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Comparison of Biomechanical Factors among Straight, Curve and Knuckle Kicking Motions in Soccer †

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Abstract: The rotation of a soccer ball is affected by several factors, such as impact point and foot posture, which are generated by joint torque in the lower limb. This study aimed to investigate joint torque in the lower limb that generates foot posture and swing trajectory, and compare three types of kicks before and after a practice period for participants to learn to control the ball rotation. An optical three-dimensional motion capture system was used to record the kicking motion of the participants. The results indicate that the adduction torque of the hip joint at the moment of impact decreased for curve kicks (from 0.56 to 0.25 Nm/kg) and increased for knuckle kicks (from −0.09 to 0.37 Nm/kg). We considered that the curve and knuckle kicks swing towards the inside (because of their positive values in the post experiment) with hip joint adduction before impact to control ball rotation.

1. Introduction

There are several types of kicks in soccer, distinguished by the impact area of the kicking foot or by ball rotation. Furthermore, many studies exist on the instep straight, curve and knuckle kicking motions [1–5]. Straight kicks with a large ball velocity can increase the possibility of scoring a goal by shortening the reaction time for goalkeepers. Thus, straight kicks are considered not to require characteristic ball rotation. Curve kicks have the feature of a curved trajectory that is difficult for the goalkeeper to reach. Thus, curve kicks can be considered to require side ball rotation to create a curved trajectory. The knuckle kick, which has the possibility to score because of an unstable trajectory that is difficult for a goalkeeper to react to, became the subject of our investigation. The unstable trajectory is reported to be due to the knuckling effect caused by the slow ball rotation [5]. In another study, wobbling similar to a knuckling effect was observed when ball rotation velocity was low; under 1.0 rev/s [6].

The rotation of a soccer ball is affected by several factors, such as the impact point and facing direction of the foot. Differences in the location of the impact point have been reported for three types of kicks; straight, curve and knuckle [7]. In that study, impact points were located in the centre area of the instep, the low area near the inside of the foot, and near the foot joint in the straight, curve and knuckle kicks, respectively. The location of the impact point is considered to depend on foot posture,

which is generated by joint torque in the lower limb. Clarifying the differences of foot posture and the joint torque that generates it in the three types of kicks is an important clue to improving ball kicking skill.

The purpose of this study was to clarify differences in foot posture, and the joint torque in the lower limb that generates it, in the three types of kicks, and to compare the three types of kicks before and after a practice period. Throughout the practice period, we tasked each participant to decrease the ball rotation until it was under 1.0 rev/s.

2. Materials and Methods

The participants were 13 collegiate soccer players (mean ± standard deviation (SD): height 1.68 ± 0.05 m, body mass 64.7 ± 4.7 kg, experience 14.1 ± 1.8 years). The experiment protocol was composed of a 3 month practice period (to learn the knuckle kicking skill), and experiments before (pre) and after (post) the practice period. They performed three types of kicks during the experiments: straight, curve and knuckle. We captured their kicking motion using a three-dimensional optical motion capture system (Oxford Metrics Ltd., 500 Hz (for whole-body), 2000 Hz (for kicking foot and ball)). Force data were collected via force plates (Kistler, Switzerland, 1000 Hz). Reflection markers were placed on the entire body of the participants according to the Plug-in Gait model. Additionally, two markers on the kicking foot were placed on both sides of the metatarsophalangeal (MTP) joint. Four markers were placed on the top, left, right and front intersection points of the ball surface, and the three axes from the centre gravity of the ball, respectively. The segment of the foot and ball were created from the markers.

We calculated initial ball rotation (on the sagittal and horizontal plane components (and their absolute value for the knuckle)), hip joint torque of the kicking side (flexion (extension), adduction (adduction) and inner (external)) and foot posture during a kick impact (pitch, roll and yaw) before and after the practice period. All variables are expressed as the mean value of all participants in the results section (excluding figures of ball rotation). Ball rotation was calculated as a three-dimensional rotation of the ball segment against the world coordinate system for an average of 10 ms after the ball launched from the kicking foot (rev/s). Hip joint torque was calculated from the data of the force and motion of the whole body using a preinstalled Plug-in Gait model (excluding force of ball impact); subsequently, we used data at the moment of (immediately before) the impact of each type of kick to focus on the approaching kick motion of the lower limb and the decrease in the effect of the kick impact (Nm/kg; divided by kg to avoid the impact of individual differences). The impact moment was defined as being immediately before the contact of foot and ball; thus, the value of the joint torque at the moment of impact excluded the contact of foot and ball. Foot posture was calculated as the Euler angle of the foot segment and expressed by the roll–pitch–yaw (y–x–z) angle of the foot segment against the world coordinate system (degree). We used a paired t-test at the 5% level in the statistical comparison of the pre and post experiments. A one-way ANOVA with Bonferroni post hoc test was used to examine differences between the types of kicks at the 5% level.

3. Results

3.1. Ball Rotation

In the pre experiment, the ball rotation of the straight kick was sagittal = 2.05 ± 0.72 rev/s and horizontal = −0.52 ± 0.88 rev/s, the curve kick was sagittal = −1.89 ± 1.39 rev/s and horizontal = 5.20 ± 1.06 rev/s, and the knuckle kick was sagittal = 0.71 ± 1.28 rev/s and horizontal = −0.02 ± 0.76 rev/s (Figure 1a–c). The mean absolute value of the knuckle kick was sagittal = 0.48 ± 0.57 rev/s and horizontal = 1.13 ± 0.89 rev/s. In the post experiment, the ball rotation of the straight kick was sagittal = 2.71 ± 1.07 rev/s and horizontal = −0.09 ± 0.56 rev/s, the curve kick was sagittal = −0.88 ± 1.03 rev/s and horizontal = 5.67 ± 1.82 rev/s, and the knuckle kick was sagittal = 0.66 ± 1.11 rev/s and horizontal = 0.13 ± 0.70 rev/s (Figure 1d–f). The mean absolute value of the knuckle kick was sagittal = 0.55 ± 0.42 rev/s and horizontal = 0.92 ± 0.90 rev/s.

After the practice period for the knuckle kick, ball rotation on the horizontal plane component decreased compared with the result of the pre experiment, although no significant difference was observed. However, the task to continuously decrease the ball rotation velocity until it was under 1.0 rev/s was accomplished in both components.
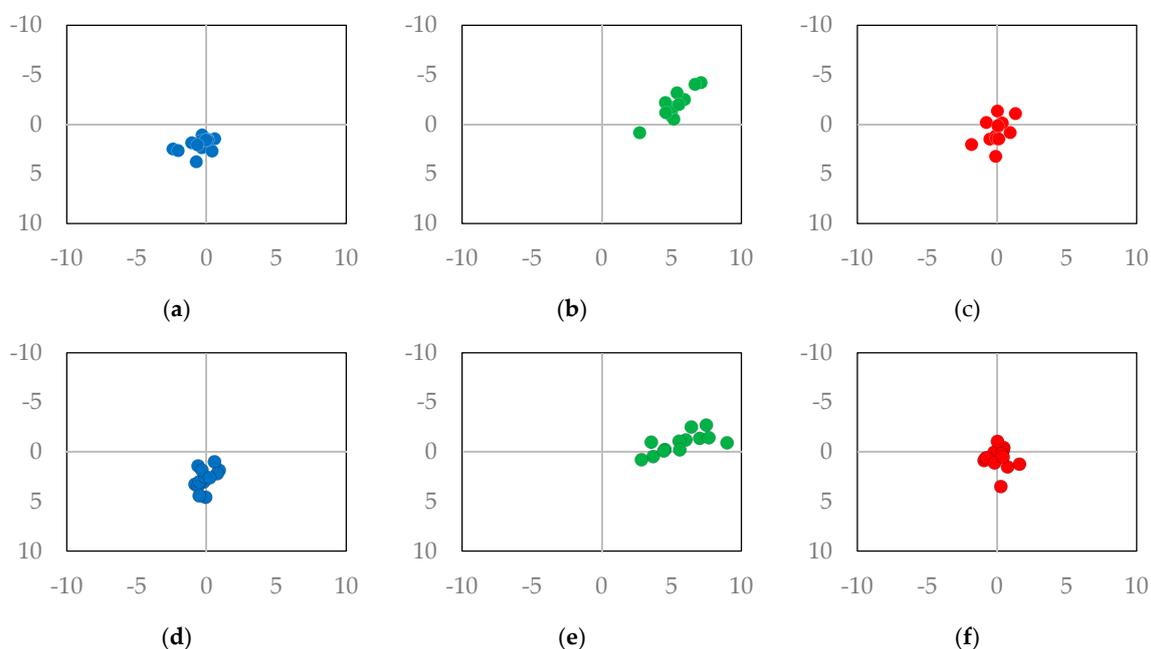
Figure 1. Sagittal (vertical axis) and horizontal (horizontal axis) components of the ball rotation of all participants: the result of the straight (**a**), curve (**b**) and knuckle (**c**) kicks in the pre experiment; the result of the straight (**d**), curve (**e**) and knuckle (**f**) kicks in the post experiment.

3.2. Hip Joint Torque

In the pre experiment, the values of the hip joint torque at the kick impact of the straight kick were flexion = 1.71 ± 0.81 Nm/kg, adduction = −0.56 ± 1.07 Nm/kg and internal = 0.22 ± 0.23 Nm/kg; curve kick was flexion = 0.67 ± 1.27 Nm/kg, adduction = 0.56 ± 1.17 Nm/kg and internal = 0.14 ± 0.17 Nm/kg; and knuckle kick was flexion = 1.45 ± 0.95 Nm/kg, adduction = −0.09 ± 1.06 Nm/kg and internal = 0.09 ± 0.22 Nm/kg (Figure 2a–c). In the post experiment, the values of the hip joint torque at the kick impact of the straight kick were flexion = 1.97 ± 0.56 Nm/kg, adduction = −0.37 ± 1.02 Nm/kg and internal = 0.26 ± 0.23 Nm/kg; curve kick was flexion = 1.09 ± 1.06 Nm/kg, adduction = 0.25 ± 0.80 Nm/kg and internal = 0.30 ± 0.20 Nm/kg; and knuckle kick was flexion = 1.52 ± 0.76 Nm/kg, adduction = 0.37 ± 1.16 Nm/kg and internal = 0.15 ± 0.19 Nm/kg (Figure 2d–f).

The hip joint internal torque at the moment of the impact of the curve kick increased significantly in the post experiment. The comparison of the pre and post experiments indicated that no significant difference was observed in the other values. The flexion torque of the hip joint of the curve kick was significantly smaller than that of others in the pre experiment. Furthermore, the adduction torque of the hip joint of the curve kick was significantly larger than that of the others in the pre experiment. The flexion torque of the hip joint of the straight kick was significantly larger than that of the curve kick in the post experiment.
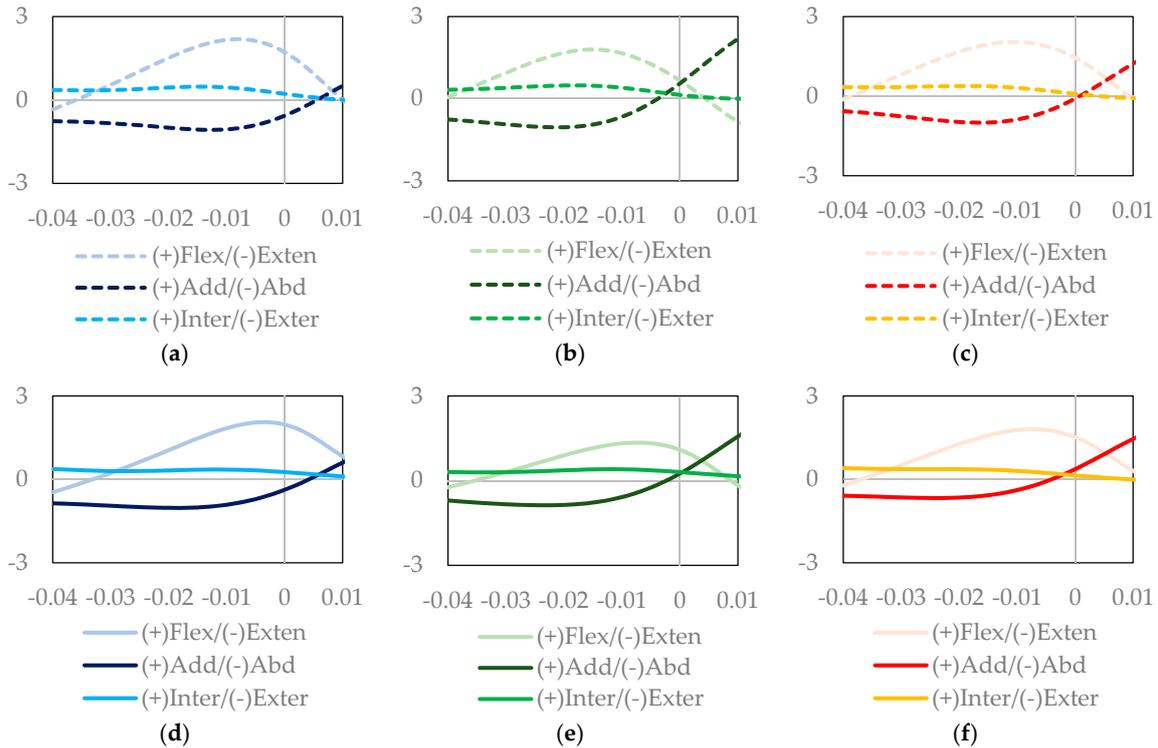
Figure 2. Hip joint torque ([Nm/kg]: vertical axis) of the mean transition value of all participants expressed with time ([s]: horizontal axis) from the impact: the result of the straight (**a**), curve (**b**) and knuckle (**c**) kicks in the pre experiment; the result of straight (**d**), curve (**e**) and knuckle (**f**) kicks in the post experiment.

3.3. Foot Posture

In the pre experiment, the values of foot posture at the impact of the straight kick were pitch = −36.5 ± 7.4 degrees, roll = −38.3 ± 5.1 degrees and yaw = −34.9 ± 10.8 degrees; curve kick was pitch = −4.6 ± 6.6 degrees, roll = −27.7 ± 5.7 degrees and yaw = −70.9 ± 8.5 degrees; and knuckle kick was pitch = −20.7 ± 13.0 degrees, roll = −31.4 ± 9.0 degrees and yaw = −54.7 ± 14.0 degrees (Figure 3a–c). In the post experiment, the values of foot posture at the impact of straight kick were pitch = −35.3 ± 8.2 degrees, roll = −40.2 ± 4.7 degrees and yaw = −34.5 ± 10.8 degrees; curve kick was pitch = −7.6 ± 4.3 degrees, roll = −28.7 ± 4.9 degrees and yaw = −69.2 ± 7.8 degrees; and knuckle kick was pitch = −20.6 ± 13.1 degrees, roll = −29.0 ± 9.3 degrees and yaw = −57.6 ± 14.3 degrees (Figure 3d–f).

The pitch angle at the moment of impact of the curve kick decreased significantly in the post experiment. The comparison of the pre and post experiments indicated that no significant difference was observed in the other values.

Significant differences occurred in all components between the straight kick versus the curve and knuckle kicks in both experiments. Significant differences in the pitch and yaw components occurred between the curve and knuckle kicks in the pre experiment. However, the significant difference between the curve and knuckle kicks occurred only in the pitch component in the post experiment.
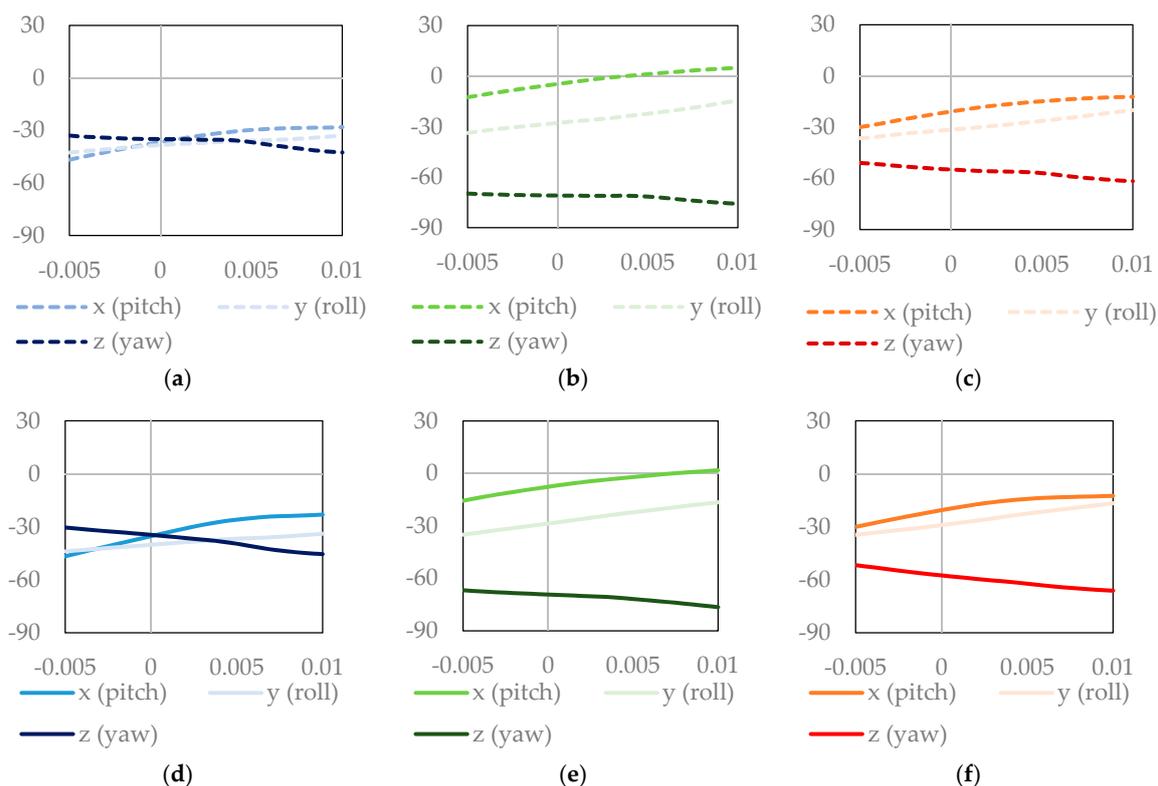
Figure 3. Euler angles ([degree]: vertical axis) of the mean transition value of all participants, expressed with time ([s]: horizontal axis) from the impact: the result of the straight (**a**), curve (**b**) and knuckle (**c**) kicks in the pre experiment; the result of straight (**d**), curve (**e**) and knuckle (**f**) kicks in the post experiment.

4. Discussion

The participants had a practice period between the experiments. However, the skill to control the ball rotation was considered not to be significantly improved after the practice period. However, the mean absolute value of ball rotation in the post experiment was smaller than 1.0 rev/s in both components. This meant that the result satisfied the required condition according to the previous study, in addition to accomplishing the task of this research.

The hip joint torque did not change significantly in the post experiment, except for the result of the inner torque of the curve kick. Flexion torque was considered dominant in the straight kick in the pre experiment, and it did not change in the post experiment. The knuckle kick exhibited a similar trend to the straight kick, in that flexion torque was dominant throughout the experiments. The curve kick exhibited a slight difference, in that adduction torque had an equivalent value to flexion torque in the pre experiment. However, that trend changed slightly in the post experiment, as flexion torque increased and adduction torque decreased (with a loss in significant difference against the knuckle kick). The trend of the curve kick was considered similar to that of the knuckle kick. Furthermore, inner torque, which significantly increased in the post experiment, was considered adjusted to gain side rotation of the ball.

Foot posture is considered a largely effective factor to control ball rotation, and is generated by the joint torque of the lower limb. The pitch angle at the impact of the curve kick increased by 3.0 degrees in the post experiment, and was the only variable with significance in all components compared between the pre and post experiments. The decreasing roll and increasing yaw angles of the curve kick in the post experiment indicated that the characteristics of the curve kick, which uses the inside of the kicking foot toward the ball, might have changed slightly, by transitioning the impact area from the inside to the upper foot, for example. This matched the trend of the hip joint torque of the curve kick becoming similar to that of the straight kick. The roll angle increased by 2.4 degrees, and the yaw angle decreased by 2.9 degrees in the post experiment of the knuckle kick. Although

there was no significant difference, the amount of changes were considered equivalent to that of the pitch angle of the curve kick (3.0 degrees). Several degree changes in foot posture can affect ball rotation because of the complexity of the kicking foot shape. The foot posture of the knuckle kick was considered to become similar to that of curve kick, unlike the hip joint torque becoming similar to that of the straight kick.

The straight kick is considered to hit the ball with the instep of the foot, because of the low pitch angle (toe down), the low roll angle (adduction) and the higher yaw angle (weak external rotation). Furthermore, leg swing with a dominant hip flexion can create a higher foot velocity. Creating a high ball velocity for the straight kick is reasonable. However, the curve kick hits the ball with the inside of the foot because of the higher pitch angle (almost horizontal) and the smaller yaw angle (strong external rotation). However, the characteristics of the curve kick changed slightly, and resembled the straight or knuckle kicks, as mentioned above. Contrary to the curve kick changes, the foot posture of the knuckle kick resembled that of the curve kick. The increase in the adduction of the hip joint torque in the post experiment (even though there was no significant difference because of a large SD) may suggest that the intermediate form of the straight and curve kicks was suitable for the knuckle kick that required a slow spinning ball.

The curve and knuckle kicks exhibited a large external foot posture (small yaw angle) in the experiments, although they aimed to produce different ball rotations. External foot posture is considered suitable to control both the increase and decrease in the ball rotation. The reason for the result of no significant difference may be the diversity in the approaching foot posture, depending on the large standard deviation. In particular, we considered that there are many approaches to the knuckle kick that can prevent the ball from rotating.

Trends in the hip joint torque were different. However, the flexion component in all types of kicks increased in the post experiment. A large ball velocity was considered to be required in all types of kicks. Furthermore, participants could control the ball rotation by hip joint torque, difference in foot posture and the shift of the impact point.

5. Conclusions

In this study, we captured kick motion data of pre and post experiments for a practice period to learn the skill of the knuckle kick. Subsequently, we obtained results as follows:

- In the straight kick, the flexion torque of the hip joint was dominant, and the instep of the kicking foot faced toward the ball at the impact.
- In the curve kick, the adduction torque of the hip joint was dominant in the pre experiment. However, that characteristic changed slightly in the post experiment, such that it resembled that of the straight or knuckle kicks.
- In the knuckle kick, the flexion torque of the hip joint was dominant in the pre experiment. The increasing adduction torque and foot posture indicated that the hip joint torque and foot posture of the knuckle kick resembled that of the curve kick.
- Foot external posture is suitable to control both the increase and decrease in ball rotation. However, the approach to prevent the ball from rotating is variable, particularly in the knuckle kick.
- After the practice period, flexion torque of the hip joint increased in all types of kick. Therefore, a large ball velocity may be required in all types of kicks, even for the curve kick that requires side ball rotation, and participants may control the ball rotation by sliding the impact point of kicks with a different foot posture.

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