

INVESTIGATING KEY FACTORS FOR FEMALE PLAYERS TO GENERATE COMPARABLE INTERACTION TORQUE TO THAT OF MALE PLAYERS

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We aimed to clarify the kinetic strategy of female players to achieve comparable motion-dependent interaction torque to that of male players during soccer instep kicking. The kicking leg motion of female and male players was captured at 500 Hz. The interaction torque was decomposed into two components due to the kicking leg and the support leg actions using the procedure of Inoue et al., (2013). Female players exhibited significantly smaller counter-clockwise (positive) interaction torque due to the support leg action while the clockwise (negative) component due to the kicking leg action was significantly suppressed in the latter part of kicking than male players. Our findings suggest coaches and female players should pay more attention to the kicking leg posture during the latter part of the leg swing to maintain their effective action of the interaction torque.

KEYWORDS: soccer, instep kicking, inverse dynamics, lower-limb coordination

INTRODUCTION: Successful soccer instep kicking would provide obvious advantages to female players because they tend to use the instep kick more frequently to achieve kicking distances that are covered by the inside and instep kicking of male players (Althoff et al., 2010). A previous study reported there was no significant difference in lower leg angular velocity between female and male players while female players were found to have a significantly smaller knee extension torque (resultant knee joint torque) in the latter part of kicking (Iitake et al., 2022). They also established that female players compensate for their significantly smaller knee extension torque by the interaction torque (motion-dependent torque) acting at the knee (Iitake et al., 2022). However, it is still unknown how female players gain a comparable amount of interaction torque acting at the knee.

Nunome & Ikegami (2005) demonstrated that a linear upward acceleration of the hip (kicking leg side) induced an effective action of the counter-clockwise component (the same rotational direction of knee extension) of the interaction torque acting at the knee. Inoue et al., (2014) also found the support leg knee exerted a positive knee joint torque power alongside its extension motion, suggesting this support leg action most likely contributes to producing the interaction torque. Thus, it is logical to assume that female players would gain the most of the interaction torque by the support leg action as male players do. However, as Brophy et al., (2010) indicated, female players were characterized by their significantly smaller muscle activation of a knee extensor muscle (vastus medialis) of the support leg. This implies that female players might not fully gain the interaction torque due to the support leg action while they somehow achieved a comparable magnitude of the interaction torque to their male counterparts (Iitake et al., 2022). Inoue et al., (2013) expanded the procedure of Putnam, (1991) to decompose the interaction torque acting at the kicking leg knee into those due to the kicking leg and the support leg actions. The procedure would help to explain how female players achieve a comparable magnitude of the interaction torque. The information would provide insightful implications to female players and coaches from viewpoint of segmental dynamics to improve the instep kicking of female players.

The purpose of the present study was to clarify the kinetic strategy of female players to achieve comparable interaction torque to that of male players during soccer instep kicking.

METHOD: Twenty females (age: 19.9 ± 1.5 years, height: 157.4 ± 4.1 cm, body mass: 52.1 ± 4.0 kg) and twenty males (age: 19.4 ± 1.2 years, height: 174.4 ± 6.3 cm, body mass: 69.2 ± 5.5 kg) experienced university-level soccer players participated in the present study. The experimental protocol was approved by the university's ethics committee and was conducted according to the Declaration of Helsinki. Informed written consent was obtained from each participant before data collection.

The three-dimensional coordinates of the kicking leg and pelvis were captured by a 12-camera optoelectronic motion capture system (VICON Nexus, VANTAGE) at 500 Hz. After a warm-up, participants were instructed to kick a FIFA-approved five-size football with maximal effort into a small indoor soccer goal (2m x 3m) eight metres ahead. All participants performed 10 shots so that three successful shots (the fastest resultant ball velocity with adequate straight forward ball trajectory towards the centre of the goal) could be selected for each participant.

In the present study, the procedure of Inoue et al., (2013) was applied to the analysis of the interaction torques due to the kicking leg and the support leg actions. The relative linear acceleration between the centre of mass of the lower leg (\mathbf{a}_L) of the kicking leg and the hip joint centre of the support leg (\mathbf{a}_{HS}) was expressed as follows (Inoue et al., 2013):

$$\mathbf{a}_L = (\mathbf{a}_L - \mathbf{a}_{HS}) + \mathbf{a}_{HS} \quad [1]$$

then, the interaction torques due to the kicking leg including pelvis motion (\mathbf{T}_K) and the support leg (\mathbf{T}_S) actions were computed as the following equations:

$$\mathbf{T}_K = \mathbf{r}_L \times m_L(\mathbf{a}_L - \mathbf{a}_{HS} - \mathbf{g}) \quad [2]$$

$$\mathbf{T}_S = \mathbf{r}_L \times m_L(\mathbf{a}_{HS}) \quad [3]$$

where \mathbf{r}_L is the moment arm vector from the centre of mass of the lower leg to the knee joint centre, m_L is the mass of the lower leg and \mathbf{g} is gravity (-9.81 m/s^2). These interaction torques were calculated as the component of the axis perpendicular to the kicking leg's thigh and lower leg plane. All kinetic parameters were normalised to the body mass (kg) and leg length (m) of each participant. To avoid substantial distortion at ball impact, interaction torques were smoothed (cut-off frequency of 25Hz) using the procedure described in Nunome et al., (2006). Time-series changes of interaction torque were time-normalised to 100% between the touch-down of the support leg and ball impact. The initial ball velocity was calculated and compared between female and male players using a two-sample t-test ($p < 0.05$). Statistical parametric mapping (SPM) was conducted to compare the time-normalised kinetic waveforms using a two-sample t-test (1DSPM, spm1d.org; (Pataky, 2010)). The alpha level was adjusted by Bonferroni adjustment ($N = 3$, $\alpha = 0.0166$).

RESULTS: Female players exhibited a significantly slower ($p < 0.001$) initial ball velocity ($20.5 \pm 1.5 \text{ m/s}$) than that of male players ($25.7 \pm 1.5 \text{ m/s}$). As shown in Figure 1, the total interaction torque (panel a) and the interaction torque due to the kicking leg action (panel b) were not significantly different between female and male players. However, female players exhibited a significantly smaller counter-clockwise (positive) interaction torque due to the support leg action (panel c) than that of male players during the latter part of kicking (79~86%).

DISCUSSION: As expected from the previous findings (Brophy et al., 2010), female players were found to generate a significantly smaller interaction torque due to the support leg action while there were no significant differences in the total interaction torque and that due to the kicking leg action (see Figure 1). These results suggested that female players somehow compensate for the smaller interaction torque due to the support leg action.

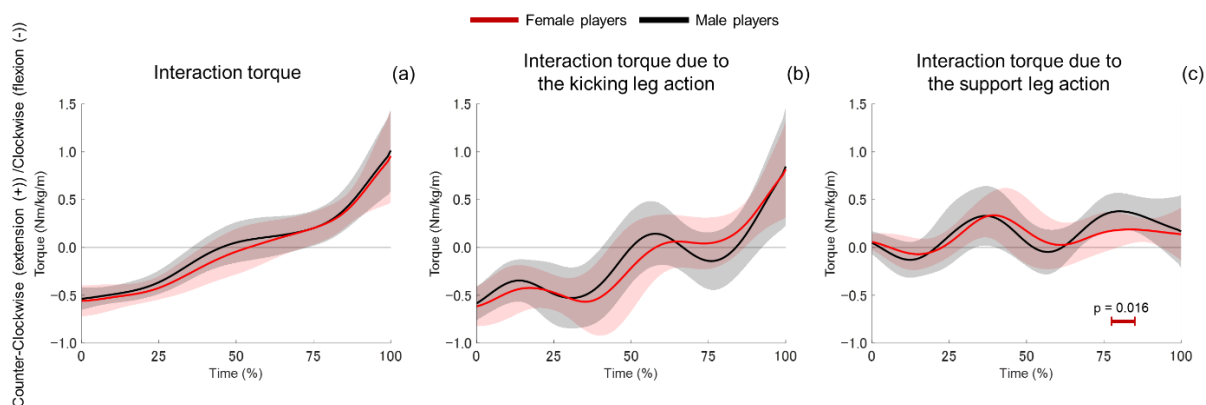


Figure 1. Total interaction torque (motion-dependent torque) (a) and Interaction torque due to the kicking leg (b) and the support leg actions (c). The red horizontal bar indicated a significant difference.

To clarify this specific compensation, the interaction torque due to the kicking leg action was decomposed into the three global components: X (medio-lateral), Y (antero-posterior) and Z (vertical) using the procedure of Nunome and Ikegami (2005). As shown in Figure 2 panel b, female players exhibited a significantly smaller clockwise (negative) component of interaction torque due to the Y component than that of male players (79~87%).

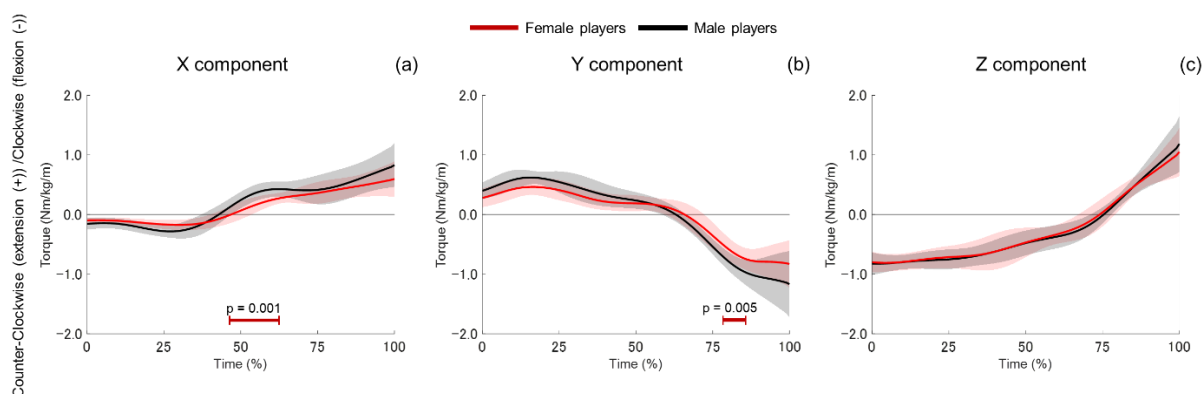


Figure 2. Three components of the interaction torque due to kicking leg action: X (a), Y(b), and Z (c). The red horizontal bar indicated a significant difference.

This finding suggested that female players were suppressing the clockwise component of the interaction torque due to the Y component in the kicking leg action. This interaction torque was calculated by the cross product of the moment arm and force due to relative acceleration between the centre of mass of the lower leg of the kicking leg and the hip joint centre of the support leg within the sagittal plane. Therefore, the moment arm was decomposed into three global components using the procedure of Nunome & Ikegami (2005) and compared the interaction torque (Y) due to each component of the moment arm. As shown in Figure 3 panel b, female players exhibited a significantly smaller clockwise interaction torque (Y) due to the Z component of the moment arm than that of male players (75~82%). We additionally compared the difference in the lower leg posture relative to the global Z axis (the angle between the longitudinal axis of the lower leg segment and the global Z axis). Figure 3 panel c illustrates that female players exhibited a significantly larger lower leg angle than that of male players (66~81%). Thus, it can be assumed that female players suppressed the clockwise interaction torque (Y) due to their specific lower leg posture with a smaller moment arm in the vertical direction. Our findings suggested that for female players, the difference in the lower leg posture in the latter part of kicking is the key to achieving a comparable magnitude of the interaction

torque due to the kicking leg action to that of male players. Therefore, female players should pay particular attention to their lower leg posture in the latter part of kicking to maintain their lower leg angular velocity.

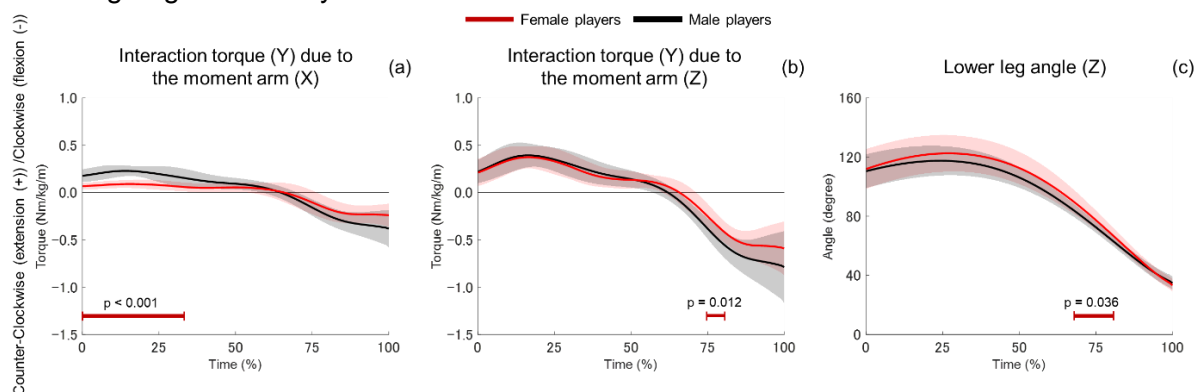


Figure 3. Interaction torque (Y) due to each component of the moment arm: X (a) and Z (b). The lower leg angle relative to Z (vertical) in the global coordinate system (c). The red horizontal bar indicated a significant difference.

CONCLUSION: Female soccer players were found to compensate for their smaller interaction torque due to the support leg action by having a specific posture of the lower leg segment of the kicking leg, thereby achieving a comparable magnitude of the interaction torque to that of male players. Our findings suggested coaches and female players should pay more attention to the lower leg posture during the latter part of the leg swing to maintain their effective action of the interaction torque.

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