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Characteristics of movement and force exerted by soccer goalkeepers during diving motion

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Abstract

The purpose of this study was to clarify the fundamental mechanism of a goalkeeper's (GK) diving motion according to the height and distance of the shot. We performed an experiment in which 11 university GKs participated. Their average height was 178.4 cm (SD = 6.2), and average mass was 71.2 kg (SD = 2.5). They were asked to dive toward and touch balls set at three different heights (2.2 m from the ground, 1.22 m from the ground, and safety mat height) located a short or a long distance (1.83 m and 3.50 m, respectively) from the GK. Kinematics and kinetic data were recorded using a three-dimensional motion analysis system (VICON; Oxford Metrix, 250frames/s) and two force platforms (9281A, Kistler Inc. 9287B, Kistler Inc., 1000Hz). By examining the GKs' diving motions, we calculated the position of center of gravity (CG), joint angle, ground reaction force (GRF) and joint torque. The results indicated that the magnitude of the GRF under both legs and the direction of the GRF under the ball-side (BS) leg differed with the ball height. We also found that a higher dive by the GKs corresponded to a larger counter-movement of the contralateral-side (CS) leg and more exertion of extension torques at the hip and foot for take-off compared to those in lower dives ($p < .05$). Furthermore, there were differences in timing of extension of the BS leg.
These findings suggest that during the take-off part of the diving motion of a GK, depending on the ball height the CS leg controls the magnitude of power and the BS leg controls both the magnitude and the direction of power in order for the GK to dive directly towards the ball.

Keywords: soccer; goalkeeper; diving motion; joint angle; joint torque; ground reaction force

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1. Introduction

Most football research has been focused on kick motions performed by field players whereas the technical analysis of goalkeepers (GK) is lacking. Due to the smaller number of GKs relative to field players, such experiments are difficult to carry out because of the problems in gathering a large number of GKs with little difference in skill. Previous diving motion research has been conducted to illustrate the strong relationship between diving and a GK's skill in that proficient players have a higher dive speed and proceed more directly towards the ball than inexperienced players (Suzuki *et al*., 1988). Biomechanical research of diving conducted by Graham-Smith and Lees (1999) indicated that a dive has a different motion depending on the distance and course of the ball flying towards the goal. However, the extant diving motion research has not explained differences in the force exertion or diving movements as a result of the position of the ball toward which the GK is diving. Therefore, clarifying how to control the magnitude and direction of diving motion forces at balls having different heights and distances would be beneficial for diving instruction and the further understanding of diving motions.

In order to delineate the characteristics by which differences in diving motions arise as a response to ball position, this study compared the velocity at which the CG moves as well as changes in lower-body joint angles, GRF, and joint torque.

2. Methods

2.1 Experiment

2.1.1 Test participants

The test participants were eleven male university football team GKs who had an average height of 178.4 cm (SD = 6.2) and an average mass of 71.2 kg (SD = 2.5). All players' diving techniques were noticeably unskilled. Since the experiment was performed indoors, the test participants wore commercially available indoor football shoes. We explained the purpose and details of the experiment, discussed experimental safety, and obtained consent from the participants.

2.1.2 Measurements

Measurements of movements were made using VICON, a three-dimensional automatic motion analysis device manufactured by Oxford Metrics, which involved attaching 47 reflective markers to each participant's body. VICON data were collected at 250 frames per second. In addition, we set up two force platforms (9281A, Kistler Corporation; and 9287B, Kistler Corporation) and measured GRF exerted while diving by using a sampling frequency of 1000 Hz.

2.1.3 Experimental trials

We analysed the diving motions for balls in six locations, made up of two different ball distances (Near: 1.83 m from GKs; and Far: 3.50 m) and three different heights (Upper: 2.20 m from the ground; Middle: 1.44 m; and Lower: balls at safety mat height). Although with Near balls the GKs dove from their initial stance, with Far balls we had each GK first take one sidestep towards the ball and then dive for the ball (Fig. 1).

The participants knew the position of the ball they would dive for prior to each trial. In addition, each run was started at the impetus of the test participant. The test participants were instructed to change their posture as little as possible before the start, move as much as possible towards the ball, and touch the ball with both hands.

2.1.4 Definition of diving motion aspects

We extracted the following four stages of movement on a force plate as part of Near and Far diving motions, classified them into four events (①Start of analysis ②BS touched down ③CS left ④Finish of analysis), and three aspects(Initiation, Transition, Take-off), and used those three aspects for analysis (Fig. 1).

2.2 Smoothing

Obtained coordinates were smoothed with a Butterworth filter. A 5-15 Hz cut-off frequency was determined based on the method described by Wells and Winter (1980).

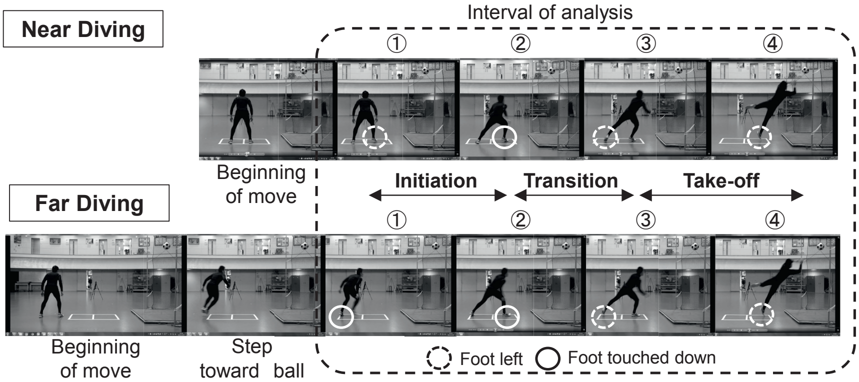


Fig. 1. Example of division of timing during diving actions. Upper figure shows example of Near diving. Lower figure shows one of Far diving. *Start of analysis* (①) for Near diving means Ball Side (BS) foot left the ground, and *Start of analysis* (①) for Far diving means Contralateral Side (CS) foot touched down. Finish of *Initiation* and start of *Transition* (②) means BS foot touched down. Finish of *Transition* and start of *Take-off* (③) means CS foot left the ground. *Finish of analysis* (④) means BS foot took off. Each figure is seen from behind.

2.3 Items measured and calculation method

・ Joint angle
・GRF per unit mass
・Joint torque and angular impulse

2.4 Statistical Processing

For all measured items, we performed a two-way factorial analysis of variance relative to distance and height. For lower verification we used a Bonferroni correction. Statistical analysis was performed with SPSS Statistics 19 software. The level of significance was set at .05.

3. Results

3.1 Leg joint angle changes

The subject's hip and knee joint changes, and the changes in the ankle joint angle axis during plantar flexion and dorsiflexion, were normalized to 100% from the Start of Analysis to Finish of Analysis. Fig. 2 displays the averages. The display of bending and dorsiflexion by the BS leg up until BS Touched Down was similar to the CS leg, but in the stage from BS Touched Down to CS Left, the BS leg started to display extension and plantar flexion during Upper and Middle trials close to BS Touched Down for the hip joint, close to CS Left for the knee joint, and after CS Left for the ankle. In Lower trials (compared to other heights), the time that extension started for each joint was later and occurred close to CS Left. This trend was seen in most test subjects.

3.2 GRF vectors during diving

Fig. 3 shows the normalised time (100% from the Start of Analysis to the Finish of Analysis) for a representative test participant, and for each 10% a stick picture (picture taken from behind the GK with the ball on the right-hand side) is displayed for the height and horizontal and vertical vectors. The horizontal and vertical vectors for the CS leg were higher with higher ball trials, but the same diagonally right direction was seen during all trials. However, the horizontal and vertical vectors for the BS leg had a different magnitude and angles in response to ball height.

3.3 Impulse of GRF

Table 1 shows the average of impulse of GRF with each period. Relative to ball height, for the CS leg, during Initiation the horizontal and vertical impulse of GRF was significantly larger for Upper than Lower. For the BS leg, during Transition horizontal values were significantly larger for Lower than Upper. In contrast, during Take-off vertical values were significantly larger for Upper than Lower.

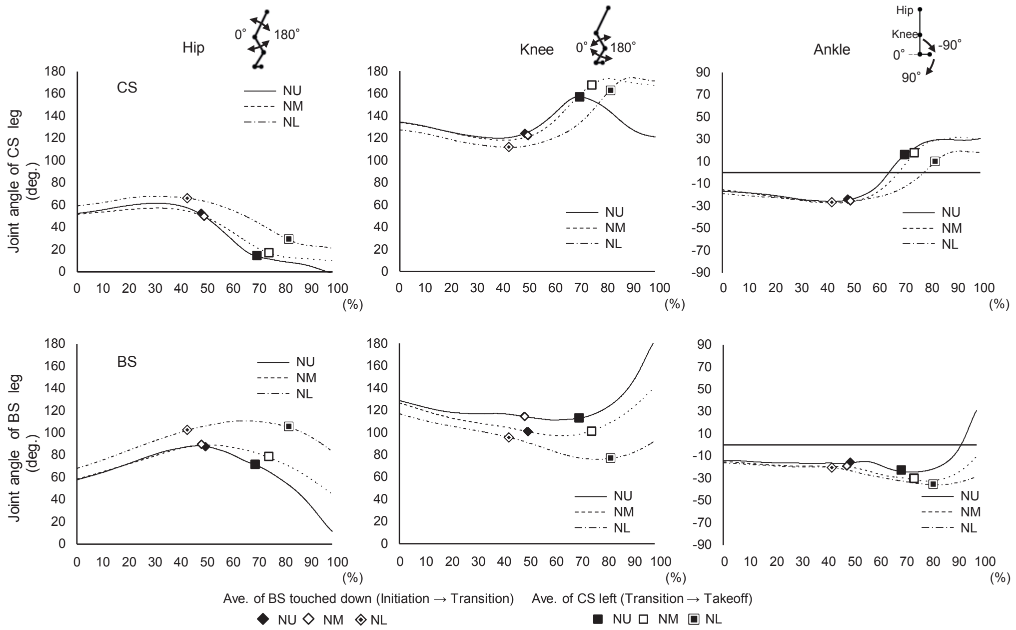


Fig. 2 Average change in joint angle of hip, knee, and ankle. Positive values mean extension (plantar flexion), negative values mean flexion (dorsal flexion). NU (Near Upper), NM (Near Middle), NL (Near Lower). For the hip joint, a completely extended position was taken as 0°, and a completely bent position was taken as 180°. For the knee joint, a completely extended position was taken as 180°, and a completely bent position was taken as 0°. In addition, for the ankle, the state where neither plantar flexion nor dorsiflexion were made was set to 0°, and values were set so that an increasingly negative value was dorsiflexion, and an increasingly positive value was plantar flexion.

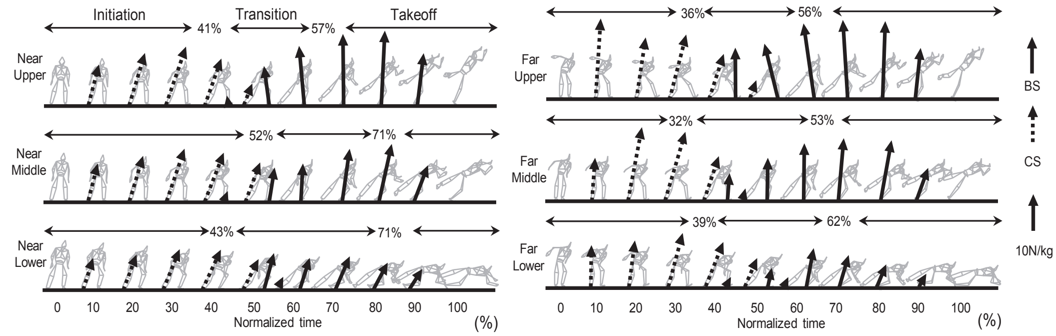


Fig. 3 Typical patterns of changes in diving motion. The stick picture shows the transition of diving motion. It starts from 0% and finishes at 100%. The arrow shows the vector of GRF. Dotted vectors indicate GRF of Contralateral Side leg. Solid vectors indicate GRF of Ball Side leg. The difference in slope and magnitude of the GRF vector can be seen.

3.4 Angular impulse of joint torque

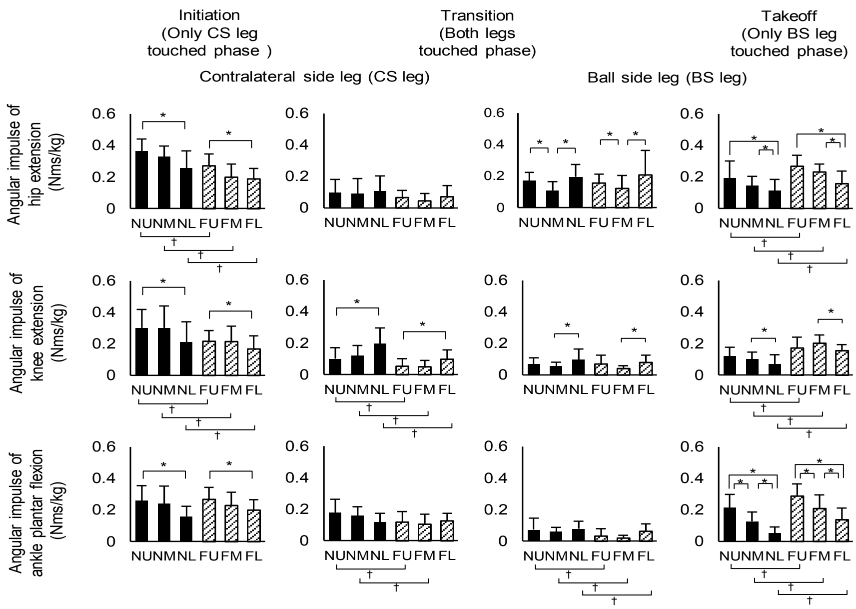
Fig. 4 displays the average angular impulse for extension torque per unit weight due to the hip, knee, and ankle joints during each stage and trial. For the CS leg relative to ball height, during Initiation the hip, knee, and ankle joint values were significantly larger for Upper than Lower trials. During Transition, the knee joint had significantly larger values for Lower than Upper trials. When comparing Near and Far Diving, the knee joint had significantly larger values for Near Diving than Far Diving. During Upper and Middle trials, the ankle had significantly larger values for Near Diving than Far Diving.

For the BS leg relative to ball height, during Transition the hip joint values were significantly larger for Upper and Lower trials than Middle trials, and knee joint values were significantly larger for Lower than Middle trials. During Take-off, hip joint values were significantly larger for Upper and Middle trials than Lower trials, and knee joint values were significantly larger for Middle than Lower trials. The ankle angular impulse was significantly larger in the order of Upper, Middle, and Lower trials. When comparing Near and Far Diving, during Transition ankle joint values were significantly larger for Near Diving than Far Diving. During Take-off, the values for all joints were significantly larger for Far Diving than Near Diving.

Table 1 Impulse of ground reaction force with each period (N/kg).

		Contralateral side leg		Ball side leg	
		Initiation	Transition	Transition	Takeoff
Horizontal GRF (N/kg)	Near Upper	1.37 (0.40)	0.61 (0.31)	0.06 (0.15)	0.22 (0.16)
	Near Middle	1.37 (0.43)	0.71 (0.31)	0.28 (0.17)	0.56 (0.12)
	Near Lower	0.94 (0.45)	0.91 (0.36)	0.57 (0.24)	0.42 (0.23)
	Far Upper	0.75 (0.27)	0.46 (0.26)	-0.13 (0.10)	0.05 (0.24)
	Far Middle	0.75 (0.34)	0.45 (0.24)	0.06(0.08)	0.64 (0.19)
	Far Lower	0.59 (0.23)	0.64 (0.25)	0.16 (0.13)	0.67 (0.21)
Vertical GRF (N/kg)	Near Upper	3.20(0.88)	1.21 (0.66)	1.30 (0.42)	2.38 (1.09)
	Near Middle	3.03 (0.82)	1.25 (0.56)	0.89 (0.29)	1.46 (0.58)
	Near Lower	1.98 (0.95)	1.42 (0.57)	1.31 (0.45)	0.72 (0.44)
	Far Upper	2.56 (0.58)	0.96 (0.53)	0.98 (0.34)	3.00 (0.65)
	Far Middle	2.27 (0.70)	0.87 (0.48)	0.62 (0.28)	2.24 (0.45)
	Far Lower	1.71 (0.50)	1.07 (0.36)	0.96 (0.59)	1.34 (0.49)

* Indicates a significant difference between each heights (P<.05) within each period.
† Indicates a significant difference between near and far diving (P<.05) within each period.



* Indicates a significant difference between each heights (P<.05) .
† Indicates a significant difference between near and far diving (P<.05)

Fig.4 Means of each angular impulse per mass (Nms/kg). Upper figures show hip extension. Middle figures show knee extension. Lower figure shows ankle plantar flexion. NU (Near Upper), NM (Near Middle), NL (Near Lower). FU (Far Upper), FM (Far Middle), FL (Far Lower).

4. Discussion

4.1 Characteristics of exhibited force from differences in diving height

The horizontal and vertical vectors for the CS leg were large when going for a high ball, but the direction taken was approximately in the same diagonally right direction (Fig. 3). In contrast, the magnitudes of the horizontal and vertical vectors, as well as the angles taken, for the BS leg, were largely different due to ball height (Fig. 3). In addition, for the CS leg there was a larger impulse of GRF when the GK dived for Upper balls than Lower balls, but for the BS leg, horizontal GRF was significantly larger for Lower than Upper. In contrast, vertical GRF was significantly larger for Upper balls than Lower balls.

From these findings, it appears that to direct the movement of the CG towards the ball, the CS leg contributes by changing the magnitude of force and the BS leg contributes by changing the magnitude and direction of force in response to ball height.

4.2 Magnitude and direction of the force exerted by each joint.

For the CS leg relative to ball height, during Initiation the hip, knee, and ankle joint values of angular impulse were significantly larger for Upper than Lower trials. In this period, the joint angle of the CS leg was formed through flexion (Fig. 2). Thus, it seems that in this phase, a counter movement via sinking was performed due to the CS leg. That is, exertion of force by the CS leg caused a counter movement due to sinking, and this may have acted as a preparation period to raise the CG. When diving for far balls, there was more energy because of the GK stepping before diving, which did not occur for trials with near balls. In the latter case, diving required more acceleration.

During the Take-off period, the hip joint angular impulse of the BS leg was significantly larger for Upper and Middle trials than Lower trials, and the ankle angular impulse was significantly larger in the order of Upper, Middle, and Lower trials (Fig. 4). Since it is necessary to reach further when diving for far balls, the BS leg exerted a large impulse and an angular impulse.

Based on these considerations, we suggest that when a GK dives for a high ball, the CS leg exhibits large joint extension torque during Initiation and the BS leg exerts large hip and ankle joint extension torque. We also suggest that when diving for a near ball, the CS leg has to exhibit large hip and knee joint extension torque during Initiation, and the knee and ankle joint exhibit greater extension torque in Transition than when diving for a far ball. For the latter, the BS leg has to exert large extension torque.

If we look at the movement of joints in the Transition period, for the CS leg extension and plantar flexion already started at BS Touched Down, regardless of ball height (Fig. 2). However, for the BS leg, extension and plantar flexion times between BS Touched Down and CS Left were different depending on the ball height. For a high ball, extension was performed immediately after contact with the ground, whereas for trials with a low ball, the extension times for each joint were delayed (Fig. 2). When the GRF vector exerted by the BS leg was inclined in a more horizontal direction, the GRF vector did not point further towards the ground (Fig. 3). Therefore, we note that the action of the BS leg making contact with the ground and extending itself exerts considerable force to make the CG move away from the ground. Although for Upper diving this action is positive to raise the CG upwards, for Lower diving the action may be considered to be negative in the sense of directly diving for the ball. Accordingly, when diving for a low ball, extending the CS leg and delaying the extension of the BS leg during the period in which both legs make contact with the ground may be to stop the CG from going upwards.

On the basis of this research, then, we suggest that differences in the BS and CS leg actions may contribute to differences in CG movement with respect to ball height.

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