SEX DIFFERENCES IN SUPPORT LEG DYNAMICS IN SOCCER INSTEP KICKING

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The present study aimed to demonstrate differences in the support leg knee joint dynamics during soccer instep kicking between female and male players. Three-dimensional lower body motion (500 Hz) and ground reaction force underneath the support leg (1000 Hz) during the instep kicking of twenty female and twenty male players, were captured to calculate knee joint torque and joint power of the support leg using inverse dynamics. Statistical Parametric Mapping (SPM) was conducted to compare these time-series changes. Female players exhibited significantly smaller knee extension joint torque (58~100%, $p<0.001$) and joint power (82~100%, $p=0.001$) than male players. Our findings suggested a possible strategy for achieving a better instep kicking of female players by enhancing the knee extensor's strength of the support leg.

KEYWORDS: football, instep kicking, support leg, inverse dynamics, female players

INTRODUCTION: Instep kicking forms the foundation of kicking techniques in soccer (Lees et al., 2010), and its motion has been recognised as the primary topic of biomechanical analysis. However, most of these studies only focused on the kicking technique of male players, while that of female players has gathered less research attention (Boyne et al., 2021). A previous study clarified playing techniques used in a game situation reported female players tend to perform maximal instep kicks more frequently to achieve distances covered by either the instep or side-foot kicks of male players (Althoff et al., 2010). Gaining knowledge regarding the instep kicking of female players can be considered more valuable than that of male players.

Several studies addressed the sex difference in the dynamics of the kicking leg of the instep kick. Recently, Iitake et al. (2022a) reported that the knee extension joint torque of female players was restrained significantly during the latter part of kicking while the magnitude of the interaction torque (counter-clockwise component) acting on the kicking leg knee was comparable to male counterparts. In addition, Iitake et al. (2022b) reported that female players tend to rely more on work due to the hip flexion joint torque necessary to execute instep kicking than male players. Although several studies focused on the differences in the dynamics of the kicking leg, the difference in support leg dynamics has never been investigated.

Nunome & Ikegami (2005) first described the source of the interaction torque acting on the kicking leg knee using the procedure of Putnam (1991). They indicated that the primary source was the upward acceleration at the kicking leg hip, representing the whole-body lifting action generally seen in skilled instep kicking. Inoue et al. (2014) clarified that the whole-body lifting action induced by the support leg knee extension joint torque immediately before ball impact produces the interaction torque acting on the kicking leg knee. In general, as female players tend to have a more collapsed (less lifting) support leg motion during the instep kicking (Shan, 2009), it can be assumed that their support leg action would be less functional to induce the interaction torque acting on the kicking leg knee. However, to date, no study has focused on this aspect of the instep kicking of female players. The lack of this information might disturb the establishment of a possible training strategy to improve the instep kicking performance for female players. A detailed understanding of the differences in the support leg knee joint action between female and male players would gain our knowledge and provide useful, practical implications for their coaches.

The purpose of the present study, therefore, was to illustrate the differences in the support leg knee joint dynamics during the soccer instep kicking between female and male players. With

regard to this aim, we set a hypothesis that in terms of the support leg action, female players would exhibit a significantly smaller knee joint torque and joint power than male players.

METHODS: Twenty females (age: 19.9 ± 1.5 years, height: 1.57 ± 0.04 m, body mass: 52.1 ± 4.0 kg) and twenty males (age: 19.4 ± 1.2 years, height: 1.74 ± 0.06 m, body mass: 69.2 ± 5.5 kg) experienced university-level soccer players volunteered to participate in the present study. The university's ethics committee approved the experiment protocol and conducted it according to the Declaration of Helsinki. Written informed consent was obtained from each participant before data collection.
The kicking motions and ground reaction forces (GRFs) underneath the support leg were simultaneously recorded using a 12-camera optoelectronic motion capture system at 500 Hz (Vicon Nexus, VANTAGE; Vicon) and a force platform (Type: 9827CA; Kistler) operating 1000 Hz, set at floor level. Participants were instructed to kick a FIFA-approved five-size football as forcefully as possible into the small indoor soccer goal (2 m × 3 m) placed eight metres ahead. All participants performed ten trials, from which the fastest three shots with adequate straightforward ball trajectory towards the centre of the goal were selected for further analysis. All kinetics and kinematics calculations were conducted using MATLAB (R2022a, MathWorks, Natick, MA). The support leg was modelled as a three-link segment model composed of the foot, shank and thigh. Segment mass, the centre of the mass location and moment of inertial values of females and males were derived from the data of young Japanese athletes (Ae et al., 1992). The resultant knee joint torque vector of the support leg was computed using inverse dynamics. Then, the knee angular velocity vector of the support leg was also calculated by subtracting the absolute angular velocity vector of the distal segment from that of the adjacent proximal segment. Finally, knee joint power was computed as the product of knee joint torque and knee joint angular velocity. These variables were computed as the component about an axis perpendicular to the thigh and shank of the support leg. The knee joint torque and power were normalised by the body mass (kg) and leg length (m) of each participant. Kinetic variables of the support leg were smoothed using a fourth-order Butterworth low-pass filter at 25 Hz.
Kicking motions were time normalised between the instance of support foot touch down to ball impact to 100%. Statistical Parametric Mapping (SPM) was conducted to compare the time-normalised waveform data using a two-sample t-test (spm1d; Pataky, 2010). Bonferroni adjustment was used to adjust the alpha level (< 0.025) for multiple comparisons (N = 2).

RESULTS: Figure 1 illustrates average (SD) changes in knee joint torque (panel a) and knee joint power (panel b) for female (line in red) and male players (line in black). Female players exhibited a significantly smaller knee joint torque (58~100%, p<0.001) than male players. Also, female players exhibited a significantly smaller knee joint power (82~100%, p=0.001) than male players.

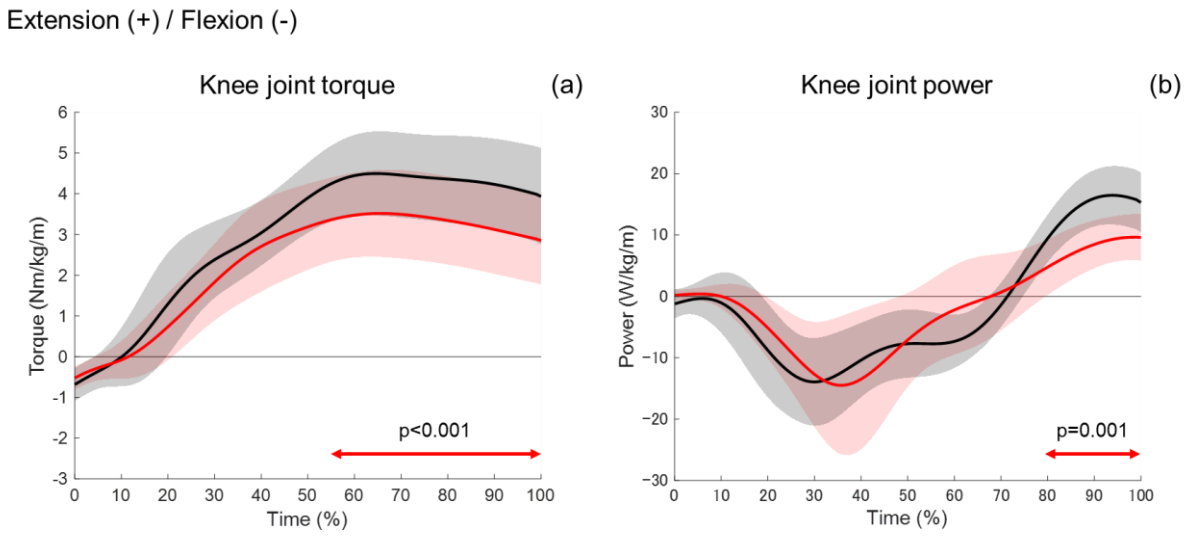

Figure 1. Average (SD) changes in knee joint torque (a) and knee joint power (b) of the support leg for female (line in red) and male (line in black) players. The red horizontal bar at the bottom of the figure indicated regions where there were significant differences between female and male players.

DISCUSSION: In the present study, we aimed to illustrate differences in the support leg knee joint dynamics during the soccer instep kicking between female and male players. From an apparent characteristic of female player's kicking motion, we set a hypothesis that female players would exhibit significantly smaller knee joint torque and joint power than male players. The primary findings of the present study were twofold. Female players exhibited a significantly smaller knee extension joint torque and a positive joint power in the latter part of kicking than male players. Thus, our hypothesis was fully supported.

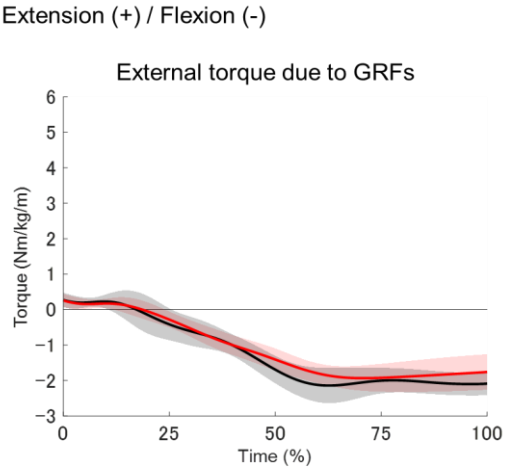

Figure 2. Average (SD) changes in external torque due to the GRFs in the support leg between female (line in red) and male players (line in black).

Our findings can be interpreted that female players found it more difficult for lifting their whole-body using knee extension joint torque of the support leg than male players. From the kinetic perspective, the behaviour of the support leg knee is determined by the "resultant knee joint torque", which is exerted internally by muscle-tendon structures and the "external torque", which is induced externally due to the GRFs. We additionally computed the external torque due to the GRFs for a better understanding of the unique support leg action seen in female players. As shown in Figure 2, female players generated a comparable magnitude of the external torque due to the GRFs to their male counterparts. On the other hand, female players exhibited a significantly smaller knee extension joint torque in the latter part of the instep kicking (Figure 1, panel a). These results indicated that in contrast to male players, female players did not exert enough knee extension joint torque to counteract the external torque due to the GRFs. As Inoue et al. (2014) illustrated, the knee extensor muscle groups are supposed to be in the eccentric contraction phase except for the final phase of kicking. As shown in Figure 1 panel b, the knee extensor muscles in both groups were assumed to be in the eccentric contraction phase for the most part of kicking (Female: 13.3 ± 9.3~70.3 ± 13.5%; Male: 9.4 ± 7.0~73.6 ± 3.6%). Montgomery et al. (2012) investigated the difference in the eccentric strength in the quadriceps (normalised by body mass) between female and male athletes using an isokinetic dynamometer. They reported that female athletes (3.2 ± 0.5 Nm/kg) were found to have a significantly smaller eccentric quadriceps strength than their male counterparts (3.9 ± 0.7 Nm/kg). After this eccentric phase, as the support leg knee comes to exert a positive joint power, the knee extension muscle group is supposed to exert a concentric contraction. Andrade et al. (2012) found a significantly smaller knee concentric strength in female soccer player group (female: 83 ± 12 Nm vs. male: 150 ± 26 Nm) than male soccer group. For a fair comparison, we normalised these torque values by the mean body mass of the participants (female: 59.8 kg vs. male: 74.7 kg). As a result, the normalised knee concentric torques (female: 1.4 ± 0.2 Nm/kg vs. male: 2.0 ± 0.4 Nm/kg) yet maintained a significant difference between the two groups with a very large effect size (Cohen's d=2.2). From these findings, inferior muscle strengths in both eccentric and concentric contraction modes may account for more collapsed (less lifting) support leg action seen in female soccer players during the instep kicking.

Our findings would provide a significant insight for improving the instep kicking of female players in daily practices. In the present study, female players generated a significantly smaller positive support leg knee joint torque and joint power in the latter part of kicking than male players. Previous studies theoretically (Inoue et al., 2014; Nunome & Ikegami, 2005) supported

positive support leg knee joint power is a decisive kinetic factor in generating the interaction torque acting on the kicking leg knee. Following these studies, Augustus et al. (2017) applied the theory to an intervention study with the instruction “lift fully your body and land on your kicking leg” to emphasise the mechanical role of the support leg action. The authors then succeeded in improving maximal foot velocity and resultant ball velocity through practical intervention on male players. Thus, it is worth considering possible strategies to improve the behaviour of the support leg of female players by enhancing the support leg musculatures, and consequently improve the instep kicking performance.

CONCLUSION: Female soccer players exhibited significantly smaller positive support leg knee joint power, which induced less lifting action of the support leg. This specific characteristic seen in female players was considered to be caused by their lower knee extension torque to counteract the external torque due to the GRFs than male players.

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