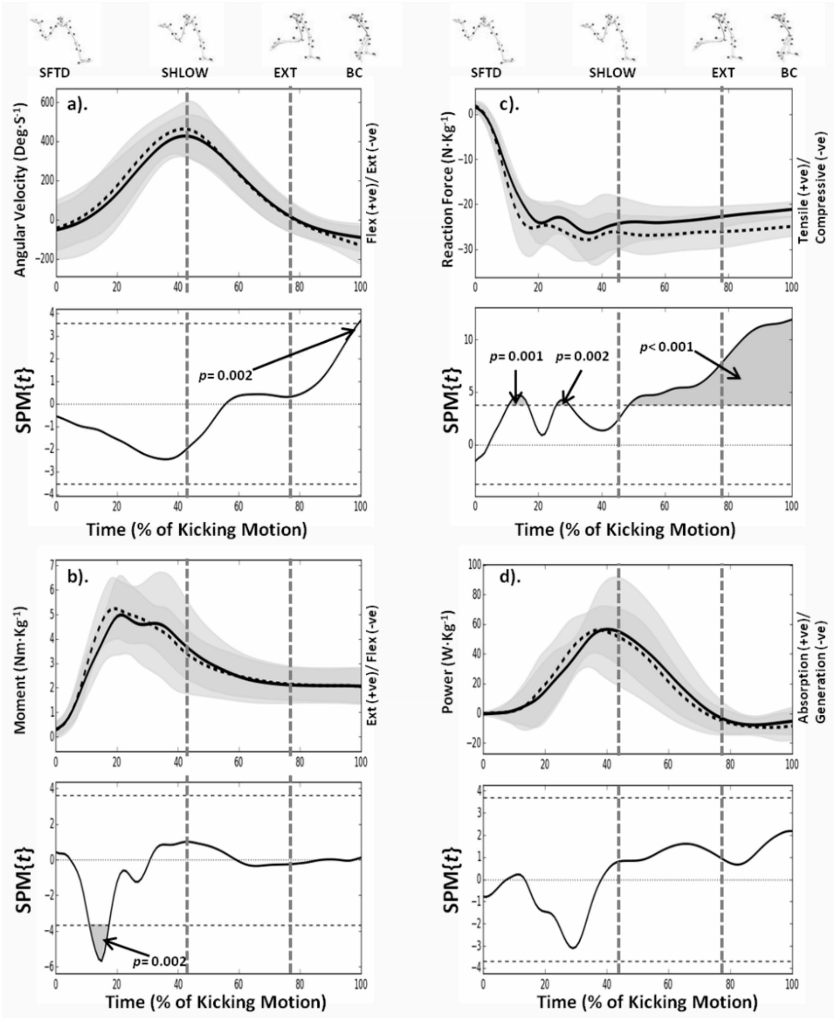
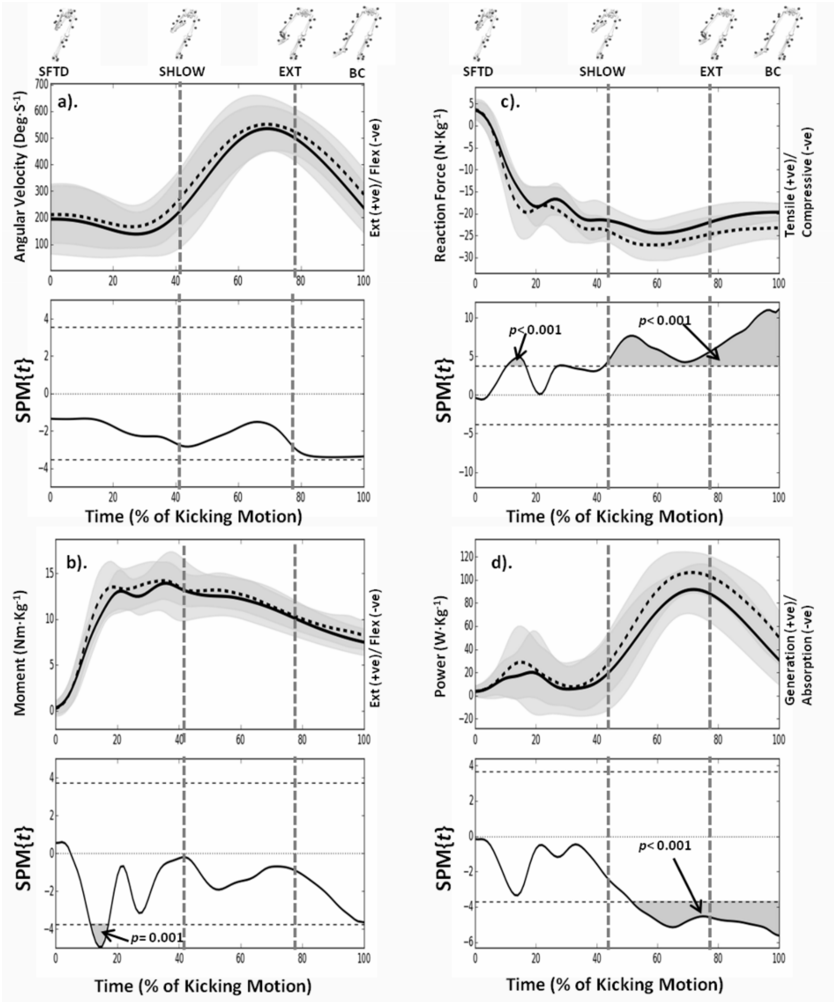
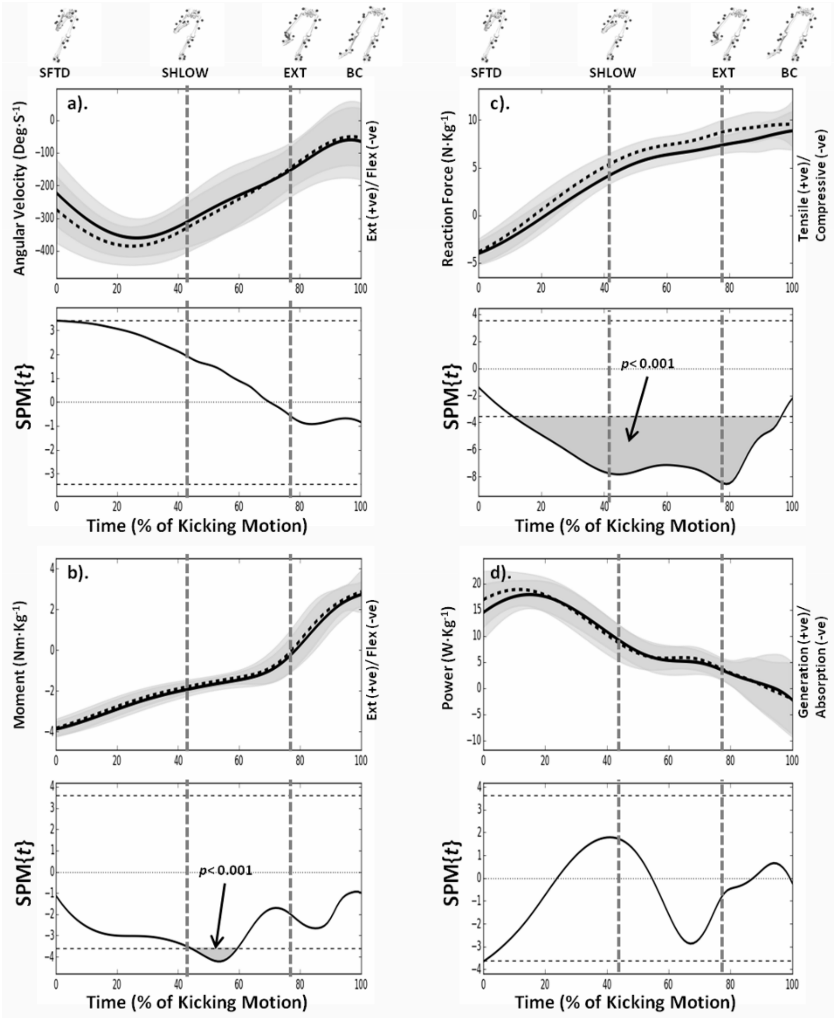
Y


SFTD
SHLOW
EXT
BC
Absorption Phase
Reversal Phase
Extension Phase
0%
100%

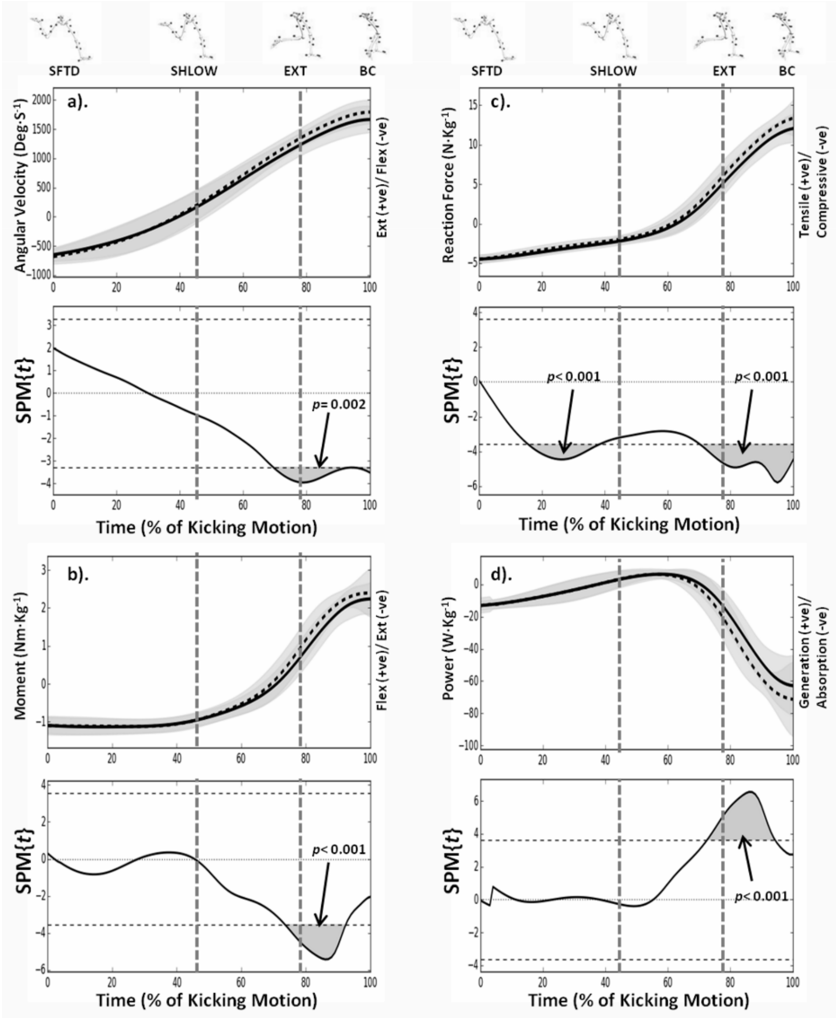

SFTD
SHLOW
EXT
BC
a).
Angular Velocity (Deg·S-1)
Flex (+ve)/ Ext (-ve)
SPM{t}
p = 0.002
Time (% of Kicking Motion)
b).
Moment (Nm·Kg-1)
Ext (+ve)/ Flex (-ve)
SPM{t}
p = 0.002
Time (% of Kicking Motion)
c).
Reaction Force (N·Kg-1)
Tensile (+ve)/ Compressive (-ve)
SPM{t}
p = 0.001
p = 0.002
p < 0.001
Time (% of Kicking Motion)
d).
Power (W·Kg-1)
Absorption (+ve)/ Generation (-ve)
SPM{t}
Time (% of Kicking Motion)


SFTD
SHLOW
EXT
BC
a).
Angular Velocity (Deg·S⁻¹)
Ext (+ve)/ Flex (-ve)
SPM{t}
Time (% of Kicking Motion)
b).
Moment (Nm·Kg⁻¹)
Ext (+ve)/ Flex (-ve)
SPM{t}
p= 0.001
Time (% of Kicking Motion)
c).
Reaction Force (N·Kg⁻¹)
Tensile (+ve)/
Compressive (-ve)
SPM{t}
p< 0.001
p< 0.001
Time (% of Kicking Motion)
d).
Power (W·Kg⁻¹)
Generation (+ve)/
Absorption (-ve)
SPM{t}
p< 0.001
Time (% of Kicking Motion)



SFTD
SHLOW
EXT
BC
a).
Angular Velocity (Deg·S⁻¹)
Ext (+ve)/ Flex (-ve)
c).
Reaction Force (N·Kg⁻¹)
Tensile (+ve)/ Compressive (-ve)
SPM{t}
p< 0.001
Time (% of Kicking Motion)
b).
Moment (Nm·Kg⁻¹)
Ext (+ve)/ Flex (-ve)
d).
Power (W·Kg⁻¹)
Generation (+ve)/ Absorption (-ve)

596



SFTD
SHLOW
EXT
BC
a).
Angular Velocity (Deg·S-1)
Ext (+ve)/ Flex (-ve)
SPM{t}
p= 0.002
Time (% of Kicking Motion)
b).
Moment (Nm·Kg-1)
Flex (+ve)/ Ext (-ve)
p< 0.001
c).
Reaction Force (N·Kg-1)
Tensile (+ve)/ Compressive (-ve)
p< 0.001
p< 0.001
d).
Power (W·Kg-1)
Generation (+ve)/ Absorption (-ve)
p< 0.001