RELATIONSHIP OF MOTIONS BETWEEN THE ARM AND THE LEGS IN THE DIVING MOTION OF SOCCER GOALKEEPERS

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The purpose of this study was to clarify the relationship between the hand movement of the goalkeeper (GK) and the velocity of center of gravity (CG) in diving motion towards various heights and distances. Three male university GKs dived towards the shot. Three male university forward players performed instep kicking to twelve shot areas by forward dribbling. Three-dimensional (3D) coordinates of the body landmarks and ground reaction forces were obtained with a 3D motion capture system and two force platforms. The novel findings in this study were summarized as follows: (1) GKs changed not only the height of their CG but also the motions of their trunk and arm according to the shot heights; (2) exerting elbow joint torques is important for GKs to dive towards the near upper and near middle places; and (3) it is assumed that not only accelerating the CG but also the trunk and arm motions are necessary for the evaluation of diving skills for GKs.

KEY WORDS: kinematic contribution, arm motion, joint torques

INTRODUCTION: In soccer games, an important factor for winning the game is not only scoring but also preventing opponents from scoring. Thus, the performance of the goalkeeper (GK) also affects the result of soccer games. In previous studies of game performance analysis of GKs (Sainz De Baranda, Ortega, and Palao, 2008; Numazu, Fujii, Nakayama, and Koido, 2016), it is reported that GKs dived most frequently of all the motions done by them in games. In the biomechanical analyses of the GK diving motion (Isokawa, Sakuma, Togari, Ohashi, and Suzuki, 1986; Matsukura and Asai, 2013), it is reported that exerting leg extension torques for accelerating the center of gravity (CG) is an important factor for the diving motion for GKs. In general, it is assumed that GKs cannot always save all the shots even if they have obtained the fast CG velocity in diving. Furthermore, it is thought that GKs mainly use their hand when they save the fast shot at various heights with diving. However, the relationship between the hand movement of the GK and acceleration of his CG while diving to the shot is still unclear. Therefore, the purpose of this study was to clarify the relationship between the hand movement of the GK and CG velocity in diving motion towards various heights and distances.

METHODS: Three male university GKs (heights: 1.80 ± 0.03 m, body mass: 73.0 ± 4.3 kg) and three male university forward players (heights: 1.72 ± 0.07 m, body mass: 67.7 ± 9.2 kg, and preferred leg: right leg) participated in the present study. The kicker stands 16.5 m away from the GK. We conducted experiments under the mimic real shooting situation in reference to Numazu, Fujii, Nakayama, and Koido (2016). Figure 1 shows a kicking direction map. We instructed only the kicker in the shot area by using the map before each trial. The trials were of a random order. Twelve areas were set as shot conditions (two shot directions, two shot distances, and three shot heights) in reference to Matsukura and Asai (2013). Shot directions were set for rightward and leftward. Shot distances from the GK were set for near and far (near is 1.8 m away from the GK, and far is 1.8 to 3.6 m away from the GK). Shot heights were set for lower (from 0 to 0.8 m high), middle (0.8 to 1.6 m high), and upper (from 1.6 to 2.4 m high). Furthermore, we asked the kickers to perform instep kicking to the shot area with forward dribbling. GKs were instructed to dive with preparatory motion towards the shot. Three-dimensional coordinate data of the diving motion (body, 47 reflective markers; ball, 4 reflective markers) was measured with a motion capture system (VICON-MX, Vicon Motion Systems, 16 cameras, 250 Hz). Ground reaction forces of both legs were measured using two force platforms (9287B, 9287C, Kistler, 1000 Hz). We analyzed 6 trials. In each shot area, one trial which both kicker and keeper evaluated “good kicking and diving trial” was selected for further analysis. Coordinate values were smoothed using a Butterworth low-pass filter with optimal cut-off frequencies (8-25 Hz), which were determined by the residual error method (Wells and Winter, 1980). The ball center was estimated from the coordinate values of the ball markers using the least-square method. For these analyses, the coordinates of the leftward diving trials were converted to rightward diving trial. The right leg was defined as the ipsilateral (IS) leg, and the left leg was defined as the contralateral side (CS) leg.

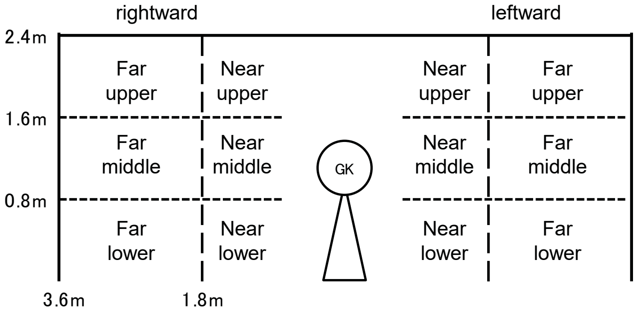

Figure 1 Shot areas

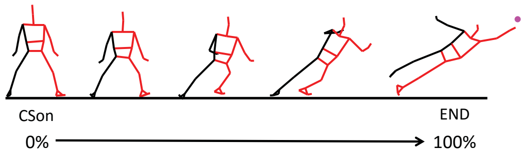

Figure 2 Analysis events

Figure 2 shows the analysis events. The time of grounding after preparatory motion was defined as CSon by using force platform. The time, at which the distance between the ball-touching side hand and ball center was minimal was defined as the end of analysis (END). The hand which the distances between each hand and ball center were shorter defined as ball-touching side hand. To normalize a diving motion, CSon and END were defined as 0% and 100% time respectively.

The trunk angle was defined as the angle between the segment and vertical line. An inverse dynamics approach with a three-rigid-segment model consisting of the hand, forearm, and upper arm was used to calculate joint torques of the elbow and shoulder joints of the ball-touching side arm. The joint torque was normalized by the body mass of the subject. Further, the magnitude of each joint torque was integrated from CSon to END.

The relationship between the CG and ball-touching side hand position can be formulated as follows:

$$\mathbf{Hand} = \mathbf{trunk} + |\mathbf{r}_{\mathrm{trk}}| \cdot \hat{\mathbf{r}}_{\mathrm{trk}} + |\mathbf{r}_{arm}| \cdot \hat{\mathbf{r}}_{arm} \qquad (1)$$

where, $\mathbf{Hand}$ is the coordinate value of the ball-touching side hand, $\mathbf{trunk}$ is the coordinate value of the center of the lower end of right and left ribs, $\mathbf{r}_{\mathrm{trk}}$ is a vector from $\mathbf{trunk}$ to the ball-touching side shoulder, and $\mathbf{r}_{\mathrm{arm}}$ is a vector from the shoulder to the hand, $|\boldsymbol{r}_{\mathrm{trk}}|$ and $|\boldsymbol{r}_{\mathrm{arm}}|$ are magnitudes of $\mathbf{r}_{\mathrm{trk}}$ and $\mathbf{r}_{\mathrm{arm}}$ respectively, $\hat{\mathbf{r}}_{\mathrm{trk}}$ and $\hat{\mathbf{r}}_{\mathrm{arm}}$ are unit vectors along $\mathbf{r}_{\mathrm{trk}}$ and $\mathbf{r}_{\mathrm{arm}}$ respectively. The relationship between CG velocity and the hand movement of the GK can be derived by differentiating the formula (1):

$$\mathbf{V}_{\mathrm{hand}} = \mathbf{V}_{\mathrm{trk}} + \mathbf{t\dot{r}k} + \mathbf{a\dot{r}m} \qquad (2)$$

where, $\mathbf{V}_{\mathrm{hand}}$ is the velocity vector of the hand, $\mathbf{V}_{\mathrm{trk}}$ is the velocity vector generated by the motion of the legs, $\mathbf{t\dot{r}k}$ is the velocity vector generated by the motion of the trunk, and $\mathbf{a\dot{r}m}$ is the velocity vector generated by the motion of the ball-touching side arm.

RESULTS: Figure 3 shows the contributions of the velocities generated by the movements of the legs, trunk, and ball touching side arm to the ball touching side hand velocity along the vertical direction. In all the shot areas, the contribution of the arm movement to the hand velocity was the highest. Further, the arm movement generated the upward velocity. The contributions of the trunk and leg movement were less than the arm movement.

Figure 4 shows the contributions of velocities generated by the movements of the legs, trunk, and ball touching side arm to the ball touching side hand velocity along the horizontal direction. In contrast with the vertical direction, the velocity contribution obtained from the leg motion to the hand motion was the highest. Further, the contributions of velocities obtained by the trunk and hand movements were smaller than the movement in all the shot areas. In 60–90% of the near upper, 90–100% of the near middle, and 90–100% of the far upper, the arm movement generated the leftward velocities. The leg motion in far diving generated more horizontal

velocity than near diving.
Figure 5 shows trunk segment leftward (+) / rightward (-) lean angles in each shot area. In all the shot areas, the trunk leaned rightward. The patterns of the segment angles were almost similar in the upper and lower diving. In the middle diving, however, the patterns of the trunk angle in the near middle were almost the same as those in the near upper, and those in the far middle were almost same as those in the far lower.
Table 1 shows the net angular impulses of the shoulder and elbow joint torques. In the near upper and middle, the elbow joint exerted more joint torques than the shoulder joint.

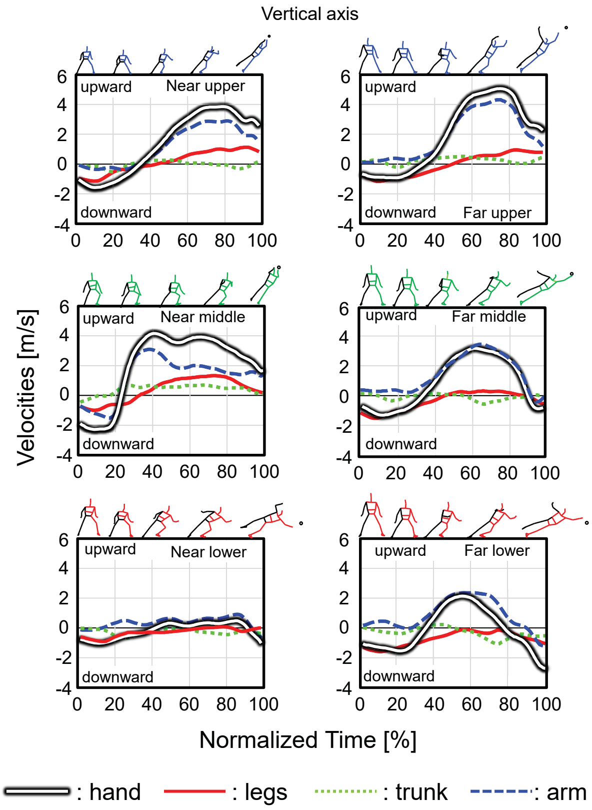

Figure 3 the contributions of velocities generated by the movements of legs, the trunk, and the ball touching side arm to the ball touching side hand velocity in the vertical direction.

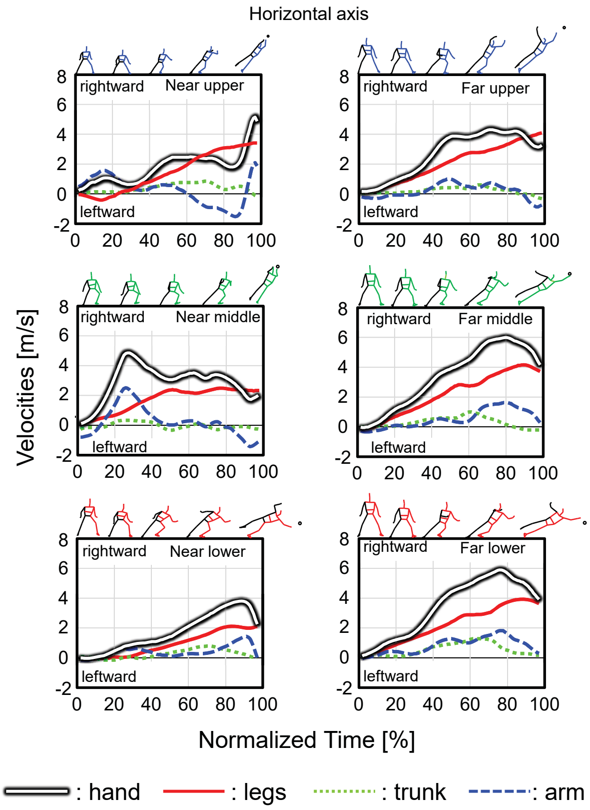

Figure 4 the contributions of velocities generated by the movements of legs, the trunk, and the ball touching side arm to the ball touching side hand velocity in the horizontal direction.

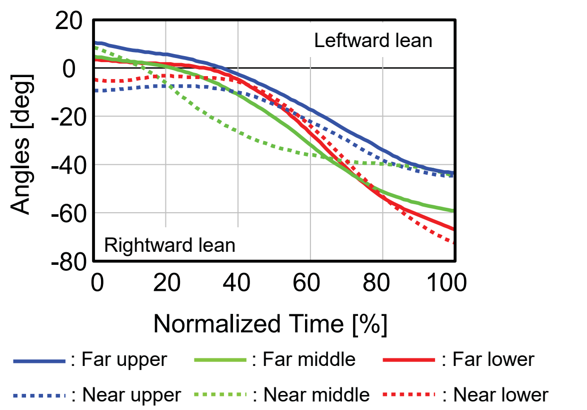

Figure 5 leftward lean (+)/ rightward lean (-) angles of trunk segment in each shot area.

Table 1 Net angular impulses of shoulder and elbow joint torques.

Joint / Shot areas	Net angular impulses [Nms / kg] Shoulder	Elbow
Near upper	0.119	0.729
Near middle	0.008	0.687
Near lower	0.102	0.119
Far upper	0.148	0.055
Far middle	0.139	0.054
Far lower	0.132	0.048

In the near lower, the elbow joint exerted the same joint torque as the shoulder joint. In far diving, the shoulder joint exerted more torques than the elbow joints.

DISCUSSION: In all the shot areas, the GKs generated almost all of hand's velocity in the upward/downward direction by their arm motion by elbow and shoulder motion, and in the lateral direction, they obtained almost of hand's velocity by their legs' motion. Furthermore, the GKs adjusted the trunk angle according to the shot heights. From these results and the previous study (Matsukura and Asai, 2013), the GKs changed not only the height of their CG but also the motion of their trunk and arm according to the shot heights. Thus, these results indicate that accelerating both the CG of the GKs and the motions of the trunk and arm are necessary for the evaluation of the diving skill for the GKs.

In the near upper, far upper, and near middle, the trunk angle was less than the far middle and lower diving. If the GKs lean their trunk more than the middle or lower diving, when they dive towards the upper places, their hand may not touch the ball. The patterns of the trunk angle in the near middle are almost the same as those in the upper diving. Angular impulses of the shoulder and elbow joints in the near middle are different from those in the upper diving. In the near middle, if the GKs exerted more shoulder joint torques, their arm would be extended. In that case, the GKs cannot adjust their hand more accurate position for the shot. Therefore, it can be concluded that the GKs did not exert their shoulder joint torques as the upper diving. Comparing upper and middle diving, GKs exerted more elbow joint torques in near diving than far diving. In near diving, it is assumed that exerting elbow joint torques helped the hand of GKs to reach the shot more quickly and correctly than exerting shoulder joint torques. Furthermore, in far diving, the shoulder joint exerted more torques than the near diving and in near diving, the elbow joint exerted more torques than far diving. Hence, GKs control the joint torques in their arm according to the shot distances. It is assumed that coaches have to be careful when they instruct how to move the GK's arm.

CONCLUSIONS: Regardless of the shot area, the contributions of velocities generated by the movements of the legs, trunk, and ball touching side arm to the ball touching side hand velocity were almost similar. The leg motion mainly contributed to the generation of the lateral direction velocity, and the motions of the trunk and arm played a role in helping their hand movement to adjust more accurately for the shot. The GKs adjusted the exertion of the elbow and shoulder joint torques, and leaning of the trunk and arm according to the shot heights. Thus, coaches have to be careful when they instruct how to move the GK's body according to the shot areas.

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