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Quantifying Inter-Segmental Coordination during the Instep Soccer Kicks

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ABSTRACT

International Journal of Exercise Science 9(5): 646-656, 2016. In order to generate a high ball speed in soccer, the inter-segmental coordination of the kicking leg is critical. The purpose of this study was to quantify the coordination between the thigh and shank movement in the sagittal plane during instep kicks. Eleven female soccer players were video recorded using a high-speed (80 Hz) video camera during penalty kicks. Hip, knee and ankle joint centers of the right leg were digitized, and the movement was analyzed using Dartfish TeamPro (6.0). The thigh and shank segment angles were generated, and the coordination was quantified using the cross-correlation and the vector coding method. Four coordination patterns were defined based on coupling angles: in-phase, anti-phase, thigh-phase and shank-phase. The time spent in each coordination pattern was analyzed. The cross-correlation coefficient was positive for all the participants, indicating that the two segments rotated with similar patterns. Based on the vector coding method, we observed dominant coordination patterns of shank-phase and in-phase during the backswing and forward swing phase, respectively. We hope the outcomes of our study could provide a better understanding of soccer kicking coordination and benefit training young soccer players. Future studies may use the methodology and outcomes in the present study to investigate the coordination of different levels of players to better understand the process of skill acquisition.

KEY WORDS: Kinematics, vector coding, kicking performance, soccer training

INTRODUCTION

Kicking is the most commonly used skill in soccer. Though there are different types of kicks, one type of kicks of particular concern is the instep kick (14), because it is mainly used for power shooting and long distance passes. An instep kick uses the upper medial surface of the foot to strike the ball. Typical movement of the kicking leg has been described by Wickstrom (30) and generally agreed by others (18, 19). The kicking side hip is extending (thigh backward rotation), and the knee is flexing (shank backward rotation) during the last step of approach. After the support foot touchdown at the side of the ball, the forward movement occurs with pelvic axial rotation (to the left if the kicking leg is right), hip flexion (thigh forward rotation) while the knee continues to flex. Following the knee flexion both segments rotate forward; the thigh decelerates while the shank accelerates until after ball contact.

An extensive number of studies have been conducted to study the kicking leg kinematics, kinetics and muscle activities (13-15, 21, 24). However, one area that has received little attention is the movement coordination of the kicking leg (i.e., thigh-shank inter-segmental coordination). Coordination of human movement is to control the multiple degrees of freedom at each level in proper relations (28). The typical coordination pattern of soccer kicking has been described qualitatively as a proximal-to-distal sequence of the kicking leg (10, 19, 30). The proximal-to-distal sequence has been considered to be important to create a high foot velocity (16). Several studies attempted to further investigate the coordination of kicking movement using timing variables (e.g., time to peak knee flexion and hip extension angles and/or velocities) and angle-angle plots (hip-knee) (1, 5, 6, 10). Coordination differences were observed between skilled and unskilled participants (6); positive effects of training on coordination were also found (1, 7). Chow and colleagues (2008) also observed that the angle-angle plots between the thigh and shank were less variable as participants progressed through the training sessions. However, the angle-angle plots were often analyzed based on visual observation (1, 6, 7). A few studies calculated motion-dependent moment at the knee joint as an indirect index of inter-segmental coordination (2, 9). For other sports, coordination has been quantified using cross-correlation (27) (volleyball serving), dot product between angular velocity vectors ((17) Taekwondo kicks) and continuous relative phase ((25) swimming). Therefore, in order to have a better understanding of inter-segmental coordination of soccer kicking, more objective, quantitative approaches are still needed.

The vector coding method is commonly used in biomechanics to quantify the inter-segmental coordination during locomotion (4, 22). This method calculates the angle of the vector between two adjacent data points in time on the angle-angle diagram relative to the right horizontal (shown in Fig. 1), named as coupling angle ranged from 0° to 360° (12). Coupling angle values of 0°, 90° 180° and 270° indicate movement of only one segment, whereas values of 45°, 135°, 225° and 315° indicate equal movement between the two segments. It has been suggested that the vector coding method could provide information not only about inter-segmental coordination but also movement dominance of one segment over the other segment (4, 22). Moreover, the vector coding method is a mathematically convenient way to assess coordination without calculation of higher derivatives (i.e., angular velocity) or normalization of data and may be more appropriate in sports and clinical applications and interpretations.

Therefore, the purpose of our study was to quantify inter-segmental coordination between the thigh and shank movement during the soccer instep kicking movement using the vector coding method. A better understanding of coordination of kicking movement could benefit soccer kicking training and skill development.

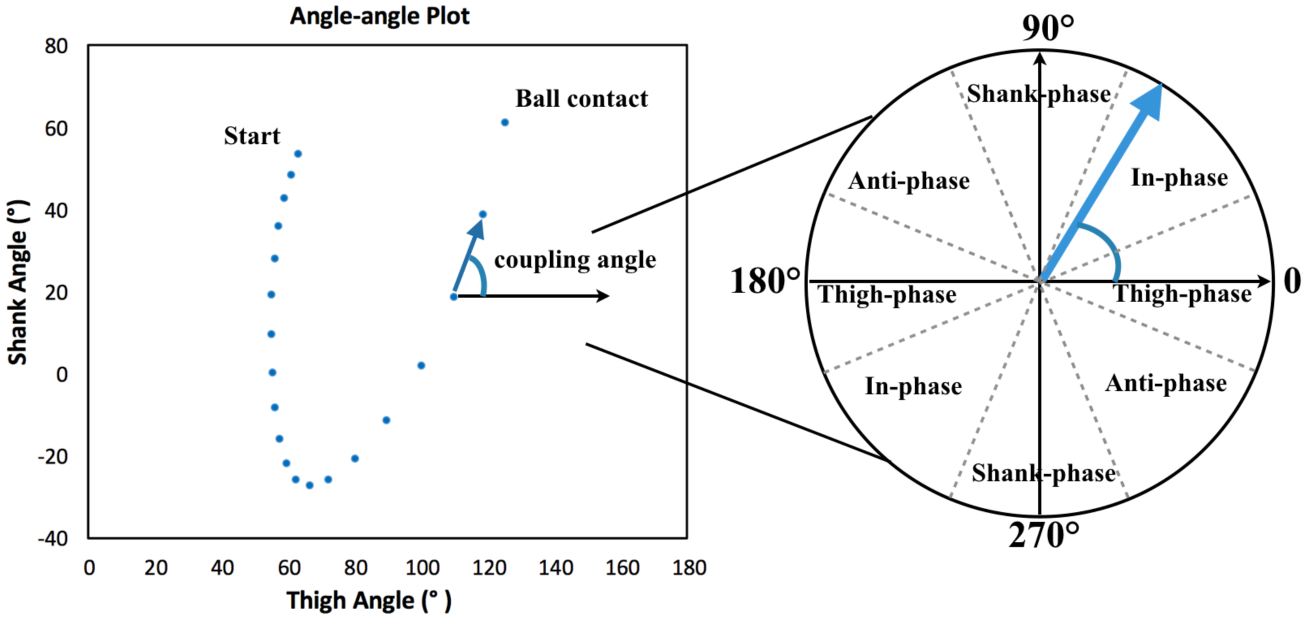
METHODS

Participants

Eleven female soccer players (height = 166 ± 8 cm, weight = 61 ± 7 kg, age = 21 ± 1 yr, years of experience = 13 ± 2 yr) were recruited from the university soccer team. All participants were right foot dominant players and wore outdoor soccer cleats to perform the kicks. The research protocol was approved by the university institutional review board. Consent forms were signed by the participants before the testing, following the university ethics protocol.

Protocol

A digital video camera (80 Hz, 640 × 480 pixels, shutter speed = 1/500 s, Fujifilm EXR) was used to capture the kicking movement in the sagittal plane (Figure 1). The camera was set up five meters on the right side the ball and perpendicular to the sagittal plane of the kicking movement. Another video camera was set up 3.5 meters directly above the ball in order to calculate the speed of the ball. A 'T' shape marker was placed in front of the ball to define the global coordinate system (20).



Coordination Pattern	Coupling Angle γ (°)
In-phase	$22.5 \le \gamma < 67.5$, $202.5 \le \gamma < 247.5$
Anti-phase	$112.5 \le \gamma < 157.5$, $292.5 \le \gamma < 337.5$
Thigh-phase	$0 \le \gamma < 22.5$, $157.5 \le \gamma < 202.5$, $337.5 \le \gamma < 360$
Shank-phase	$67.5 \le \gamma < 112.5$, $247.5 \le \gamma < 292.5$

Figure 1. Coupling angle on the thigh-shank angle-angle plot and coordination pattern definition based on the coupling angle. The four coordination patterns were based on Chang et al. (2008). The coupling angle was shown by the angle between the blue vector and the right horizontal axis.

The testing was conducted on an outdoor soccer field with Federation Internationale de Football Association (FIFA) standard size and goal. A ten-minute warm up including jogging, dribbling and passing was performed before the testing. Three reflective markers (15 mm diameter) were placed on participant's right greater trochanter, lateral femoral epicondyle and lateral malleolus, respectively. To ensure kicking consistency, the participants were instructed to kick the ball placed at the penalty spot to the left target within the goal (Figure 1) as fast and accurately as possible. The target was defined by the left goal post and the vertical axis of a pylon that was 1.2 m inside of the goal post. Participants were also instructed to use the instep kick and their self-selected approach pattern. The three trials that successfully placed the ball into the target area were captured for each participant. A 20-second break was taken after each trial to minimize fatigue.

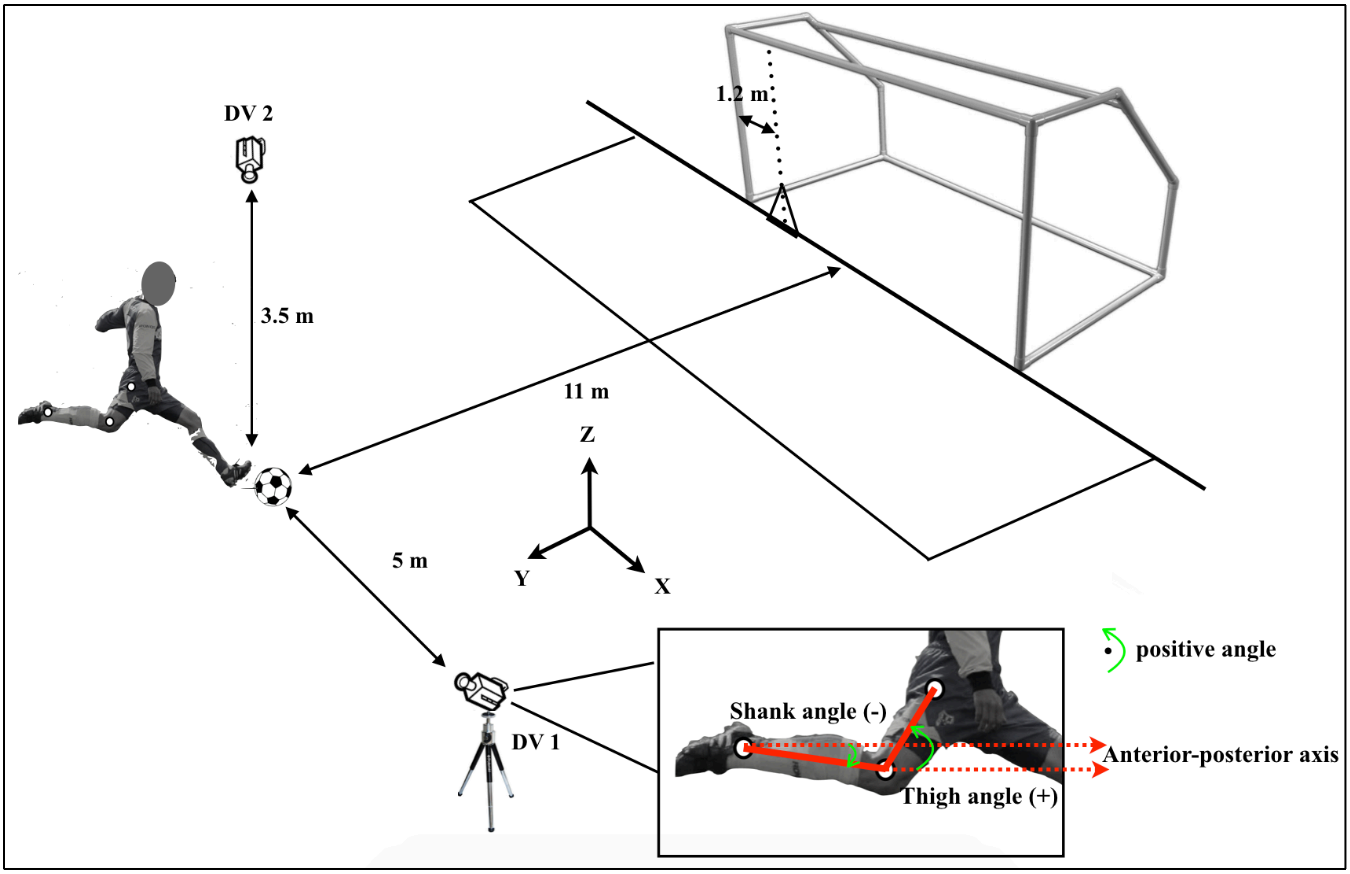


Figure 2. Schematic representation of the experiment set up and segment angle measurement. The angles were measured relative to the anterior-posterior axis (horizontal), and counter-clockwise direction is positive.

The Dartfish Team Pro 6.0 (Dartfish, Fribourg, Switzerland) was used to analyze video clips from five frames before the kicking event to five frames after the kicking event. The Dartfish is a 2D motion analysis software that provides good validity compared to Vicon system when studying the planar motion (11). The kicking event was defined from the kicking foot toe-off during the last step of approach to ball contact. Two phases in the kicking event were also defined: backswing phase (from kicking foot toe-off to support foot touchdown) and forward swing phase (from support foot touchdown to ball contact). The reflective markers placed on the right leg were manually digitized to estimate the centers of hip, knee and ankle in the sagittal plane. The center of the ball was also digitized to generate the ball kinematics (i.e. ball speed) from the overhead view. To test the reliability and accuracy of the manual digitizing process, two trials from two participants were re-digitized. Test-retest intra-class correlation indicated a high reliability for both intra-investigator (α = .95 – .98) and inter-investigator (α = .90 – .93). The root mean square error of digitized points was 0.02 m. The digitized points were smoothed with a 4th order Butterworth low pass filter (12 Hz); and the cutoff frequency was determined using the residual analysis method (31) with a customized Matlab code (MathWorks™ MA, USA). Segmental angles (absolute angles) of thigh and shank were generated relative to the right horizontal axis (Figure 2). The segmental angles in kicking were averaged across the three trials for each participant based on time normalization (29).

The movement coordination between the shank and thigh was quantified using both cross-correlation and the vector coding method with a customized Matlab code (MathWorks™ MA, USA). The cross-correlation coefficient has been used to investigate the general types of coordination relationship between two joints (in-phase or anti-phase) and the strength of the relationship (27). The vector coding method was employed to provide further detailed information about inter-segmental coordination (4, 22).

The vector coding method calculates the angle of the vector between the two adjacent data points in time on the angle-angle diagram relative to the right horizontal (between the blue arrow and right horizontal axis in Figure 1). Mathematically, the coupling angle (γ) (shown in Fig.1) was calculated as (4, 22):

$$\gamma_{j,i} = \tan^{-1}\left(\frac{y_{j,i+1} - y_{j,i}}{x_{j,i+1} - x_{j,i}}\right) \qquad [1]$$

where $0° \leq \gamma < 360°$; x and y are the thigh and shank segmental angles, respectively; j represents multiple trials and i represents a data point in a trial. The mean coupling angle was averaged across the three trials using the circular statistics (22, 29), because the coupling angle is directional.

$$\bar{x}_i = \frac{1}{n}\sum_{j=1}^{n}(\cos\gamma_{j,i})\,;\ \bar{y}_i = \frac{1}{n}\sum_{j=1}^{n}(\sin\gamma_{j,i}) \quad [2]$$

The mean coupling angle ($\bar{\gamma}_i$) was calculated from the mean horizontal and vertical components across multiple (n =3) trials (j) for each data point (i) (22).
The mean coupling angle is calculated in the range from 0° to 360°:

$$\begin{cases} \tan^{-1}\left(\frac{\overline{y_\iota}}{\overline{x_\iota}}\right), \overline{x_\iota} > 0, \overline{y_\iota} > 0 \\ \tan^{-1}\left(\frac{\overline{y_\iota}}{\overline{x_\iota}}\right) + 180, \overline{x_\iota} < 0 \\ \tan^{-1}\left(\frac{\overline{y_\iota}}{\overline{x_\iota}}\right) + 360, \overline{x_\iota} > 0, \overline{y_\iota} < 0 \\ 90, \overline{x_\iota} = 0, \overline{y_\iota} > 0 \\ 270, \overline{x_\iota} = 0, \overline{y_\iota} > 0 \\ undefined, \overline{x_\iota} = 0, \overline{y_\iota} = 0 \end{cases} \quad [3]$$

Four coordination patterns were defined based on the mean coupling angle: in-phase (rotating in the same direction), anti-phase (rotating in the opposite directions), thigh-phase (the thigh is rotating dominantly) and shank-phase (the shank is rotating dominantly) (Figure 1) (4). Time spent in each coordination pattern was calculated and normalized to % of kicking event time.

RESULTS

Most participants could achieve three successful kicks within five trials. The ball speed ranged from 16.0 to 20.6 m/s, with a mean of 17.5 m/s and standard deviation of 2 m/s. The cross-correlation coefficient between thigh and shank was positive for all the participants. However, the variation was large among participants. The mean coefficient was 0.44 with a standard deviation of 0.27 and a range from 0.08 to 0.85.

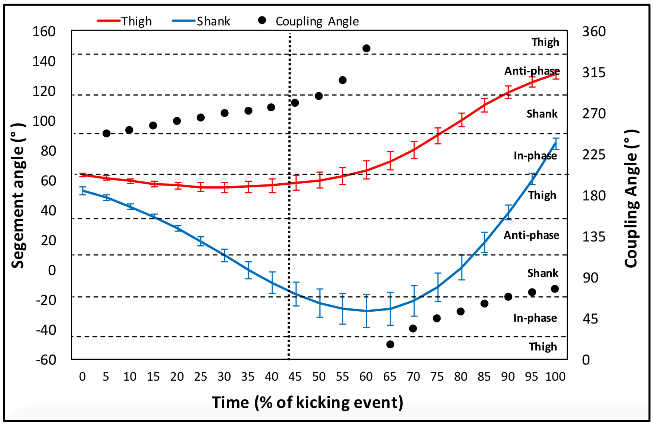


Figure 3. Ensemble average of thigh and shank segment angles (mean and SD) and coupling angles during the kicking event. Positive segment angles indicate forward rotation (i.e. hip flexion and knee extension). The vertical dotted line indicates the instant of support foot touchdown; the horizontal dash lines define the four coordination patterns: in-phase, anti-phase, thigh-phase (thigh) and shank-phase (shank).

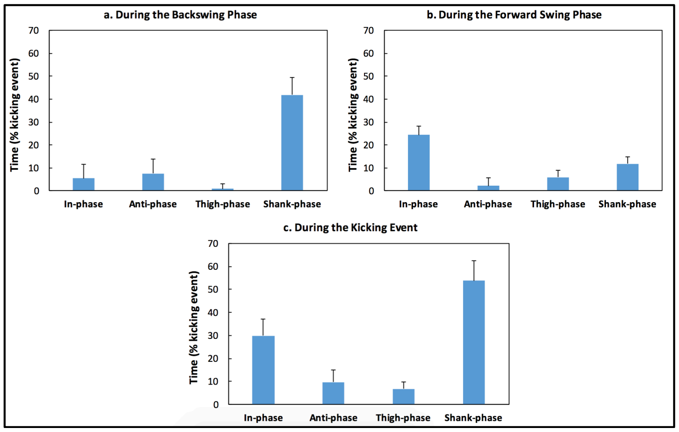


Figure 4. Time spent in each coordination pattern (mean and SD) during (a) backswing phase, (b) forward swing phase, and (c) kicking event. All time variables were normalized to % of the kicking event time.

The coupling angle, time spent in each coordination pattern and segment angular velocity was shown in Figure 3, 4 and 5, respectively. In general, the major coordination phase patterns are in-phase (about 30% of kicking event time) and shank-phase (about 50% of kicking event time). Specifically, during the backswing phase, the thigh rotated backward slightly (about 5°) while the shank rotated backward drastically (about 70°) (Figure 3). The coordination pattern was mostly shank-phase (about 40% of kicking event time) (Figure 4). After the support foot touchdown, the thigh rotated forward slightly while the shank continued rotating backward, which resulted in some time spent in shank-phase and anti-phase. Then the shank reduced the backward rotation velocity and thigh-phase coordination pattern was displayed (about 6% of kicking event). The shank started to rotate forward at about 60% of kicking event; both segments rotated forward, so the in-phase pattern was displayed (about 24% of kicking event time). Just prior to (10% of kicking event time) the ball contact, the shank-phase pattern was shown with greater shank forward rotation velocity (Figure 5).

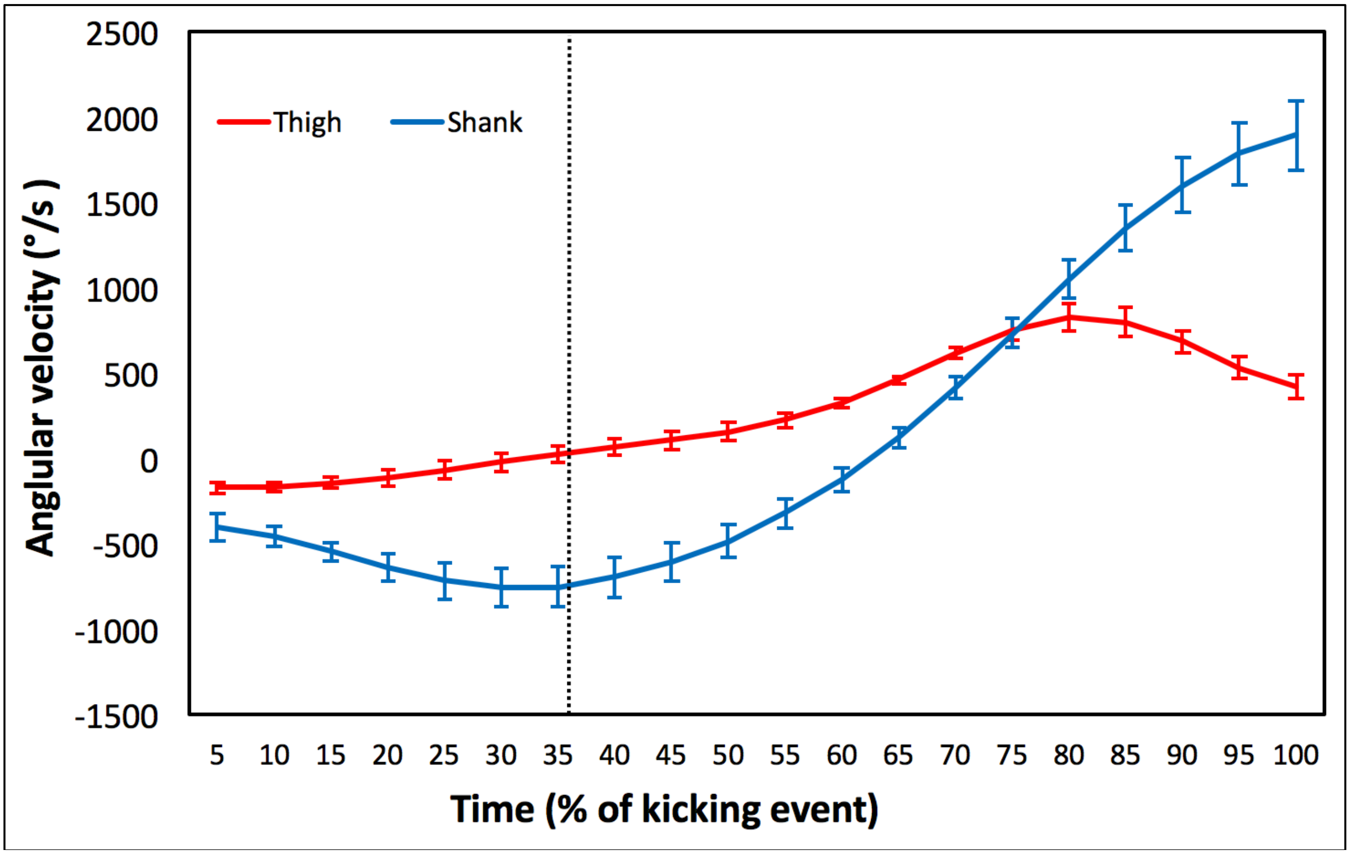


Figure. 5 Ensemble average of thigh and shank angular velocity (mean and SD) during the kicking event. Positive values indicate forward rotation (i.e. hip flexion and knee extension). The vertical dotted line indicates the instant of support foot touchdown.

DISCUSSION

Coordination of soccer kicking was mainly assessed qualitatively using joint angles/velocities plots or angle-angle plots in the previous studies (19, 27). More direct and objective approaches were needed to better understand the coordination of kicking movement. The present study employed both cross-correlation and the vector coding method to quantitatively investigate the inter-segmental coordination. Coordination patterns at different phases of the kicking movement were presented, which provided us detailed information of coordination that has not been revealed previously.

The cross-correlation coefficient between thigh and shank movement was positive for all the participants. This suggests that, in general, the two segments rotate with similar patterns (i.e., in-phase) (26) during the kicking event. However, possibly due to the lag and velocity difference between thigh and shank movement, the strength of the cross-correlation is low (r = 0.44 ± 0.27). By initial observation of our data, the participants who generated a high ball speed tended to have a low cross-correlation coefficient. This low coefficient may be considered as an advantage to create 'inertial lag' and allow transferring energy from thigh to shank (3). However, more evidence is still needed to confirm this. A similar low coefficient was also observed in shoulder-elbow coordination in volleyball serving exhibited by expert players compared to novice players (r = 0.25 vs. 0.65) (27).

Cross-correlation could provide a general movement relationship between thigh and shank, whereas the vector coding method could provide more details about coordination at different phases in kicking and movement dominance of one segment over another (4, 22). During the backswing phase, the dominant coordination pattern is the shank-phase because the shank rotated backward (knee flexion) dominantly with a minor thigh backward rotation (hip extension). The shank backward rotation could stretch the knee extensor muscles to contribute to the 'tension arc' introduced by Shan and Westerhoff (26). In addition to the shank-phase pattern, participants displayed in-phase at the beginning of the backswing because both segments rotated backward with comparable velocities. Some participants also exhibited anti-phase just prior to the support foot touchdown, because the thigh started to rotate forward and shank continued rotating backward. The anti-phase pattern continued until the early part of the forward swing phase. This anti-phase could help to achieve a greater knee flexion thus a greater stretch on the knee extensor muscles. Then the participants exhibited in-phase pattern when both thigh and shank rotated forward. The shank accelerated forward while the thigh slowed down, so the energy flowed from the thigh to the shank and further accelerated the shank (8, 31). The thigh decelerated due to exertion of motion-dependent moments from the shank (2, 9). Just before the ball contact (at about 90% of kicking event), as the thigh continued to slow down and shank accelerated and became dominant, the participants displayed shank-phase pattern again. The quantified coordination based on the vector coding method in the present study was consistent with commonly agreed soccer kicking skill description (8, 19) and provided detailed information of inter-segmental coordination at different phases of kicking movement.

In order to have a more comprehensive understanding of inter-segmental coordination during kicking, future studies may need to incorporate the pelvis and lower extremity in three-dimensional motions. Pelvic axial rotation around the support leg could influence the biomechanics of the kicking leg (23). Other studies may need to compare inter-segmental coordination among participants with different levels of kicking skill (e.g., expert vs. novice) to better understand the process of skill acquisition and benefit training young soccer players effectively.

There are some limitations in the present study. First, we calculated joint angles and angular velocities from planar projection based on two-dimensional (2D) analysis. However, because the primary leg movement during the instep kick occurred in the sagittal plane, the 2D kinematics should be sufficient for the purpose of quantifying inter-segmental coordination in the sagittal plane. Second, though participants were recruited to represent expert female soccer players, there were some variations of instep kicking skill level among participants. For example, some participants who played forward generated ball speed up to 20 m/s with high accuracy. Other participants who played defense may be slightly less skilled in instep kicks. Lastly, though we ensured data validity and reliability with extreme cautions, data collection accuracy could be improved by increasing sample rate, camera resolution, number of trials and participants.

In conclusion, the present study quantitatively investigated the thigh-shank inter-segmental coordination of the instep kicking movement. We observed dominant coordination patterns of shank-phase and in-phase during the backswing and forward swing phase, respectively. Coaches should take into consideration that proper coordination between thigh and shank may be important to generate a high ball speed. We hope that the methodology and outcomes of the study could stimulate further investigation of inter-segmental coordination and provide evidence-based recommendations that benefit soccer training.

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