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Original

Kinematic Analysis of Punt Kick in Football Goalkeepers Based on the Level of Kick Effort

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Abstract: In the present study, we aimed to investigate the differences in punt kicks by football goalkeepers based on the level of effort required. Twelve experienced goalkeepers participated in the study. The participants were instructed to kick the ball as far as possible in the maximum distance trial (100% trial) and to have a more controlled approach for the 80% and 60% trials. Each punt kick was divided into three events: release of the ball from the left hand (BR), pivot foot ground-contact (LFC), and ball impact (IMP). Right lower limb joint velocity, right hip and knee joint angles, flight distance, ball velocity, and kick angle were calculated. The 80% and 100% trials yielded almost the same velocity for each part of the right leg; however, in the 60% trial, the level of kicking effort was managed by adjusting the velocity of the right ankle joint, starting from BR, in addition to adjustment of the velocity of the right knee joint at LFC. Compared to punt kicks with a lower level of effort, the punt kicks with a higher level of effort involved an increase in the hip joint extension angle for the right leg during the backswing and the lowering of the knee joint angle of the right leg at the start of the forward swing, thus producing forward swing velocity for the right foot.

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Key words: motion analysis, football, goalkeeper, punt kick

Introduction

In football, goalkeepers are the only players on the field who are allowed to use their hands while playing. The main objective of a goalkeeper is to protect the goal and prevent the opponent team from scoring. A team's attack starts once the goalkeeper has possession of the ball; therefore, the goalkeeper is not only a cornerstone of defense but also the player who initiates attacks. In general, goalkeepers have 2 ways of passing—either by throwing grounders and liners to teammates on the same side of the field or close to the half line, or by kicking and sending the ball high into the air toward a teammate on the opponent's side of the field. The ultimate aim of an attack in football is to kick the ball into the opponent's goal, which requires techniques for quick connecting passes that would allow the team to score with few passes. Therefore, a kicked pass from the goalkeeper is believed to be an ideal means to send the ball to a teammate who is close to the opponent's goal, as long as sufficient distance and accuracy are achieved. At present, football is characterized by a very high level of competition and evolved tactics that have reduced the amount of space in which a player can maneuver as well as the time for playing and situation assessment (Lees and Nolan, 1998). In an attack, it is important that the ball is transported to the front of the opponent's goal with as few passes as possible. Kick accuracy and the technique to send the ball over long distances are currently considered elements of good goalkeeping in football (Wesson, 2002). Improvements to the kick technique are therefore critical to improving the level of play of the goalkeeper.

The Japan Football Association Technical Committee (2002), in their Soccer Coaching Book (Goalkeeper Series), enumerated guidelines for punt kicks that include the approach, positioning of the standing leg, flexibility of the standing leg, firmness of the surface of contact, manner of separation from the ball, and ability to see the ball well. However, these are only guidelines, and the book does not describe the types of actions that work well; therefore, proper training is still necessary to develop good goalkeepers.

Many studies have attempted to clarify the mechanisms underlying kicking techniques in football—some of these assessed inside kicks (Levanon and Dapena, 1998; Nunome et al., 2002) or instep kicks (Dewitt and Hinrichs, 2012; Lees and Nolan, 2002; Levanon and Dapena, 1998; Nunome et al., 2002; Roberts et al., 1974; Robertson and Mosher, 1985; Teixeira, 1999), while others assessed the performance of drop and punt kicks by the goalkeeper (Kermond and Konz, 1978; Bloomfield et al., 1979; McCrudden and Reilly, 1993; Linthorne and Patel, 2011). However, very few studies have specifically addressed techniques for punt kicking by the goalkeeper. Thus, evidence for specific improvements in punt kick techniques for goalkeepers is limited.

In the actual game, although a punt kick of the goalkeeper changes the level of effort in many ways, not much research on the influence of the difference in the level of effort on kicking motion. Considering that a difference in the level of effort will have an influence on the regulation of motion mainly of a swing leg, we hypothesized that clarifying a difference in the swing leg motion would lead to elucidation of the punt kick motion of the goalkeeper. In addition to the method of instruction used on the field so far, the knowledge gained by uncovering this hypothesis can be considered as being capable of making the guidance further detailed.

Accordingly, in the present study, we aimed to investigate differences in punt kicks by football goalkeepers based on the level of effort required and to determine basic techniques to help improve punt kick accuracy and distance.

Methods

Participants

The participants in the present study were 12 male goalkeepers from a Division 1 university football league, who were presumed to have no major differences in their punt kicking ability by the three coaches. All were right leg-dominant players (Table 1). They were informed about the objectives and experimental methods of the study and provided informed consent for participation. All procedures were approved by the Institutional Review Board. The participants wore athletic training clothes and their own football boots. Each participant was provided an unlimited amount of time for stretching and kicking drills.

Table 1. Characteristics of the subjects.

	Mean ± SD	Range (max–min)
Height (m)	1.78 ± 0.06	1.88–1.73
Body weight (kg)	72.6 ± 4.8	78.0–66.0
Age (yrs)	20.7 ± 1.0	22.0–19.0
Career of competition (yrs)	12.0 ± 2.4	15.0–9.0
CV of the 100% kicking	2.6 ± 0.9	3.6–1.3

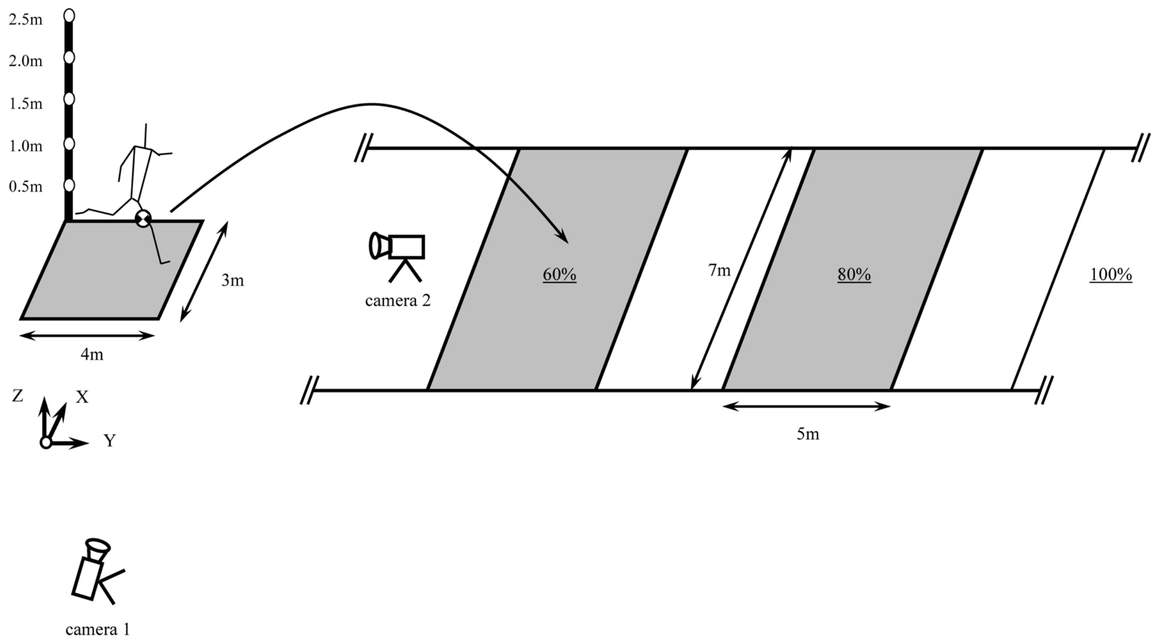

Figure 1. Experimental set up in this study.

Experimental trials

First, the maximum distance (100%) of each kicker's punt kick was measured, and a frame (5.0-m long and 7.0-m wide) was placed at 80% and 60% of the maximum distance. Thereafter, the goalkeeper aimed punt kicks at the frames (Figure 1). For the 100% trial, the participants were asked to kick the ball as far as possible. For the 80% and 60% trials, a more controlled approach was required, with the aim of kicking the ball into the frame. The participants elected to use a short run-up of 2–5 steps. For each trial, participants were asked to formulate a 5-point assessment (5, very good; 3, normal; 1, very bad) that comprehensively considered the trajectory, rotation, control, and distance of the ball. The participants were performed kick up into three times at the frame in each level of effort, and the trials that received the highest assessment scores for each level of effort were subjected to analysis. The coefficient of variation at the time of the kick of 100% of each participant showed in Table 1. All of the punt kicks used in the present study were those normally used in the competitive field. The order of the trials for each level of effort following the 100% trial was determined randomly and included at least a 2-min rest before the next trial.

Data collection

The experiments were performed in a stadium, on the artificial turf used by teams of the university football league. An imaging area, 3.0 m in the right-left direction (X-axis), 4.0 m in the kicking direction (Y-axis), and 2.5 m high (Z-axis), was calibrated using a calibration pole consisting of 5 control points (Figure 1). Two high-speed cameras (HSV-500C^3; NAC Inc., Tokyo, Japan) were placed in the front of and to the right of the kicker, perpendicular to the primary plane of motion. They were positioned 30 m from the kick area and 2.0 m above the playing surface. The experimental trials were videotaped at a frame rate of 250 Hz and an exposure time of 1/1000 s.

The video images were digitised with a motion analysis software (Frame-DIAS system; DKH Inc., Tokyo, Japan) by using 24 points model of the participants and 1 ball point, as well as control points established every 1.0 m in the X- and Y-axis and at 0.5 m in the Z-axis within the imaging area. A 24 point model was used, including the centres of the left and right mid-toes, heels, ankles, knees, hips, ribs, shoulders elbows, wrists, hands, ears and upper sternum, top of head. Markers were directly placed on the player's skin or clothing. All digitising was performed by the same operator so as to maximise the consistency of the measured values. A direct linear transformation method (Abdel-Aziz and Karara, 1971) was employed to calculate 3D coordinates from the 2D coordinates of the 24 points model and control points of 2 video images. The minimal and maximal values of the standard deviation in the calculated 3D coordinates of the 24 points model were as follows: X-axis, 0.005–0.012 m; Y-axis, 0.006–0.015 m; and Z-axis, 0.004–0.013 m.

The 3D coordinates were smoothed with a fourth Butterworth low-pass digital filter. The optimal cut-off frequency was determined by the residual error method proposed by Wells and Winter (1980), and the optimal cut-off frequencies ranged from 3.0 to 14.0 Hz.

Data analysis

To assist with the analysis, each punt kick was divided into three events: release of the ball from the left hand (BR), pivot foot-ground contact (LFC), and ball impact (IMP).

Flight distance of the ball

The kick for each level of effort was performed from within the established imaging area, and the distance travelled by the ball was defined as the rectilinear distance to the point where the ball landed (Figure 1).

Ball velocity

The ball velocity was defined as the average resultant velocity between 1 frame and 4 frames immediately after the ball left the right foot, with no smoothing applied for the ball.

Ball kick angle

The vertical angle of the ball was defined as the angle formed by the Y-axis vector on impact and a vector from the time of impact to that after 4 frames, with the movement of the ball being projected onto the YZ plane (Figure 2).

Right lower limb joint velocity

3D coordinate data were numerically differentiated to calculate the resultant velocity of the right ankle, right knee, and right hip joint.

Right lower limb joint angles

1. Right hip joint angle

Two angles, flexion/extension (flex–ext) and adduction/abduction (add–abd), were measured for the right hip joint. A vector from the left hip joint to the right hip joint served as the x'_{lt} axis, and a vector from the midpoint of the 2 hip joints to the midpoint of the 2 shoulder joints served as the z_{lt} axis. The y_{lt} axis was calculated from the cross product of the z_{lt} and x'_{lt} axes, and the x_{lt} axis was calculated from the cross product of the y_{lt} and z_{lt} axes, to establish a lower torso coordinate system.

1.1. Right hip joint flex–ext angle

The vector from the right shoulder joint to the right hip joint and the vector from the right hip joint to the right knee joint were projected onto the $y_{lt}z_{lt}$ plane in the lower torso coordinate system. The angle formed by the 2 projected vectors served as the right hip joint flex–ext angle. An instance was considered to be positive (+, flexed position) if the thigh was to the front with respect to the vector from the shoulder joint to the hip joint (Figure 3).

1.2. Right hip joint add–abd angle

The vector from the right shoulder joint to the right hip joint and the vector from the right hip joint to the right knee joint were projected onto the $x_{lt}z_{lt}$ plane in the lower torso coordinate system. The angle formed by the 2 projected vectors served as the right hip joint add–abd angle. An instance was considered to be positive (+, adducted position) if the thigh was to the inside with respect to the vector from the shoulder joint to the hip joint (Figure 3).

2. Right knee joint angle

The angle formed by the vector from the right knee joint to the right ankle joint and the vector from the right knee joint to the right hip joint served as the right knee joint angle (Figure 3).

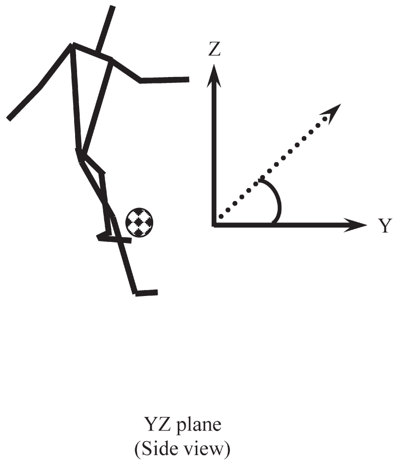

Figure 2. Angle definition of ball kicking.

Statistical analysis

The right lower limb joint velocity, right hip and knee joint angles, flight distance, ball velocity, and kick angle were compared using a 2-way repeated-measures analysis of variance (level of effort×event) to investigate the interaction of the event and level of effort, and the main effects of the event and level of effort. The level of significance was set under 5%. As multiple comparisons were made, a Bonferroni adjustment was performed to adjust the α-level. All statistical analyses were conducted with SPSS v.17.0 (SPSS Inc., Chicago, IL, USA).

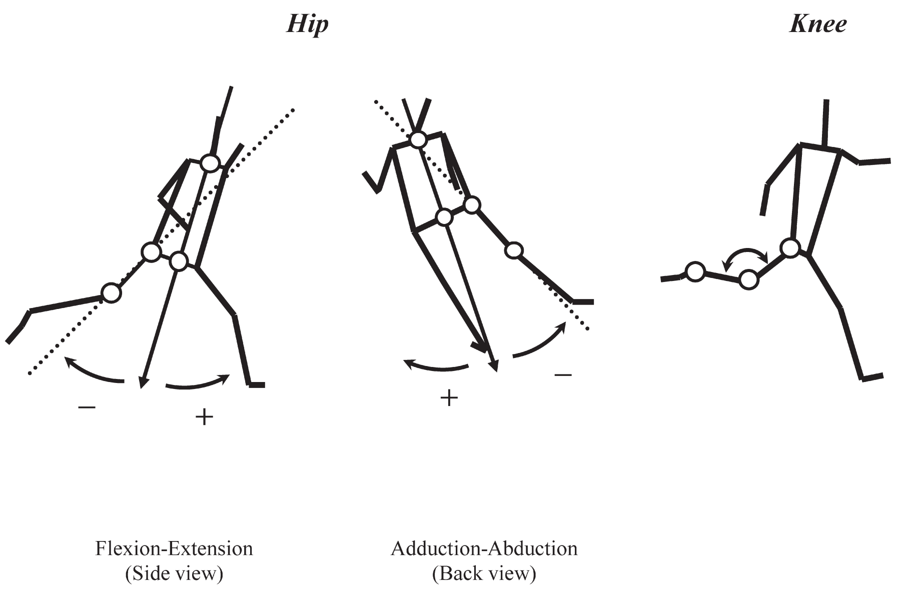

Figure 3. Definitions of the right lower limb angles.

Table 2. Velocity of the right lower limb joint (Mean ± SD).

		60%	80%	100%
Hip	BR	2.8 ± 1.0	3.1 ± 1.0	3.2 ± 0.9
	LFC	5.6 ± 1.9	5.8 ± 1.5	6.0 ± 2.4
	IMP	2.5 ± 0.8	2.5 ± 1.2	2.6 ± 1.1
Knee	BR	3.1 ± 2.2	3.3 ± 1.6	3.6 ± 2.2
	LFC	10.2 ± 1.3 ※	12.5 ± 2.1	13.5 ± 1.9
	IMP	5.4 ± 0.8	5.5 ± 1.0	5.5 ± 0.8
Ankle	BR	2.5 ± 1.2 ※	3.2 ± 1.1	3.8 ± 1.4
	LFC	9.0 ± 1.3 ※	11.2 ± 1.4	11.8 ± 1.2
	IMP	16.5 ± 1.2 ※	19.8 ± 1.2 †	22.5 ± 1.3

Unit: m/s
※ : Significant difference: 60% vs. 80%, 100% ($P < 0.05$)
† : Significant difference: 80% vs. 100% ($P < 0.05$)

Table 3. Angle of the right hip joint (Mean ± SD).

	60%		80%		100%	
	Flex–ext	Add–abd	Flex–ext	Add–abd	Flex–ext	Add–abd
BR	29.5 ± 15.2	1.7 ± 3.3	30.2 ± 14.2	3.5 ± 4.6	30.8 ± 11.6	3.6 ± 5.2
LFC	− 22.5 ± 10.8	− 14.2 ± 4.8 ※	− 24.1 ± 8.7	− 10.2 ± 6.1	− 26.3 ± 9.2	− 9.5 ± 4.1
IMP	36.3 ± 9.1	− 54.2 ± 4.8 ※	38.9 ± 11.7	− 48.2 ± 6.1 †	40.4 ± 8.5	− 39.1 ± 7.4

Unit: deg
※ : Significant difference: 60% vs. 80%, 100% ($P < 0.05$)
† : Significant difference: 80% vs. 100% ($P < 0.05$)
Flex–ext: Flexion (+)–extension (−), Add–abd: Adduction (+)–abduction (−)

Table 4. Angle of the right knee joint (Mean ± SD).

	60%	80%	100%
BR	132.3 ± 4.2	130.8 ± 5.1	131.2 ± 6.4
LFC	88.7 ± 3.6※	84.1 ± 2.6 †	80.2 ± 3.1
IMP	154.3 ± 5.5※	158.8 ± 4.2 †	161.6 ± 4.4

Unit: deg
※ : Significant difference: 60% vs. 80%, 100% ($P < 0.05$)
† : Significant difference: 80% vs. 100% ($P < 0.05$)

Table 5. Flight distance, ball velocity and kick angle (Mean ± SD).

	60%	80%	100%
Flight distance (Unit: m)	31.0 ± 7.2 ※	41.0 ± 8.1 †	52.0 ± 9.3
Ball velocity (Unit: m/s)	23.2 ± 2.7 ※	27.1 ± 3.4	29.4 ± 4.0
Kick angle (Unit: deg)	YZ plane 23.0 ± 7.2 ※	YZ plane 29.6 ± 5.3	YZ plane 32.0 ± 7.3

† : Significant difference: 80% vs. 100% ($P < 0.05$)
※ : Significant difference: 60% vs. 80%, 100% ($P < 0.05$)

Results

Table 2 shows the right lower limb joint velocity by the level of effort for each event. At the right hip joint, no significant difference was observed at any event for the levels of effort. At the right knee joint, a difference was found only between the 60% trial and the 80% and 100% trials at the LFC event; the velocity in the 60% trial was significantly lower. At the right ankle joint, a difference was found between the 60% trial and the 80% and 100% trials from the BR to the IMP event, and also between the 80% trial and the 100% trial at the IMP event; the 100% trial had a significantly higher velocity.

Table 3 shows the right hip joint flex–ext and add–abd angles by the level of effort for each event. The right hip joint flex–ext angle showed no significant difference between the levels of effort at any event. However, there was a significant difference in the right hip joint add–abd angle between the 60% trial and the 80% and 100% trials at the LFC event—the lower the level of effort, the greater the angle of abduction. There was also a significant difference between the IMP event in the 60% trial and the 80% and 100% trials, as well as between the 80% trial and the 100% trial—the lower the level of effort, the greater the angle of abduction.

Table 4 shows the right knee joint angle by the level of effort. At the BR event, no significant difference was observed in any of the levels of effort. At the LFC event, a significant difference was found between the 60% trial and the 80% and 100% trials, and between the 80% trial and the 100% trials—the lower the level of effort, the greater the right knee joint angle. Similarly, at the IMP event, a significant difference was found between the 60% trial and the 80% and 100% trials, as well as between the 80% trial and the 100% trial—the higher the level of effort, the greater the right knee joint angle.

Table 5 shows the flight distance, ball velocity, and ball kick angle by the level of effort. For flight distance, differences between the 60% trial and the 80% and 100% trials, and between the 80% trial and the 100% trial were observed—higher levels of effort produced significantly greater distances. The 60% trial had a significantly lower ball velocity than the 80% and 100% trials. In terms of the ball kick angle, the 60% trial had a significantly smaller ball kick angle than the 80% and 100% trials. The 100% trial had the greatest angle in the YZ plane, and the angle decreased as the level of effort decreased.

Discussion

Kermond and Konz (1978) indicated that the movement of the swing leg is a more important consideration than the movement of the support leg during a punt kick in football. Therefore, we investigated the swing leg in the present study.

For the right lower limb joint (Table 2), there was no significant difference at any event for any of the levels of effort for the right hip joint. In contrast, the right knee and right ankle joint showed significant differences. The right knee joint differences were apparent at the LFC event, while the right ankle joint differences were observed at all events, with the 60% trial showing a lower velocity than the 80% and 100% trials. According to Winter (2005), the trunk has the greatest mass and moment of inertia, followed by the thigh, shank, and foot. Moreover, the central part of the body is able to exert greater force and energy than the extremities. Therefore, because a greater velocity is required of the right lower limb joints in the 80% and 100% trials to kick the ball farther than in the 60% trial, it might be more effective to start the kick with movement of the trunk because it has the greatest mass and moment of inertia. However, the kicking action may need to be adjusted when attempting to kick the ball to a target area. Accordingly, the kicking action is performed at essentially the same velocity for the right lower limb joints in the 80% and 100% trials. However, in the 60% trial, adjustment of the right ankle joint velocity from the BR to the IMP event and of the right knee joint velocity at the LFC event appears to have contributed to the controlled level of effort. Therefore, when compared with the 80% and 100% trials, an increase in the right lower limb joint velocity was not required in the 60% trial, where the required kick distance was less than that of the 80% and 100% trials. Furthermore, the 60% trial can be initiated by moving the thigh, which has the second highest mass and moment of inertia, followed by adjustment of the movement velocity of the shank.

The right hip joint flex–ext angle (Table 3) was not significantly different between the trial types at any event. However, at the LFC event, the 100% trial had the greatest extension, followed by the 80% trial and 60% trial. Therefore, at the LFC event, the right leg movement occurs during the back swing and appears to represent an action during which extension of the right hip joint was adjusted based on the kick distance; a greater right hip joint extension during a back swing yields a greater distance for forward swing of the right leg. At the LFC, the right hip joint add–abd angle (Table 3) was significantly different between the 60% trial and the 80% and 100% trials. The 60% trial had a greater angle of abduction than either of the other trials. Significant difference between the 60% trial and the 80% and 100% trials and between the 80% trial and the 100% trial were also found at the IMP event. The 60% trial had the greatest and the 100% trial had the smallest abduction angle. A smaller abduction angle of the right hip joint indicates that the foot has a more vertical impact on the ball, whereas a greater abduction angle indicates that the foot has a more horizontal impact on the ball. With a small abduction angle, the ball can be kicked up from below, and the ball-kicking angle in the YZ plane can be increased. In contrast, with a large abduction angle, the ball is kicked from the side, and it becomes difficult to increase the ball-kicking angle in the YZ plane. Therefore, adjustment of the abduction angle will also adjust the ball-kicking angle in the YZ plane. Linthorne and Patel (2011) reported that the optimum projection angle in a punt kick is close to 45° because the projection velocity of the ball remains almost constant across all projection angles. This differs from throwing and jumping, during which the projection velocity decreases substantially at high projection angles (Hubbard et al., 2001; Leigh et al., 2010; Red and Zogaib, 1977; Viitasalo et al., 2003; Wakai and Linthorne, 2005). Moreover, kicking differs from throwing and jumping in that the projection velocity is generated during an impact between the player and the projectile (i.e., the ball). Similarly, based on the ball-kicking angle results in the present study (Table 5), the angle in the YZ plane was greatest for the 100% trial, followed by the 80% trial and 60% trial. This suggests that the abduction angle should be lowered to perform a kicking action that will result in the leg being raised when a greater kick distance is desired. However, for greater kick control, increasing the abduction angle is likely an effective measure.

There were significant differences between the 60% trial and the 80% and 100% trials and between the 80% trial and the 100% trials in the right knee joint angles at the LFC event (Table 4). The kickers exhibited greater right knee joint angles during the 60% trial than during the other trials. At the IMP event, significant differences were also found between the 60% trial and the 80% and 100% trials and between the 80% trial and the 100% trial. The 100% trial had the greatest right knee joint angle in comparison with the other trials. This might indicate that the movement of the right leg at the LFC event occurs during the back swing, as is the case with the right hip joint flex–ext angle. Moreover, a smaller right knee joint angle toward the forward swing after the back swing enables the moment arm to be lowered and can be expected to generate swing velocity for the foot, as indicated by the greater flexion of the right knee joint in the trials that involved a greater level of effort. This is also related to the right lower limb joint velocity (Table 2) for the different levels of effort and suggests that right hip joint flexion is also influenced; the 100% trial had the greatest ball velocity, followed by the 80% trial and 60% trial, similar to the right ankle joint velocity upon impact. This finding suggests that the right hip joint and right knee joint flex–ext angles are adjusted to produce velocity for the forward swing, thus leading to the differences in the ball velocity.

In this study, many similar tendencies were observed between 80% and 100% trials, while compared with 80% and 100% trials, a different tendency was clearly observed in 60% trials. It would be extremely interesting to see what is between 60% and above 80% trials. However, we would like to investigate as the future study because we were not able to clarify from the result of this study about these differences.

Conclusion

The results for right lower limb joint velocity showed that the 80% and 100% trials yielded largely the same velocity for each part of the right leg. However, in the 60% trial, the lower level of effort was managed by adjusting the velocity of the right ankle joint starting from the BR event in addition to adjusting the velocity of the right knee joint at the LFC event. Compared to the punt kicks with a lower level of effort, the punt kicks with a higher level of effort involved a greater hip joint extension angle for the right leg during the back swing and a smaller knee joint angle of the right leg at the start of the forward swing, thereby producing forward swing velocity for the right foot. Furthermore, the punt kicks with a controlled level of effort involved adjustment not only of the forward swing velocity of the right foot to control the velocity of the ball but also the hip joint abduction angle of the right leg to control the ball-kicking angle in the YZ plane.

Our findings show that the level of effort in punt kicking by the football goalkeeper is adjusted by using the forward swing velocity of the right foot to adjust the ball velocity in addition to the hip joint abduction and knee joint angles of the right leg. The results also demonstrate that the hip joint of the right leg undergoes greater abduction with a lower level of effort for the kick, thus suggesting that abduction of the right hip joint could become a focal point of guidance for adjusting the level of effort.

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