THE EFFECT OF APPROACH VELOCITY ON CENTRE OF MASS MOTION AND PERFORMANCE OF THE MAXIMAL INSTEP SOCCER KICK

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The purpose of this study was to investigate the influence of approach velocity on centre of mass (CoM) motion and total body angular momentum during the maximal instep soccer kick. Four semi-professional players performed kicks at Self-Selected (SS), Fast and Slow approach speeds and full body motion was captured at 1000Hz. Dependent variables were CoM approach velocity, CoM deceleration impulse, foot velocity, ball velocity and maximum angular momentum about total body CoM. Foot and ball velocities were significantly larger in the Fast compared to Slow condition. Approach speed was strongly correlated to foot and ball velocity, whereas there was no correlation between CoM deceleration impulse and foot and ball velocities. Training soccer players to approach the ball at slightly faster velocities than their perceived optimal speeds may be beneficial for performance.

KEYWORDS: 3D motion analysis, angular momentum, energy transfer.

INTRODUCTION: The ability to produce a fast ball velocity represents a distinct advantage for a soccer player when attempting a direct shot at goal, since this gives the goalkeeper less time to react, and increases the chances of scoring. Subsequently, researchers have attempted to determine how players maximise foot and ball velocities during maximal kicking. Extensive deceleration of the the centre of mass (CoM) during the kicking stride is one mechanism that has previously been linked to performance of Soccer instep (Potthast, Heinrich, Schneider & Bruggemann, 2010) and Australian Rules punt kicking (Ball, 2011). Similarly, faster approach velocities and intensive CoM deceleration has also previously been cited as a prerequisite for generating faster release speeds in cricket bowling (Ferdinands, Marshall & Kersting, 2010). It is thought that deceleration of CoM can facilitate transfer of momentum and energy to the distal segments of the swinging limb. Specifically, Potthast et al. (2010) noted larger decelerations were associated with greater thigh angular impulses and Bezodis, Trewartha, Wilson & Irwin (2007) that angular momentum of the kicking leg augments the linear velocity of the foot at ball impact. However, the relationship between approach speed, CoM deceleration and swing limb velocities have not been established in sub-optimal kicking conditions. Since during match play a player might approach the ball at slower or faster speeds than desired (e.g. with pressure from defender), the question remains to whether this leads to performance decrements (i.e. slower foot/ ball velocities) or the player can adapt technique to maintain performance. Therefore, the purpose of this study was to investigate the influence of approach velocity on CoM motion, total body angular momentum and performance of the maximal instep soccer kick.

METHOD: Following institutional ethical approval, four semi-professional football players (Males, age: 26 ± 5 years, height: 1.82 ± 0.04m, mass 83.8 ± 10.2kg, right footed, experience > 10 years) performed 20 maximal effort instep kicks towards a target placed 3.6m away. Ten kicks were first performed with a self-selected (SS) approach speed, then five with approach speeds both greater than (Fast) and less than (Slow) self-selected. The order of Fast and Slow conditions was counterbalanced and familiarisation trials were allowed for each condition. Length and angle of approach were controlled to 2m and 45°, respectively.

Kicking motions were captured by a 10 camera motion analysis system (1000Hz, Vicon MX-40, Vicon Motion Systems, Oxford, UK) and raw marker trajectories were exported to Visual 3D (V6, C-Motion, Rockville, USA). Nine segments were incorporated into a six degrees of freedom model whereby, following static calibration, each segment was tracked via the

CAST method (Cappozo, Catani, Della Croce & Leardini, 1996). Inertial characteristics of bilateral feet, shanks and thighs were derived according to De Leva (1996) and pelvis, lumbar spine and thorax segments according to Pearsall, Reid & Livingston (1996). Raw marker trajectories were filtered with a dual pass, fourth-order Butterworth low pass filter with cut-offs between 28-34Hz. Cut-offs were determined by residual analysis and visual inspection of the data.

Six markers were applied to the ball to define its centre, and maximal resultant ball velocity (VBall) was calculated as the average of the 1st derivative of the unfiltered components obtained from the first five airborne frames. Similarly, maximal resultant kicking foot velocity (VFoot) was determined from the 1st derivative of the components of kicking foot CoM position. Approach velocity was defined as total body CoM velocity in the frame preceding support foot touchdown (SFTD) and deceleration impulse during the kicking stride as the product of body mass and change in total body CoM velocity between SFTD and ball contact (BC) (Ball, 2011; Potthast et al., 2010).

The contribution of each segment to whole body angular momentum about the total body CoM was calculated according to Bahamonde (2000). Briefly, the contribution of a segment was determined at each time point by the sum of its local and remote terms. The local term defines angular momentum of the segment about its CoM and is equal to the product of segment moment of inertia and segment angular velocity. The remote term is the product of the distance between a segment's CoM to total body CoM and the mass of the segment multiplied by translational velocity of total body CoM. Angular momentum values were calculated about three orthogonal axes passing through the total body CoM of the kicker. Positive Y pointed in the direction of intended ball travel (forwards), positive X perpendicular to this and pointing to the right and positive Z pointed vertically from the ground. Values of angular momentum were subsequently reported as clockwise or anti-clockwise about these three axes (see Figure 1).

Pearson's correlations were also used to explore correlations between variables, where alpha was Bonferroni adjusted to p = 0.008 to account for multiple comparisons. Due to the small sample size, a statistical approach was not used to examine differences between conditions. Instead, emphasis was placed on pairwise effect sizes which were determined according to Cohen (1988) (d = small > 0.2, medium >0.5 and large >0.8).

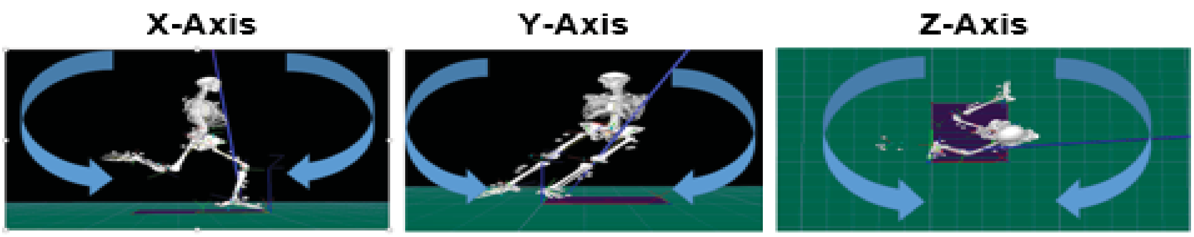

Figure 1. Reference system used for determining direction of angular momentum. Anti-clockwise = positive, Clockwise = negative.

RESULTS: Table 1 shows Mean (± SD) values of the six dependent variables, for individual participants and the overall sample. Approach velocity in the Fast condition was 110% (range 104-118%) of that of SS and Slow 80% (range 79-87%) of SS. Medium to large effect sizes were noted for all pairwise comparisons of Approach Velocity (range: d = 0.85 - 1.8), Vball (d = 0.67- 0.94) and Vfoot (d = 0.87 - 1.82). Pairwise effect sizes for deceleration impulse were medium to large between SS and Fast (d = 0.78) and very small between SS and Slow (d = 0.05). Effect sizes between pairwise comparisons for maximum angular momentum in both X and Z were very small or small (range: d = 0.18 - 0.41). Approach velocity was strongly and significantly related with both foot (r = 0.71, p<0.001) and ball velocities (r = 0.66, p<0.001). However, deceleration impulse was not correlated to foot (r = 0.03, p = 0.84) and weakly and non-significantly related to ball velocity (r = 0.29, p = 0.04).

Maximum angular momentum (Z axis) was moderately and significantly related to foot velocity (r = 0.58, p<0.001) and approach velocity (r = 0.63, p<0.001).

Table 1. Mean ± SD values for Self-Selected (SS), Fast and Slow conditions for each individual participant, and the overall sample.

	Participant 1			Participant 2			Participant 3			Participant 4			**Sample Mean**		
	SS	Fast	Slow	SS	Fast	Slow	SS	Fast	Slow	SS	Fast	Slow	**SS**	**Fast**	**Slow**
CoM approach velocity (m/s)	3.3 ± 0.2	3.6 ± 0.1	2.6 ± 0.1	3.5 ± 0.1	4.2 ± 0.0	2.9 ± 0.2	4.1 ± 0.1	4.2 ± 0.0	3.1 ± 0.1	3.0 ± 0.2	3.6 ± 0.1	2.6 ± 0.2	**3.6 ± 0.4**	**3.9 ± 0.3**	**2.8 ± 0.3**
Vball (m/s)	26.2 ± 0.8	24.5 ± 1.2	23.5 ± 1.3	25.2 ± 0.2	27.1 ± 0.3	24.6 ± 1.0	26.0 ± 0.9	28.2 ± 0.6	25.5 ± 0.1	25.4 ± 1.3	27.9 ± 1.3	23.7 ± 1.0	**25.8 ± 0.87**	**26.8 ± 1.8**	**24.4 ± 3.3**
Vfoot (m/s)	18.6 ± 0.3	17.9 ± 0.1	17.3 ± 0.5	18.0 ± 1.2	18.9 ± 0.3	16.8 ± 0.9	19.1 ± 0.4	20.4 ± 0.2	18.7 ± 0.1	16.9 ± 0.7	20.0 ± 0.1	16.9 ± 0.6	**18.4 ± 0.96**	**19.3 ± 1.1**	**17.4 ± 1.0**
CoM deceleration impulse (kg*m/s)	132 ± 7	132 ± 11	112 ± 13	125 ± 6	170 ± 12	145 ± 5	123 ± 5	123 ± 8	108 ± 2	123 ± 4	133 ± 17	112 ± 23	**123 ± 16**	**137 ± 20**	**122 ± 20**
Max ang mom X (kg*m²/s)	27.7 ± 2.0	24.9 ± 2.9	26.8 ± 2.3	39.5 ± 2.4	42.0 ± 1.2	37.0 ± 1.1	34.0 ± 1.4	31.1 ± 1.2	30.0 ± 2.0	33.0 ± 0.6	34.2 ± 0.5	32.4 ± 1.3	**33.1 ± 4.6**	**32.1 ± 6.6**	**32.0 ± 4.4**
Max ang mom Z (kg*m²/s)	23.7 ± 0.6	22.5 ± 2.2	22.1 ± 1.1	25.7 ± 1.3	27.3 ± 1.3	26.7 ± 2.9	27.5 ± 0.6	26.8 ± 1.6	25.1 ± 0.9	19.5 ± 0.4	25.9 ± 1.5	20.1 ± 2.3	**24.8 ± 2.8**	**25.4 ± 2.6**	**24.1 ± 3.6**

DISCUSSION: Small increases of approach velocity (~10%) were beneficial for generating faster foot and ball velocities during maximal instep soccer kicking. Effect sizes were large, faster approach speeds were associated with faster foot and ball velocities and three of the four participants displayed performance increases during the Fast condition. Similarly, slower approach speeds compromised foot and ball velocities. These findings oppose that of Ball (2011) who noted that slower approach speeds were associated with higher foot speeds. One possible explanation might be differences between punt and soccer instep kicking technique. In the present study approach angle was 45º, and although Ball (2011) did not specify approach angle, punt kicking tends to be performed in a more planar fashion (Ball, 2008). Thus, axial rotation of the trunk, pelvis and kicking leg about the support leg during the kicking stride may be important for generating a fast foot velocity during the downswing phase in soccer kicking. Indeed, the present study showed positive relationships between maximum angular momentum about the Z (vertical axis) and both approach speed and foot velocity. However, since small effect sizes existed for maximum angular momentum values (Z) between conditions, it is likely the profile of angular momentum is not altered with varying approach velocities. Instead, axial rotation contributed directly to the linear speed of the foot as previously suggested by Ball (2008). Furthermore, Ball (2011) previously advocated an optimal rather than maximal relationship between approach velocity and foot speeds. It is sensible to assume that large increases in approach velocity would disrupt co-ordination and energy transfer mechanisms observed in the kicking motion. In the present study the small increases in approach velocity (4-18%) meant the participants were able to maintain or enhance performance. Training soccer players to approach the ball at slightly faster velocities than their perceived optimal might therefore be beneficial for performance. However, it is currently unclear how these changes to approach speed might influence accuracy of kicks.

Surprisingly, CoM deceleration impulse was not correlated to foot and ball velocities. The values obtained in the current study do agree with the previously reported values (80-180 kg.m/s), however this finding is in direct opposition to Potthast et al. (2010) and Ball (2011) who reported that greater decelerations were associated with higher ball velocities. In the current study, three of the four participants kept the deceleration of CoM relatively constant regardless of condition, whereas one participant (P2) increased CoM deceleration in both Fast and Slow conditions. One possible explanation is that the current sample controlled CoM deceleration independent of approach velocity. Instead of increasing or decreasing deceleration impulse and total body angular momentum at Fast and Slow approach speeds, respectively, the participants were able to control CoM motion to keep these variables relatively constant (see Table 1). Such a strategy could serve to maintain optimal conversion of linear (forward) momentum to angular momentum during the kicking stride under sub-optimal approach velocities. We therefore postulate that experienced performers may regulate CoM motion to facilitate an optimal movement pattern for a given kick. However, it should be noted that Ball (2011) and Potthast et al. (2010) also used relatively small samples of experienced players, so future research with larger sample sizes is warranted to confirm the existence of such a strategy. At present it is unknown whether variables such as accuracy constraints, angle of approach and technical proficiency confound these relationships. To elucidate these complex interactions it would be beneficial to examine the energy transfer mechanisms between the trunk, pelvis, support and kicking leg in more detail.

CONCLUSION: Training soccer players to approach the ball at slightly faster velocities than their self-selected speeds (~10% increase) may be beneficial for generating faster foot and ball velocities during the maximal instep kick. However, it is unclear how these changes might influence accuracy. In opposition to the findings of Ball (2011) and Potthast et al. (2010), greater deceleration of CoM during the kicking stride was not associated with faster foot and ball velocities. Controlling CoM deceleration may be a strategy used to regulate conversion of linear to angular momentum and maintain a functional movement pattern. However, due to the small number of participants included in the present study (N=4), these findings should be considered as preliminary. Further research is warranted to confirm the existence of such a strategy.

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