HOW LOWER BODY SEGMENT ROTATIONS CONTRIBUTE TO THE UPWARD FOOT VELOCITY IN SOCCER VOLLEY KICKING

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We aimed to quantify the contribution of lower body rotations in producing upward foot velocity during soccer volley kicking. The kicking motions at various ball heights were captured from fifteen male university soccer players using an optical motion capture system at 500 Hz. The effectiveness of lower body rotations in producing upward foot centre of gravity velocity were computed (Sprigings et al., 1994) and time integrated. Major contributors to generating the upward foot CG velocity in volley kicking were 1) knee flection, 2) hip internal rotation, 3) pelvis clock-wise rotation within the frontal plane and 4) hip flection. The contributions of 1) and 4) become smaller as the ball height increased gradually, while the contributions of 2) and 3) become larger systematically.

KEYWORDS: kicking leg, joint angular motion, foot CG velocity, coaching cues

INTRODUCTION: Volley kicking, striking the ball directly in the air, is an advanced kicking technique in soccer. This kicking technique has been recognized as one of the most difficult for generating fast, accurate shots during the course of a match. The biggest feature of volley kicking is to raise the foot high according to the ball height. Recently, Sugi et al. (2016) clarified the three-dimensional joint kinematics of soccer volley kicking at various ball heights (25 cm, 50 cm and 75 cm). They succeeded in extracting several unique motions required for the volley kicking. To make a fast and straight shot of the volley kicking, it is necessary to raise the foot high to make a posture so that the rotational axis of the knee joint is approximately normal to the ball travel direction. This posture allowed players to effectively maximize the foot horizontal velocity using knee extension and squarely hitting the ball with the instep part of foot (Sugi et al., 2016). However, it is still unknown how players induced upward foot velocity during volley kicking. More recently, Sugi et al. (2017) applied the procedure of Sprigings et al. (1994) to detect the contribution of lower body segment rotations to the upward component of the velocity of foot centre of gravity (foot CG), thereby showing instantaneous trends in the contribution of each segment rotation. However, concrete values of these contributions have not been demonstrated yet. To investigate these contributions more quantitatively, an attempt was made to compute the time-integrals of upward foot CG velocity created by the lower body joint rotations.
The purpose of this study, therefore, was to quantify the contribution of the lower body segment rotations in producing upward foot CG velocity during soccer volley kicking.

METHODS: Fifteen experienced male university soccer players (age = 21.5 ± 0.9 yrs; 172.7 ± 1.6 cm; 64.7 ± 4.2 kg; career = 14.7 ± 1.4 yrs) volunteered to participate in this study. To mimic the situation of soccer volley kicking in the laboratory, the ball was set on light weight paper pipes with three different heights (25cm, 50cm and 75cm). The participants were asked to conduct a static instep kicking (0cm height) and the three types of volley kicking towards a goal (2 m x 3 m) 7 m ahead using their preferred leg, and a runway is free. Their kicking trials were captured by an 8 cameras optical motion capture system (Vicon Nexus; Vicon Motion Systems, Oxford, UK) at 500 Hz. Eight reflective markers were placed on the ball and 23 reflective markers were placed on both sides of the subject's lower body. The contributions of the pelvis and the kicking leg segment rotations in producing upward velocity of the foot CG were computed from the three-dimensional coordinate data according to the procedure of Sprigings et al. (1994). All parameters were digitally smoothed by a fourth order Butterworth filter with the cut-off frequency at 20 Hz. To quantify the contributions of lower body joint rotations to upward foot CG velocity, the upward foot CG velocity induced by each joint rotation was time-integrated using the trapezoidal rule, yielding upward displacement due to each joint rotation. This method allowed us to show that the concrete contribution value of each joint rotation to the whole kicking motion rather than some instantaneous contributions. Comparisons were made among the four height conditions using one-way ANOVA followed Bonferoni multiple comparison test. The criterion for statistical significance was set at $P < 0.05$ for all analysis.

RESULTS: Initial ball velocities of the four conditions were 0 cm (placed ball): 24.2 ± 1.5 m/s, 25 cm: 23.3 ± 1.3 m/s, 50 cm: 21.8 ± 2.2 m/s, 75 cm: 19.6 ± 2.4 m/s, respectively. Significant differences were observed between all conditions except for 0 cm vs. 25 cm.

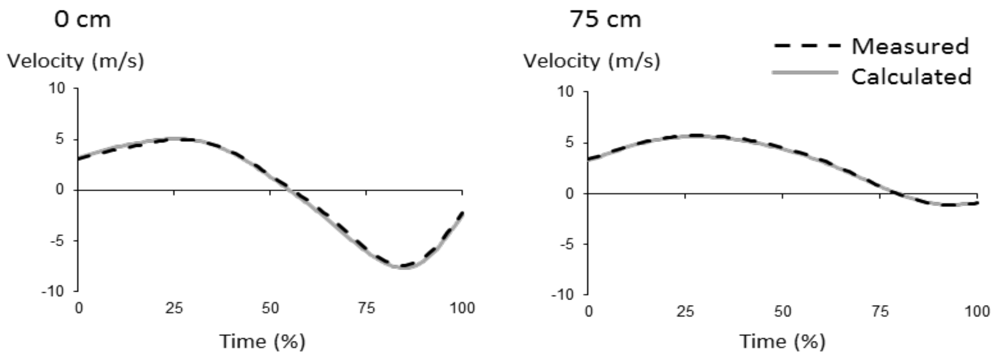

Figure 1: Comparison between the measured and calculated upward foot CG velocity. The time was normalized by the definition of Nunome et al. (2002), in which 0% and 100% of time correspond to toe-off and ball impact, respectively.

Figure 1 shows the comparison of measured and computed upward foot CG velocities of the two extreme heights (0 cm and 75 cm). Good agreements were obtained between the foot CG velocity directly measured from the coordinates and that calculated from the present procedure. Similar good agreements were also obtained in other heights. Figure 2 shows the ensemble average changes of individual contributions to the upward foot CG velocity produced by the lower limb joint motions (left panels) and the angular velocities of these joint motions (right panels). The data of 75 cm volley kicking are shown as a typical sample. Table 1 summarizes the upward displacements (mm) obtained from the time integration of major contributions (excluding those not contributing more than 10% at any height) and their relative values (%) against the whole displacement. For the pelvis and hip joint motion, the upward displacement due to the pelvis clock-wise rotation and to the hip internal rotation increased significantly as the ball height increases except for no significant difference between 50 cm and 75 cm heights. In contrast, the displacements due to the hip extension showed an opposite trend. The upward displacement due to this motion was systematically decreased as the ball height increases. There were significant differences between each height. While there were no significant differences between each height for the displacement due to the hip abduction motions. For the lower leg angular motions, the knee flection motion showed the largest displacement. The upward displacement due to this motion was systematically decreased as the ball height increases. There were significant differences between each height except no significant difference was observed between 50 cm and 75 cm heights. Regarding the relative contributions, the knee flection motion showed the largest contribution in all heights. In the place kicking, the proportion is occupying more than half of the total displacement. Although the proportion systematically decreased as the ball height increases, it is still accounted for approximately 30% of contribution in the highest kick condition (75 cm). There were clear differences in contribution next to the knee flection motion between the place and the volley conditions. The hip extension motion was the second largest contribution in the place kicking (14.4%). However, in volley kicking, this contribution becomes very small (6.0% at 25 cm height, 1.5% of 50 cm height and 0.3% of 75 cm height). In contrast, the hip internal rotation and the pelvis clock-wise rotation showed substantial contributions accounted for 15.1 to 22.5% and 14.7 to 20.9%, respectively.

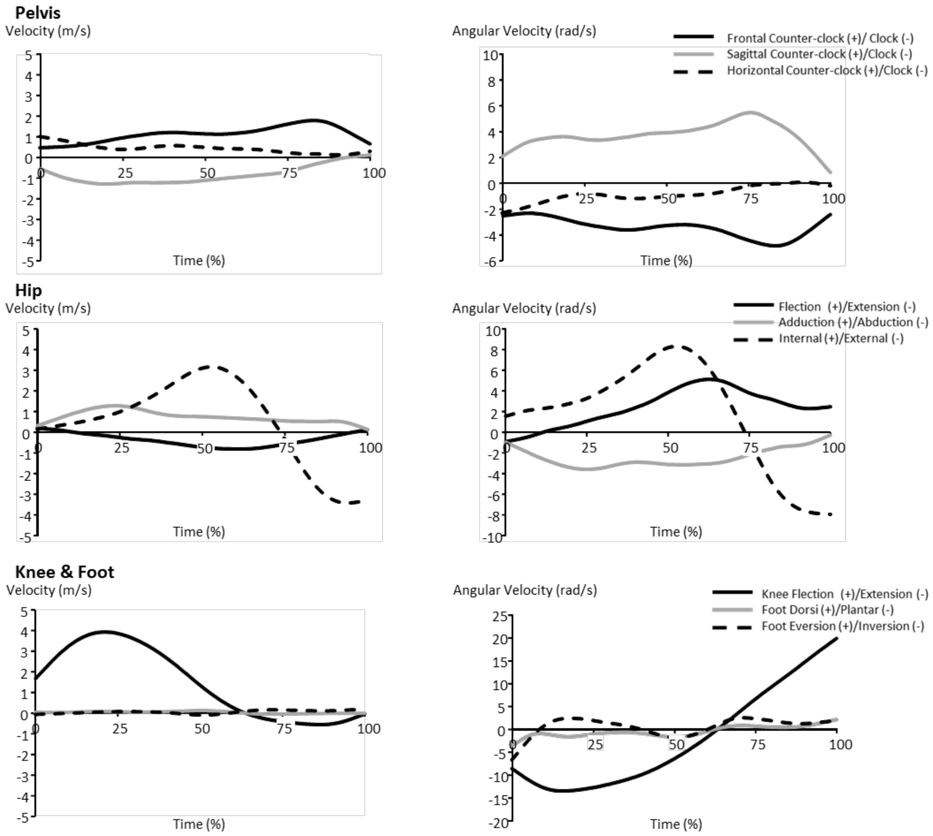

Figure 2: Ensemble average changes of individual contribution of each joint motion (left panels) and angular velocity (right panels) in volley kicking of 75 cm height.

Table 1: The displacements obtained from the time integration of individual contributions to the upward foot CG velocity and these relative contributions to the total displacements.

		0 cm	25 cm	50 cm	75 cm
Pelvis a. Frontal rot.	(mm)	65.1 ± 0.6	135.8 ± 0.8	215.0 ± 0.9	223.3 ± 0.8
Significance		0 vs 25 cm: ***	25 vs 50 cm: *	0 vs 50 cm: ***; 25 vs 75 cm: **	0 vs 75 cm: ***
	(%)	7.4 ± 0.5	14.7 ± 0.4	18.8 ± 1.2	20.9 ± 1.1
Hip b. Flection/Extension	(mm)	126.8 ± 1.3	55.9 ± 0.7	17.5 ± 0.3	3.0 ± 0.1
Significance		0 vs 25 cm: ***	25 vs 50 cm: **	50 vs 75 cm: *; 0 vs 50 cm: ***; 25 vs 75 cm: **	0 vs 75 cm: ***
	(%)	14.4 ± 0.8	6.0 ± 0.2	1.5 ± 0.2	0.3 ± 0.2
c. Adduction/Abduction	(mm)	98.7 ± 0.4	95.9 ± 0.4	147.9 ± 0.6	149.6 ± 0.5
	(%)	11.3 ± 1.0	10.4 ± 0.8	13.0 ± 0.7	14.0 ± 0.6
d. Internal/IExternal rot.	(mm)	71.2 ± 0.6	139.7 ± 0.8	256.2 ± 2.0	230.5 ± 2.0
Significance		0 vs 25 cm: **	25 vs 50 cm: **	0 vs 50 cm: **; 25 vs 75 cm: **	0 vs 75 cm: **
	(%)	8.1 ± 0.4	15.1 ± 1.1	22.5 ± 1.4	21.5 ± 1.8
Knee e. Flection/Extension	(mm)	447.1 ± 2.2	422.1 ± 2.5	398.7 ± 2.6	321.8 ± 2.5
Significance		0 vs 25 cm: *	25 vs 50 cm: ***	0 vs 50 cm: ***; 25 vs 75 cm: ***	0 vs 75 cm: ***
	(%)	51.1 ± 1.4	45.6 ± 2.1	34.9 ± 1.6	30.1 ± 2.2

＊＊＊ P < 0.001; ＊＊ P < 0.01; ＊ P < 0.05

DISCUSSION: In this study, we aimed to quantify the contribution of the lower body joint rotations in producing upward foot CG velocity during soccer volley kicking.

Knee flection motion showed the highest contribution at all heights. However, the relative contribution of this motion systematically decreased when the height of ball increases. It is evident that this motion directly contributes to the upward foot CG velocity while the leg swing motion is executed within the sagittal plane. A systematic decrease seen in the contribution of this motion suggests that the leg swing motion of volley kicking come to include more non-sagittal plane motions when the ball height increases.

Among the non-sagittal plane motions, the hip internal rotation motion showed the largest contribution to the upward foot CG velocity in volley conditions (15.1% at 25 cm height, 22.5% at 50 cm height and 21.5% at 75 cm height). Sugi et al. (2017) suggested that the hip axial rotation motion has a role to raise the kicking foot CG high in volley kicking. In fact, this motion showed the largest contribution next to that of the knee flection motion. The given result, therefore, can be a support of their suggestion, thereby reinforcing the importance of the hip internal rotation motion during soccer volley kicking.

Pelvis clock-wise rotation within the frontal plane is also extracted as the main contributor to induce the upward foot CG velocity in volley kicking, suggesting players utilize the body tilting to left side (opposite to the ball side) to achieve a higher foot CG position. In the field of soccer, coaches often advice players “to raise your foot firmly to prepare for a volley kicking". That coaching cue implies the necessity of the hip abduction motion for volley kicking, however, the contribution of this motion was not significantly different among all heights including the place kicking. Sugi et al. (2016) suggested that players tend to use the trunk lean motion rather than the hip abduction motion corresponding to the ball height of volley kicking. This result strongly endorsed their suggestion, again.

Variables seen in two high volley conditions (50 cm and 75 cm) were significantly different than those of the other conditions. However, except for the displacement due to the hip extension motion, there are no distinguishable differences between the two volley conditions. It can be suggested the motions contributing the upward foot CG displacement are very similar in these two rather high volley kicking conditions. However, all participants recognized that volley kicking at 75 cm is more difficult task than that of 50 cm, and there was a significant difference in the resultant ball velocity between these two conditions. Further studies other than kinematics or kicking leg motion (ex. kinetics or support leg motion) are warranted to clarify the cause of these difficulties in volley kicking at 75 cm height.

CONCLUSION: We quantified unique contributions of the rotational motions of the pelvis and kicking leg to produce upward foot CG velocity during soccer volley kicking. Major contributors to generating the upward foot CG velocity in volley kicking were 1) knee flection, 2) hip internal rotation and 3) pelvis clock-wise rotation within the frontal plane and 4) hip extension. The contributions of 1) and 4) become smaller as the ball height increased gradually, while the contributions of 2) and 3) become larger systematically. Also in two high volley conditions, the relative contributions of 2) and 3) are very similar. From these quantitative data, coaching cues for volley kicking should be reconsidered.

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