THE EFFECT OF ACCURACY CONSTRAINTS ON LOWER LIMB JOINT CONTRIBUTIONS DURING THE INSTEP SOCCER KICK

David E. Lunn[1] and Iain Spears[2]

Leeds Beckett University, Carnegie School of Sport, Leeds, UK[1]
Newcastle University, Population Health Sciences Institute, Newcastle, UK[2]

The aim of this study was to quantify the effect of accuracy constraints on the kinematics of the soccer instep kick with specific reference to the relative contributions of the segments of the kicking leg. Eight university level soccer players were recruited into the study. Targets of three sizes were positioned and upon a verbal cue the subjects kicked the ball towards the requested target. For each, successful, kick the lower limb 3-dimensional kinematics and relative joint contributions in the local flexion-extension plane immediately prior to impact were recorded. We found foot speeds decreased significantly for the smaller targets. Soccer kicks between the no target and small target significantly increased the contribution of the ankle joint by 24%. This was at the expense of decreases in both the knee (10%) and hip (14%) contributions. Incorporating targets in soccer kicking affects the proximal to distal transition and relative joint contributions of the lower limb.

KEYWORDS: instep kick, soccer, speed-accuracy trade-off, joint contribution, kinematics

INTRODUCTION: One of the most used kicks in soccer is the instep kick and is normally used for the generation of fast ball speeds. It has been described as a planar quasi whip-like motion of the leg in which the ball is struck with the medial-superior portion of the foot (Barfield *et al,* 2002). The biomechanics of the soccer kick has been analysed extensively from the perspective of performance enhancement (Lees and Nolan, 1998; Katis *et al*, 2012) and injury prevention (Tol *et al,* 2002). To date, most research has focused on the maximal power instep kick, yet in the game, where the ball is required to travel in a specific direction, the sub-maximal power instep kick is more often used. Despite its importance in the game, biomechanical analyses of the sub-maximal kick are rare. Lees and Nolan (2001) found an inverse relationship between accuracy demands and kick speed. Nunome *et al* (2018) identified reduction in joint activity during reduced kicking speeds and subjects controlled leg speed in a proximal to distal segmental sequential system and adjusted ball velocity by changing the position of impact on the ball.

The soccer kick is a complex sequence of segmental movements with the goal being to transfer joint rotations into optimum velocities to the foot and hence the ball. Controlling these degrees of freedom takes practice and can increase maximum foot speed (Anderson and Sideway, 1998). It is established in the literature that the soccer kick is made up of relative contributions of the lower limb joints, there has been little research on the contribution of the individual joints during the kick. The calculation of relative joint contributions has proved to be useful tool in the analysis of different sports and activities (Tillaar and Ettema, 2004). Notably, the technique enables to reduce the data into manageable figures and assess the specific cause of overall kinematic differences (Riemann *et al,* 2003). Despite the abundance of studies on the soccer kick, the relative joint contributions of the soccer kick under varying accuracy constraints has yet to be performed. The aim of this study is to quantify the relative contributions of the lower limb joints when kicking a soccer ball at different-sized targets.

METHODS: Eight University level male soccer players were recruited to take part in the study; age-21 years (mean) ±0.9 (S.D); weight- 78.7kg ±8.5; height-178.6cm ±4.9; and footedness-right. The experimental procedure was passed by local University Ethics Committee. The subjects completed a warm-up (Kellis *et* al., 2004) and familiarization session (Tol *et al* 2002) prior to data collection. A standard size 5 soccer ball was positioned in the middle of the calibrated volume. The distance between the ball and targets was 11m (e.g. Lees and Nolan, 2001) replicating the distance from the goal during a penalty kick. Since the optimal angle of approach is likely to vary depending on the speed of the kick (Kellis *et al*, 2004) and thus the random target size, subjects were allowed to self-select their approach angle. One of four targets were randomly assigned, the target sizes follow a similar pattern to that described in Lees and Nolan (2001) who used a target of 1.0m^2, and a maximal power kick. A greater number of targets was used. These targets were; No Target (NT- maximal power), Large Target (LT- 6.8m^2), Medium Target (MT- 1.75m^2) and Small Target (ST- 0.6m^2). The target size was decreased by a factor of 3 from the largest to the smallest. If the ball hit the target the kick was deemed successful and the kinematic data from that kick were analysed further.

A five-camera VICON motion capture system (VICON Motion Systems, Oxford Metrics Ltd, Oxford, England) was used to track 14mm markers at a rate of 100Hz .Passive markers were placed on the participants in accordance to Plug-in-gait lower extremity model, for reducing interaction between the second metatarsal marker and the ball, soft markers were used (Shan, 2005). The raw kinematic data was processed in Vicon Nexus and was filtered using a low pass Butterworth filter with a cut-off frequency of 12Hz (Katis et al, 2015). Statistical analyses were conducted using Microsoft Excel and SPSS for Microsoft (version 11.5; SPSS, Inc., Chicago, IL). Three successful kicks on each target were chosen for analysis. In order to calculate the relative contribution of each joint in the lower extremity to the end foot speed a similar model to that described by Putnam (1991) and Tillaar and Ettema (2004) was adopted.

(wh x Rh) + (wk x Rk) + (wa x Ra) = foot speed

Where wh, wk and wa represent angular velocity (rads per second) in the local flexion-extension plane for the hip, knee and ankle respectively. Rh, Rk and Ra represent the distance from the impact zone of the foot to the joint centres of the hip, knee and ankle, respectively. The maximum power kick (NT) was used as a baseline measure and relative joint contribution of the hip, knee and ankle were calculated for the different conditions. Means and standard deviations were calculated for the eight participants and a one-way ANOVA was conducted followed by a post-hoc paired samples t-test with Bonferroni correction.

RESULTS: Angular velocity for the hip, knee and ankle, at the point of impact, were significantly different between all accuracy constraints (Table 1). Relative contribution of the hip for NT, LT, MT and ST was 33% ± 0% (mean ± S.D), 33% ± 15.6%, 28%± 16.3% and 19%± 8.3%, respectively. The difference between NT and ST was found to be significant (p<0.05). Similarly, the relative contribution of the knee decreased with target size reduction. Specifically, the contribution of the knee for NT, LT, MT and ST was 33%± 0% (mean ± S.D), 36%± 9.6%, 22%± 14.2% and 23% ± 11.1%, respectively. Significant differences (p<0.05) were found between the NT and the MT/ST conditions. In contrast, the relative contributions of the ankle increased with target size reduction. Specifically, ankle contribution NT, LT, MT and ST was 33% ± 0.0% (mean ± S.D), 31% ± 19.9%, 50%± 28.5% and 58%± 22.3%, respectively. Again, this change was found to be significant (p<0.05) between NT-MT and NT-ST conditions (Figure 1). Mean foot speeds for NT, LT, MT and ST were 15.0m/s ± 1.0, 14.3m/s ± 0.9, 14.0m/s ± 0.8 and 13.4m/s ± 1.1 respectively. All reductions in foot speed from the NT to the target conditions were found to be significant (p<0.05) (Figure 1).

Table 1. Mean and standard deviations of eight subjects at impact for angular velocities in the lower extremities.

Kick Condition		No Target		Large Target		Medium Target		Small Target	
		mean	±S.D	mean	±S.D	mean	±S.D	mean	±S.D
Angular	Hip	1.7*	±0.9	1.7	±0.7	1.5*	±0.8	1.8*	±1.0
Velocity	Knee	10.8*	±3.9	9.1	±4.0	8.4*	±2.8	7.6*	±2.4
($rad.s^{-1}$)	Ankle	2.4*	±2.1	2.4	±2.3	1.9*	±1.6	2.1*	±1.4
Velocity (m/s)	Foot Speed	15.0*	±1.0	14.3*	±0.9	14.0*	±0.8	13.4*	±1.1

* denotes significance at a level of p<0.05

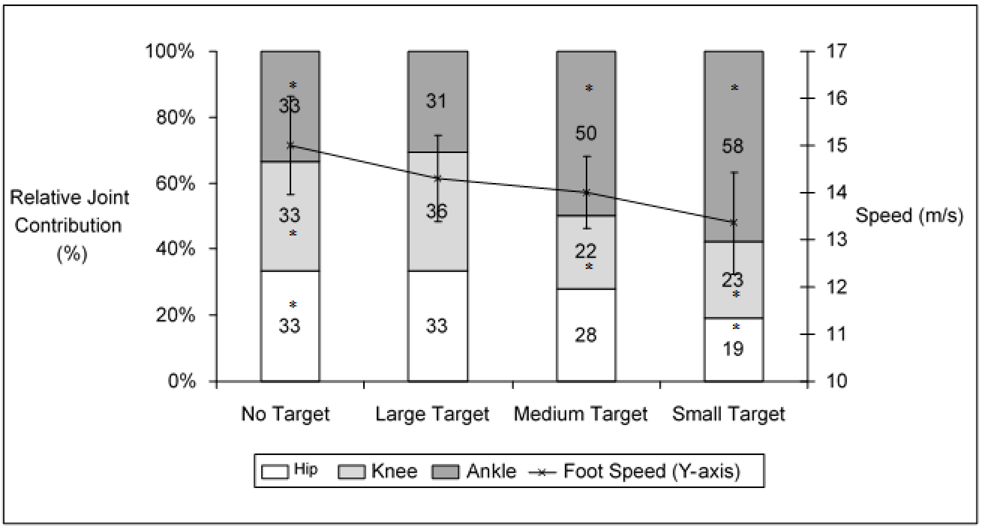

Figure 1a: Relative joint contributions expressed as a percentage of the maximum kick at impact of the ball during each condition (*significant at *p*<0.05). Mean linear speed of the centre of mass of the kicking foot at impact of the ball (standard deviation indicated by the error bars).

DISCUSSION: Our study showed there is a significant change in the relative contributions of the lower limb segments during the soccer kick when kicking under increasing accuracy constraints. Furthermore, the findings from this study confirm a well-documented speed-accuracy relationship, whereby foot speed was reduced when there was an increased demand for accuracy. It has previously been shown to occur in the soccer kick, Lees and Nolan (2001) found significant differences between foot speeds between target and non-target kicking. Our results build on this and suggest that the relationship is continuous. By reducing target size by increments of a factor of three, the foot speed decreased linearly (Figure 1). Furthermore the players in our study reduced their kicking speed to ~89% of the maximal kicking speed during the ST condition. This is in the same range, 80-90%, players were found to reduce their kicking speed by to produce the most accurate kicks in a study by Izovska *et al* (2016). Along with our findings this may suggest there is a continuous speed-accuracy trade off during the soccer kick to a certain point, but beyond that level a reduction in kicking speed does not increase accuracy. Our results do not allow us to draw this conclusion and further studies would need to be conducted to test if a threshold exists where reducing kicking speed no longer increases accuracy. A limitation of the present study is the relatively low sampling rate of 100Hz. The reader should be mindful of this when interpreting the results.

With regards to the change in joint contributions, we found an increase of 24% from the NT to the ST condition in relative contribution of the ankle, this was at the expense of reductions in the relative contributions of the hip and knee (14% and 10%, respectively). It appears the ankle is playing an increasingly important role in the instep kick at the expense of the more proximal joints as the target size, and foot-speed, is reduced. These findings are similar to those observed in other activities, badminton players (Sakurai and Ohtsuki (2000) and overarm throwers (Hore *et al,* 1996) have all been shown to rely more on the distal segments when accuracy requirements are increased. It has been argued that when targets are present the limb acts as a multi-joint structure with greater distal movement. This ensures greater degrees of freedom when impacting the object (Tseng *et* al, 2003). Our results, regarding the increased ankle contribution, support the suggestions of (Luhtanen, 1987) that the ankle is most influential in the control of impact between the foot and the ball. To our knowledge this is the first time relative joint contribution of the lower limb segments has been considered under different accuracy constraints. Our results build on the findings documented by Nunome *et al* (2018) where it was found that adjustments are made in all segments, proximal and distal, in response to different accuracy constraints. It is unclear why these changes occur; however, it is possible the changes in contribution from the ankle is a protective mechanism during the higher velocity kicks. For example, the higher forces at the instant of impact during maximal kicking speed has been shown to momentarily force the ankle into hyper plantar flexion; a mechanism believed to contribute to the development of footballer's ankle. From this perspective the reduced contribution of the ankle at the higher kicking speeds may be to ensure that joint is locked at the impact stage as part of the protective mechanism against anticipated high-impact forces.

CONCLUSION: In our study subjects reduced their foot speed but increased ankle contributions to perform more accurate tasks and increased foot speed but reduced ankle contribution during less accurate tasks. We postulate that this could be to protect the ankle from injury during higher velocity kicks. If this is the case then increased strengthening of the ankle, specifically improving the isometric/concentric strength of the dorsi-flexors, by increasing the joint stiffness could enable the ankle to move through the ball at more powerful kicks. Since strength training of the proximal segments has been shown to improve power kicks (Manolopoulos *et al,* 2006), it may be that strengthening/conditioning of the distal muscles (e.g. Tibialis anterior) could have similar benefits for accuracy.

REFERENCES

Anderson, D, I., Sideway, B. (1994) Coordination changes associated with practice of a soccer kick. *Research Quarterly for Exercise and Sport,* 65(2): 93-99

Barfield, W, R., Kirkendall, D. and Yu, B. (2002) Kinematic instep kicking differences between elite female and male soccer players. *Journal of Sports Science and Medicine,* 3: 72-79.

Hore J, Watts S, Tweed D. Errors in control of joint rotations associated with inaccuracies in overarm throws. Journal of Neurophysiology. 1996; 75(3): 1013-1025.

Izovska, Jana, Tomas Maly, and Frantisek Zahalka. "Relationship between speed and accuracy of instep soccer kick." *Journal of Physical Education and Sport* 16.2 (2016): 459.

Katis, A., Giannadakis, E., Kannas, T., Amiridis, I., Kellis, E., & Lees, A. (2013). Mechanisms that influence accuracy of the soccer kick. *Journal of Electromyography and Kinesiology*, *23*(1), 125-131.

Katis, A., Kellis, E., & Lees, A. (2015). Age and gender differences in kinematics of powerful instep kicks in soccer. *Sports Biomechanics*, *14*(3), 287-299.

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

Kellis, E. and 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: 1017-1028.

Lees, A., Nolan, L.(1998)The biomechanics of soccer: A review. *Journal of Sport Sciences,* 16:211-234.

Lees, A. and Nolan, L. (2001). Three-dimensional kinematic analysis of instep kick under speed and accuracy conditions. In Science and Football IV (edited by T. Reilly, W. Spinks and A. Murphy), pp. 16–21. London: E & FN Spon

Luhtanen, P. (1987) Kinematics and kinetics of a serve on volley ball at different age levels. In Biomechanics XI-B (edited by G, de Groot, A, P,. Hallander, P, A., Huijing, G, J., Van Ingen Schenau). Amsterdam: Free University Press.

Manolopoulos E, Papadopoulos C, Kellis E. Effects of combined strength and kick coordination training on soccer kick biomechanics in amateur players. Scandinavian Journal of Medicine and Science in Sports. 2006; 16(2): 102-110.

Nunome, H., Inoue, K., Watanabe, K., Iga, T., & Akima, H. (2018). Dynamics of submaximal effort soccer instep kicking. *Journal of sports sciences*, *36*(22), 2588-2595.

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

Riemann, B,L., Myers, J,B., Lephart, S,M. (2003) Comparison of the ankle, knee, hip, and trunk corrective action show during single-leg stance on firm, foam, and multiaxial surfaces. *Archives of Physical Medicine and Rehabilitation,* 84: 90-95.

Sakurai, S., Ohtsuki, T. (2000) Muscle activity and accuracy of performance of the smash stroke in badminton with reference to skill and practice. Journal of Sports Sciences, 18(11): 901 – 914.

Van Der Tillaar, R., Ettema, G. (2004) Effect of body size and gender in overarm throwing performance . *European Journal of Applied Physiology,* 91(4): 413-418.

Tseng, Y, W., Sholz, J, P., Schoner, G., Hotchkiss, L. (2003) Effect of accuracy constraint on joint coordination during pointing movements. Experimental Brain Research, 149(3): 276-288

Tol, J, L., Slim, E. Van Souest, A, J., Van Dijk, C, N. (2002) The Relationship of the kicking Action in Soccer and Anterior Ankle Impingement Syndrome: A Biomechanical Analysis. *American Journal of Sports Medicine*, 30: 45.