

KINETIC ADJUSTMENTS OF SUBMAXIMAL SOCCER INSTEP KICKING

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We aimed to demonstrate segmental dynamics during submaximal effort of soccer instep kicking. Eight male university level soccer players volunteered. Their kicking motions at 50, 75 and 100 % effort levels were captured at 500 Hz and the resultant ball velocities were monitored simultaneously using a pair of photocells. Apparent kinetic adjustments (angular impulses due to resultant joint and interaction moments) were clearly identified in both proximal and distal segments in response to the three target effort levels, thereby supporting the interpretation that the velocity of the distal end of the leg (foot) is controlled in a context of a proximal to distal segmental sequential system. Additionally, these players tended to hit the lower, off-centre part of the ball and also hit the ball more on the medial side of the foot using a less upright foot position to meet the lowered demands.

KEYWORDS: kicking leg motion, joint moment, motion-dependent moment.

INTRODUCTION: There is a substantial number of studies that have investigated maximal soccer instep kicking (Dörge et al., 2002; Levanon & Dapena, 1998; Nunome et al., 2006a; Nunome et al., 2006b). During the course of match, however, players are more often required to control either the ball velocity or ball trajectory accuracy. In those situations, players typically execute the kicks with submaximal effort to meet the demands of the tasks. To date, little information is available for the fundamental qualities associated with kicking at various levels of effort. Although there have been a few attempts to illustrate kinematic aspects (Andersen & Dörge, 2011; Scurr & Hall, 2009) or muscle recruitment patterns of lower limb muscles (Katis et al., 2013; Scurr et al., 2011) of instep kicks for accuracy with submaximal effort, the dynamics of submaximal kicking has yet to be examined. Nunome et al. (2006b) applied the procedure of Putnam (1991) to illustrate the time-series changes of the moment due to musculature (joint moment) and motion-dependent interactions (interaction moment) during maximal instep kicking. It is expected that illustrating the segmental dynamics of the lower limb during submaximal effort kicking will provide in-depth insight as to how players adjust their kicking motion to achieve the required outcome. The purpose of the present study, therefore, was to illustrate segmental interactions of the kicking leg during submaximal effort of soccer instep kicking. We set two hypotheses 1) players will alter the joint dynamics around the distal segment and 2) the knee joint moment will play an essential role in adjusting the kicking leg swing speed.

METHODS: Eight male university level soccer players (20.4 ± 1.5 years, 172.4 ± 4.6 cm, 63.3 ± 5.2 kg, soccer experience = 13.1 ± 3.1 years) volunteered to participate in the study. The experiment protocol was approved by the Human Research Committee of a university. All participants preferred to kick the ball with their right leg, and were free from any lower limb injuries. After a warm-up, participants were asked to perform instep kicks with three effort levels, towards the centre of a small indoor soccer goal 7 m ahead. These effort levels were defined by the resultant ball velocity on an individual basis. To obtain the target ball velocity baseline (100% effort), participants were asked to perform their maximal effort kick twice before the trials. The target velocity of each effort level was determined for each individual (at 50%, 75% and 100% of their maximum ball velocity) and monitored by a pair of photocells

(aligned towards the goal with a 1 m interval). All participants repeated kicks at each effort level until three 'good' shots with $\pm 5\%$ of the target velocity with adequate centre targeting in the goal (straight forward trajectory along the floor).

Three dimensional coordinates of the kicking leg were collected at 500 Hz using a 10-camera optoelectronic motion capture system (Vicon Motion Systems, Oxford, UK). The participants wore the same type of soccer shoes for indoors although differing in size. Joint and interaction moments were computed using the procedure of Nunome et al (2006b). To exclude artefacts caused by smoothing through ball impact, the smoothing procedure defined by Nunome et al. (2006b) was also applied using a fourth-order Butterworth filter at 12.5 Hz. Initial ball velocity, foot CG velocity immediately before ball impact, ball-foot velocity ratio, angular impulses due to the moments and segmental angular velocities were calculated. One-way ANOVA with repeated measures was used for comparisons between effort levels and statistical significance was set at $P < 0.05$. Multiple comparisons using the Bonferroni adjustment were used for post-hoc testing.

Table 1: Average (\pm SD) values of the velocity of ball and foot centre of gravity (CG) and foot CG–ball velocity ratio.

Effort level	100%	75%	50%	
Ball velocity (m/s)	26.6 (1.4)	20.0 (1.1)	14.1 (0.6)	*†‡
Foot CG velocity (m/s)	18.6 (1.0)	14.8 (0.9)	11.4 (0.8)	*†‡
Foot CG–ball velocity ratio	1.43 (0.03)	1.35 (0.03)	1.24 (0.06)	*†‡

* : Significantly different between 100% and 75%

† : Significantly different between 100% and 50%

‡ : Significantly different between 75% and 50%

RESULTS AND DISCUSSION: In response to three target effort levels, apparent adjustments were clearly identified in the dynamics of both proximal and distal segments, in contrast to our hypotheses. This finding indicates that the velocity of the foot is controlled through a proximal to distal segmental sequential system.

Significant differences ($P < 0.05$) between each effort level were evident for resultant ball velocity, foot CG velocity before ball impact and the ratio between the foot CG and the resultant ball velocity (Table 1). During submaximal effort kicking, the players actually used 80.0 % and 61.5 % of maximum foot CG velocity to produce 75.3 % and 53.2% of resultant ball velocities respectively. It is worth noting how and why these apparent discrepancies of relatively higher foot CG velocities for ball velocities compared to maximal kicking existed. A post hoc analysis revealed that players tended to hit the lower, off-centre part of the ball in proportion to the reduced effort levels (100% trial = 10.53 ± 1.29 cm; 75% trial = 8.30 ± 1.06 cm; 50% trial = 7.20 ± 0.92 cm from the ground) and also hit the ball more on the medial side of the foot using a less upright foot position, thereby causing lower foot-ball velocity ratios.

Proximal (thigh) segment angular motion, characterized by a rapid transition from forward to backward rotations, systematically increased with an increase in effort levels. Among the moments acting on the segment, the hip joint moment seemed to be the main driver responsible for forward rotation motion and its forward angular impulses were systematically and significantly increased with each effort level. Interestingly, those values relative to 100 % effort, were closely matched with the values of relative foot CG velocity (80.1 vs. 80.0% at 75% of effort; 60.0 vs. 61.5 % at 50% of effort), suggesting proportional adjustments were produced by hip muscle moments. A systematic regulation also existed for the interaction moment due to the force acting on both ends of the segment and reaction knee joint moment (Table 2), thereby inducing a more drastic reduction in thigh forward angular velocities seen in higher effort levels (Figure 1).

Distal (lower leg) segment angular motion was characterized by a rapid forward rotation coinciding with a rapid decrease of thigh forward rotation, forming a typical proximal to distal sequence generally seen in soccer instep kicking (Dörge et al., 2002; Nunome et al., 2006b). Obviously, the knee joint moment is the main driver for the forward lower leg rotation.

Relative values (against 100%) of the forward angular impulse due to the knee joint moment were again closely matched with the relative foot CG velocities (80.0 vs. 80.0 % at 75% of effort; 65.6 vs. 61.5 % at 50% of effort) seen in two submaximal effort levels, suggesting proportional adjustments were also controlled by the knee joint moment as well as the hip joint moment. On the other hand, similar to the study of Nunome et al. (2006b), the interaction moment due to proximal end force was another main driver of the forward moment during the final phase of kicking. However, the adjustment of this moment was not proportional to the effort levels. Inoue et al (2014) demonstrated that the support leg action plays an important role in controlling the pelvis motion that precedes the proximal-to-distal sequence of segmental action of the kick leg. Further studies investigating kinetic adjustments on more proximal parts of body including the support leg in various effort levels of kicking are warranted.

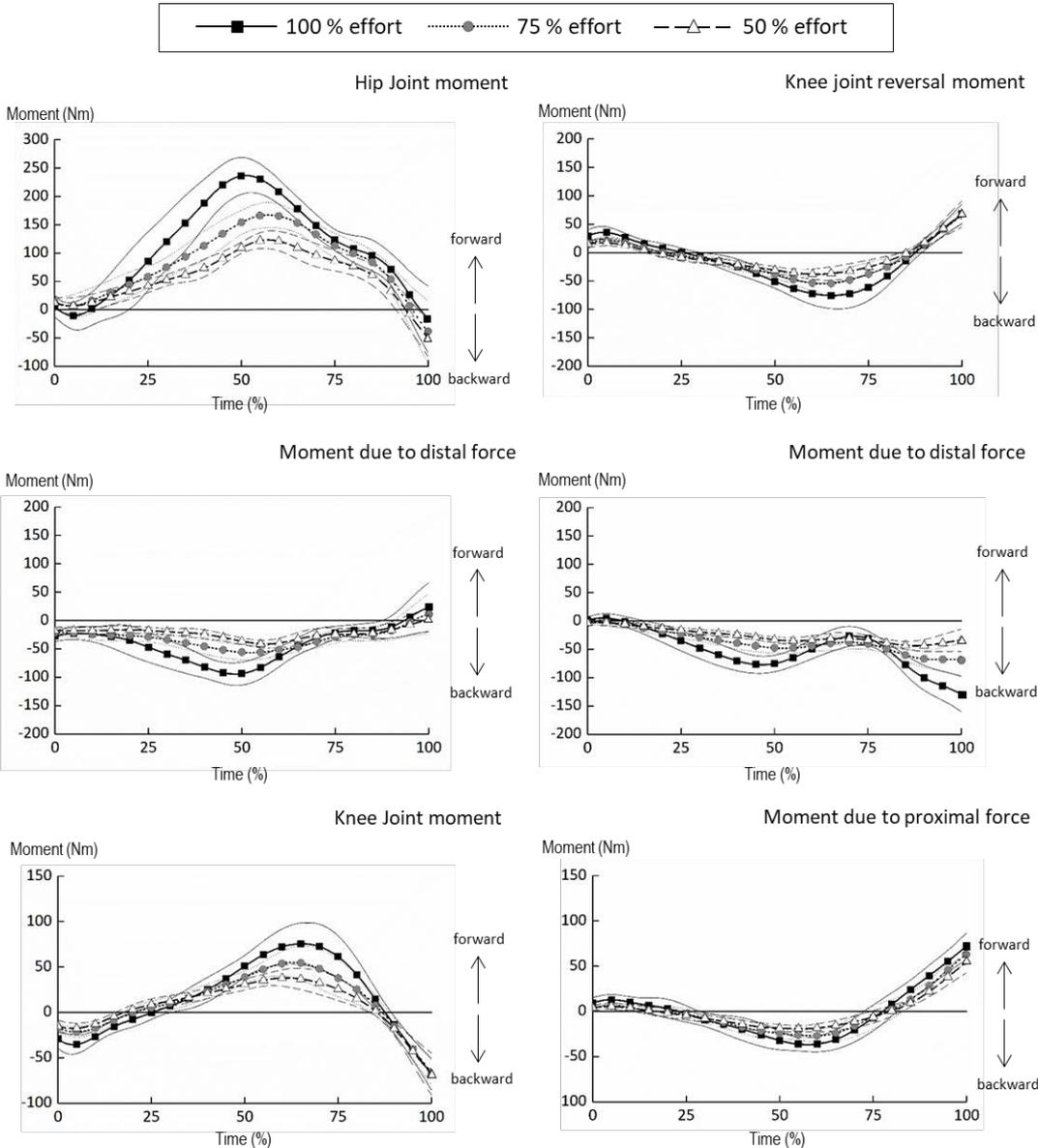


Figure 1: Average (\pm SD) changes of hip joint moment, reaction knee joint moment, motion-dependent interaction moments due to thigh proximal and distal end forces, knee joint moment and motion-dependent interaction moments due to lower leg proximal end force in three effort levels of soccer instep kicking.

Table 2: The average (\pm SD) amount of angular impulses (in Nm) due to moments acting on thigh and lower leg segments throughout kicking motion.

Effort level		100%	75%	50%	
<i>Thigh Segment</i>					
Hip joint moment	forward	27.7 (2.7)	22.0 (2.6)	16.6 (1.9)	*†‡
	backward	-0.8 (0.9)	-0.6 (1.1)	-0.7 (0.7)	
Reaction knee joint moment	forward	1.1(0.3)	1.2 (0.4)	1.4 (0.4)	
	backward	-6.4 (1.0)	-5.1 (0.9)	-4.2 (0.6)	*†‡
Interaction moment (proximal end)	forward	0.5 (0.3)	0.3 (0.4)	0.2 (0.2)	†
	backward	-10.5 (1.6)	-8.5 (1.6)	-6.4 (1.3)	*†‡
Interaction moment (distal end)	forward	0.2 (0.2)	0.0 (0.1)	0.0 (0.1)	
	backward	-12.4 (1.4)	-9.6 (1.2)	-7.2 (0.8)	*†‡
<i>Lower leg Segment</i>					
Knee joint moment	forward	6.4 (1.0)	5.1 (0.9)	4.2 (0.6)	*†‡
	backward	-1.1(0.3)	-1.2 (0.4)	-1.4 (0.4)	
Interaction moment (proximal end)	forward	2.1 (0.7)	1.7 (0.5)	1.4 (0.4)	*†
	backward	-2.9 (0.6)	-2.5 (0.4)	-2.1 (0.3)	†‡

* : Significantly different between 100% and 75%

† : Significantly different between 100% and 50%

‡ : Significantly different between 75% and 50%

CONCLUSION: We succeeded in illustrating on how segmental interactions during soccer instep kicking adjusted to submaximal demands (decreased ball velocity). In response to three target effort levels (50, 75 and 100%), systematic adjustments were demonstrated in both proximal and distal segment kinetics. Counter-clockwise (forward) hip muscle moments and clockwise (backward) interaction moments due to distal end force and reaction knee muscle moments were identified as key kinetic sources whose angular impulses are systematically adjusted during altered effort kicking. Moreover, the forward knee muscle moment was highlighted as the only kinetic source whose angular impulse is controlled in proportion to the three effort levels in lower leg angular motion.

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