KINEMATICS OF LOW, MIDDLE AND HIGH VOLLEY KICKING IN SOCCER

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The present aimed to clarify the three dimensional kinematics of soccer volley kicking, and to demonstrate how players change their motion to balls in varied heights. Fifteen experienced male university soccer players were participated. To mimic the situation of the volley kicking, the ball was set on paper pipes with different heights (25 cm, 50 cm and 75 cm). Thought a comparison with normal instep kicking, the volley kicking motion was characterized: 1) significantly smaller knee joint angle, 2) significantly larger hip joint axial rotation, 3) significantly larger trunk lean angle and 4) significantly larger pelvis horizontal rotation. These motions were emphasized systematically with the increase of ball heights. It can be interpreted that these characteristic motions enable players to adjust their volley kicking motion to varied ball heights.

KEY WORDS: kicking leg, joint angular motion, lower leg configuration, coaching cues

INTRODUCTION: Kicking is the defining action in soccer (Lees, Asai, Andersen, Nunome and Sterzing, 2010). A number of biomechanical researches have been conducted for soccer kicking, however, most were done for maximal instep kicking (Romano and Tavana, 1993; Levanon and Dapena 1998; Nunome, Asai, Ikegami and Sakurai, 2002) or pass kicking (Levanon and Depena, 1998; Nunome et al., 2002). To date, other kicking techniques gathered scant attention from researchers, in particular, only a few studies were conducted for volley kicking (Ishihara Nunome and Yamamoto, 2000; Shinkai and Isokawa, 2004).
Volley kicking is an advanced kicking technique in soccer, where a player strikes the ball directly in the air, thereby allowing the goalkeepers less time to react. This kicking has been recognized as one of the most difficult technique to make fast, accurate shot during the match. When the volley kicking is used offensively, the volley kicking can play a crucial role in scoring straight goals. In the 2014 FIFA World Cup in Brazil, all 171 goals, 33 goals, which accounts for its 19.2% were due to volley kicking including the best goal of the tournament by James Rodriguez (Columbia) and the winning goal of the final by Mario Gtoze (Germany). During the course of a soccer match, players are occasionally required to volley the ball of varied heights in the air. To squarely strike the ball, they are demanded to adjust their volley kicking motion depends on the ball heights. However, little is known about how players change their volley kicking motions to different ball heights from biomechanical perspective. In the present study, we focused on the kicking leg and lower trunk motion of volley kicking and aimed 1) to illustrate its three dimensional kinematics, especially for joint angular motions required for this highly technical kicking, and 2) to demonstrate how players change their volley kicking motion to different ball heights.

METHODS: Fifteen experienced male university soccer players (age = 21.5±0.9yrs; height = 171.7±5.5cm; mass = 64.7±6.2kg; career = 14.7±1.4yrs) volunteered to participate in this study. To mimic the situation of volley kicking, 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 and the three types of volley kicking towards a goal (2mx3m) 7m ahead using their preferred leg. Kicking trials repeated so that we obtained five good trials having a good foot-ball impact and straight forward ball trajectory. Of these five trials, two trials, in which kicked the ball hit the middle of the goal vigorously were chosen for further analysis.
A FIFA standard, regulation (size 5) soccer ball was used and its internal pressure (900 hPa) was controlled throughout the experiment. The subjects wore the same type of training shoes for artificial turf, compression spats and compression shirts. Their kicking trials were captured by a 8 cameras optical motion capture system (VICON) at 500 Hz. Eight reflection markers were placed on the ball and twenty three reflection markers were placed on the both sides of

subject's lower body (greater trochanter, anterior superior iliac spine, posterior superior iliac spine, lateral surface of thigh, lateral epicondyle of femurs, medial epicondyle of femurs, lateral surface of shank, lateral malleolus, medial malleolus, the fifth metatarsal head, tips of toe and heel).

From the three-dimensional coordinates, initial ball velocity, kicking leg and lower trunk kinematics: 1) knee joint angle, 2) hip internal/external rotation, 3) hip adduction angle, 4) trunk lean angle and 5) pelvis horizontal rotation angle were computed.

The time of leg swing motion was normalized to 100%. 0% of time corresponds to the moment of toe-off the ground, and 100% of time corresponds to the moment of ball impact.

After ANOVA as the height 0cm basis, Dunnett's multiple comparison were conducted with the significant level set at < 0.05 %.

RESULT: Initial ball velocities of the four conditions were 24.0±1.5m/s (0 cm, placed ball), 23.3±1.3m/s (25cm), 21.8±2.2m/s (50cm), 19.6±2.4m/s (75cm), respectively. The ball velocity of the two volley kicking conditions (50 cm and 75 cm) decreased significantly ($p< 0.01$) compared to that of the place kicking.

Figure 1 shows the changes of knee flexion angle in the four conditions. The three volley kicking conditions showed apparently deeper knee flexion angle than that of the place kicking. The maximum knee flexion angle increased systematically with ball heights. There are significant differences between the place kicking condition and the three volley kicking conditions for the maximum knee flexion angles ($p<0.05$).

Figure 2 shows the changes of hip internal external rotation angle in the four conditions. Compared with the place kicking condition, the hip internal/external rotation motion of the three volley kicking conditions were apparently emphasized. Also, the range of the hip internal external rotation motion increased systematically with ball heights. There are significant differences between the place kicking condition and the three volley kicking conditions for the ranges of hip internal/external rotation ($p< 0.01$).

Figure 3 shows the changes of trunk lean angle in the four conditions. In the static kicking condition, the trunk lean motion was small to be negligible, however, the three volley kicking conditions showed remarkable trunk lean motions. The maximum trunk lean angle increased systematically with ball heights. There are significant differences between the place kicking condition and the three volley kicking conditions for the maximum trunk lean angles ($p< 0.01$).

Figure 4 shows the changes of pelvis transverse plane rotation angle in the four conditions. As well as the other angular motions, the range of this motion increased significantly ($p<0.01$) and systematically with ball heights.

Additionally, the hip adduction motion showed a different trend from the other four angular motions. Only the high volley condition (75 cm) showed significantly ($p<0.01$) larger maximum hip adduction angle than that of the place kicking condition.

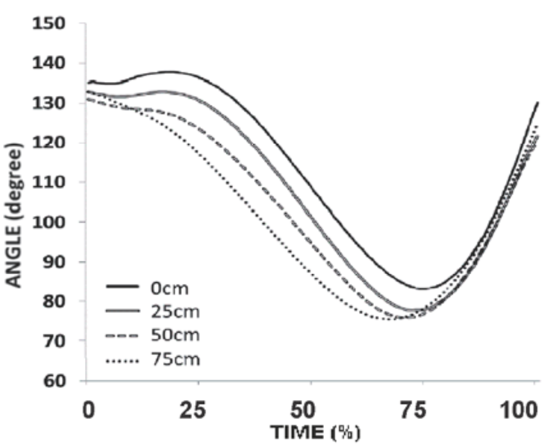

Figure 1. Average changes of knee flexion angle during kicking.

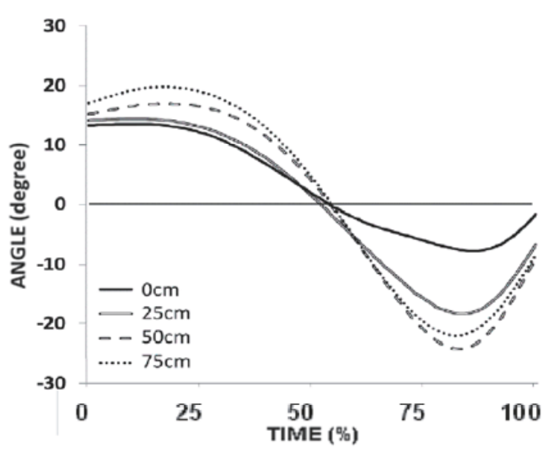

Figure 2. Average changes of hip internal / external rotation angle during kicking.

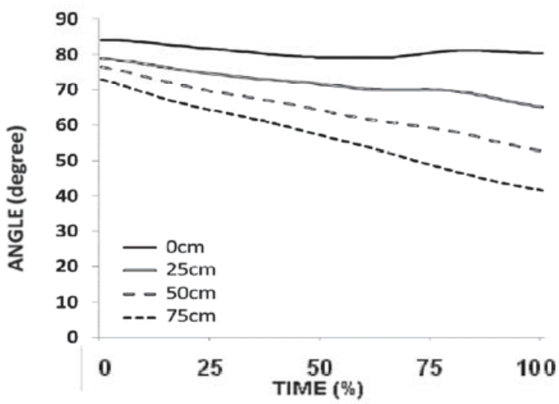

Figure 3. Average changes of trunk lean angle during kicking.

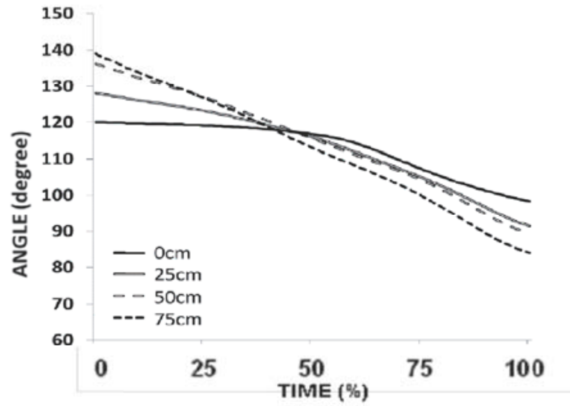

Figure 4. Average changes of pelvis transverse plane rotation angle during kicking.

Table 1. Comparison to normal kicking and volley kicking.

Type of angle (degree)	0cm	25cm	50cm	75cm
MAX. Knee flexion (Significant difference to the 0cm)	82.5±6.3	76.8±8.1 (p< 0.05)	74.9±8.1 (p< 0.01)	73.9±7.0 (p< 0.01)
Range of Hip int/ext rotation (Significant difference to the 0cm)	23.1±5.3	34.9±5.7 (p< 0.001)	43.3±5.8 (p< 0.001)	44.4±7.3 (p< 0.001)
Range of Trunk lean (Significant difference to the 0cm)	3.7±3.9	13.8±2.6 (p< 0.001)	23.8±3.5 (p< 0.001)	31.3±5.1 (p< 0.001)
Range of Pelvis rotation (Significant difference to the 0cm)	21.6±7.2	36.5±7.7 (p< 0.01)	46.6±9.2 (p< 0.001)	54.9±10.1 (p< 0.001)

DISCUSSION: The present study had two aims 1) to illustrate the three dimensional joint angular kinematics of volley kicking, and 2) to demonstrate how players change their volley kicking motion to different ball heights. Initial ball velocities systematically decreased with an increase of ball heights. The ball velocity of the volley kicking conditions above 50 cm decreased significantly ($p < 0.01$). From joint angular kinematics, the volley kick motion was characterized by 1) significantly smaller knee joint angle during leg swing (Figure 1 & Table 1), 2) significantly larger range of hip joint axial rotation (Figure 2 & Table 1), 3) significantly larger trunk lean angle (Figure 3 & Table 1) and 4) significantly larger range of pelvis transverse plane rotation (Figure 4 & Table 1). Additionally, we observed significantly ($p<0.01$) lager hip abduction motion when the players kick the ball at the top most height of the ball (75 cm).

Nonaka et al. (2004) showed the changes of muscle activity of single joint muscles (vastus medialis, vastus lateralis) with the increased of hip external rotation angles. They suggested that the presence of hip external rotation possibly suppress the knee extension motion. This study showed that the volley kicking includes remarkable hip external–internal rotation motion during leg swing (Figure 2). Thus, suppressed activity of these muscles regarding knee extension motion may account for the reduced ball velocity seen in the two volley kicking conditions (50 cm and 75 cm).

In general, joint configurations have a substantial influence on the moment of inertia of human body. For example, in diving event, a tighter pike position gives divers a smaller moment of inertia, thereby helping them to complete somersaults. From this point, deeper knee flexion angle seen all the volley kicking conditions (Figure 1) likely make players easier to swing up the whole leg to required height and to swing the whole leg horizontally with pelvis rotation by reducing its moment of inertia.

Also, the hip axial rotation motion was emphasized in all the volley kicking conditions (Figure 2). It can be assumed that this motion enables players to align lower leg configuration horizontally to the ball travel direction. As shown in Figure 5, this configuration allowed players effectively maximizing the foot horizontal velocity using knee extension motion and squarely hitting the ball with instep part of foot.

Furthermore, trunk lean angle was associated with an increase of ball heights (Figure 3) rather than hip adduction motion. Probably, tilting the trunk is a sound instruction to execute good volley kicking for most cases except for very high balls.

The present study, however, might have some limitation to lead practical implication for volley kicking. Due to practical difficulties, we used "static ball" instead of "moving ball", to which players must adjust their volley kicking motion in the course of actual match. To the best of our knowledge, Shinkai and Isokawa (2004) was the only study, which demonstrated the volley kicking kinematics to a moving air ball. They found systematical decrease of the range of knee flexion-extension motion and increase of trunk lean against the increase of ball height. These findings were quite consistent with the present findings, suggesting our experimental set up had little impact on the volley kicking kinematics.

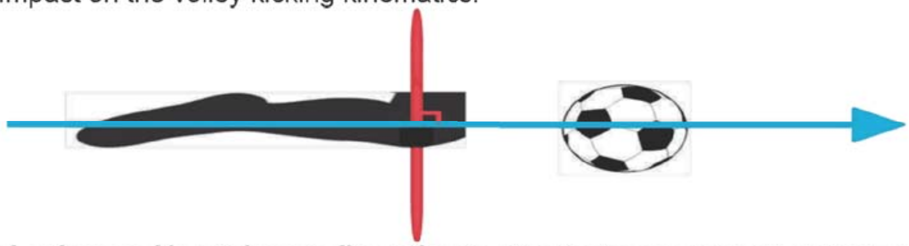

Figure 5. A schema of lower leg configuration to effectively accelerate foot horizontal velocity and to squarely hit the ball with instep part of foot.

CONCLUSION: We succeeded in illustrating peculiar joint angular motions required for volley kicking executed to varied ball heights. The following motions are extracted: 1) deeper knee flexion angle, 2) larger hip joint internal external rotation motion, 3) larger trunk lean angle and 4) larger pelvis transverse plane rotation. Also all these motions were systematically emphasized with an increase of ball heights.

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