

Exploring the Handball Goalkeeper's Proper Defence Position and Efficient Movement Strategy: Considering the Goalkeeper's Last Defence Line

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Abstract

This study aims to mathematically verify the final defence positions at which the goalkeeper divides the defence range into half. The most efficient moving line strategy for goalkeeping was proposed, thereby providing basic data for goalkeeping. First, the erroneous claim from existing handball literature that handball goalkeepers should defend at the centre of the goal line and the extension of the ball was mathematically proven. Second, the final defence positions where the goalkeeper can defend at the centre of the defensive range were mathematically verified. Third, the final defence positions of the goalkeeper when shots are made from positions 6 and 9 m away from the outermost goalpost were calculated. Fourth, the positions of 231 shootings that occurred in actual game situations and the defence positions of the goalkeeper based on each shooting were compared with the mathematically verified final defence positions. Consequently, the goalkeeper's efficient positioning strategy was presented through the comparison. An error in the goalkeeper's defensive position suggested in the existing textbook was verified. This study proposed a goalkeeper's movement line that is more efficient than the semicircular movement line that was previously presented.

Key words: handball, goalkeeper, last defence line, efficient movement strategy

Introduction

Football, handball, and hockey all have a goalpost and a goalkeeper. Players in all positions are important; however, the mistakes of the goalkeepers directly affect the winning or losing outcome of the team. Thus, they are more important than the other positions. The goalkeeper trains not to lose a point and practices defensive tactics with the defender. The purpose of defensive tactics is to prevent the opponent from

shooting or to minimise the range that the goalkeeper must defend even if a shot occurs. When a shot occurs, the goalkeeper blocks the ball based on their quickness and predictive power. This effort to minimise the loss can be maximised when the goalkeeper blocks the shot from the ideal defensive position. Having a reasonable defence posture and an ideal defence position is important to effectively defend against attacks (Gutierrez-Davila et al., 2011; Molotnovs et al., 2011; Rojas et al., 2012). When a soccer or handball goalkeeper blocks a shot (penalty kick or 7-m draw) from the front of the net, he defends along a straight line from the centre of the goal line to the ball. Determining where the goalkeeper should be located

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if the shooting is not performed from the front but from the side is also necessary.

According to a handball study conducted by Yang & Lee (2016), the goalkeeper is located along the centre of the goal line when defending the 9-m jump shot from the front. In handball studies conducted by Yang & Chun (2015), Yang et al. (2019), and Clanton & Dwight (1996), the position of the goalkeeper defending the 7-m penalty draw was found to be the centre of the goal line.

Studies related to the handball goalkeeper's defence position were primarily limited to the situation of defending forward shots, particularly focusing only on how forward the goalkeeper should be at the goal line. The reason was that the goalkeeper was located in the middle of the range that must be defended. Thus, there was no need to consider the goalkeeper's left and right positions. Handball-related professional books only suggest that the left and right criteria for the handball goalkeeper's defence position should be in the middle of the range to be defended, and they do not specifically define where the defence position is. Certain textbooks suggest that goalkeepers should be located in a straight line between the centre of the net and the ball, and training is conducted on the basis of handball goalkeeper training (Figure 1). In addition, the position of the handball goalkeeper rapidly changes depending

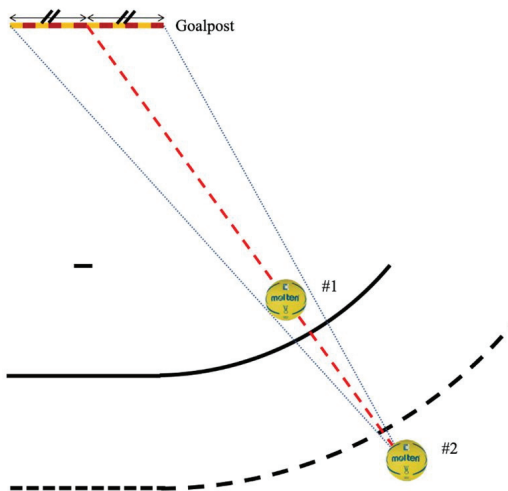


Figure 1. Example of goalkeeper defence line based on shooting positions #1 and #2

on the position of the ball moving through a fast pass; however, there is no specific instruction on the movement strategy or skill of the defence position.

Determining whether it would be ideal for a goalkeeper to be located in a straight line between the centre of the goal line and the ball regardless of the shooting distance or angle is necessary, as shown in Figure 1. In other words, it is important to determine whether the virtual line (the thick red dotted line shown in Figure 1) that connects the ball with the centre of the goal line divides the range that the goalkeeper has to defend in half. Despite being a simple and important question, this has not been addressed and verified. Therefore, this study aims to define an ideal left and right reference point (a position that divides the defence range in half) when the goalkeeper defends the ball coming from the side and propose the most efficient movement path strategy for goalkeeping.

Results

Error Verification of the Goalkeeper's Left and Right Positions

Figure 2 shows a schematic of the ball and goalpost. Point B is the position of the ball, point L is the left goal post, and point R is the right goal post. \overline{BR} is

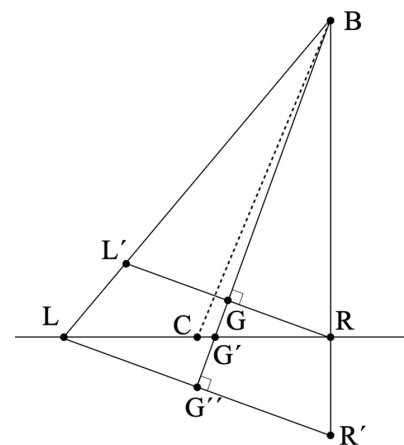


Figure 2. Schematic of the position of the ball, goalpost, and goalkeeper. B: ball position, L: left goalpost, R: right goalpost, G: goalkeeper

the distance to the goal post close to the ball, and \overline{BL} is the distance to the goal post far from the ball.

For $\overline{BL}' = \overline{BR}$, $\overline{BL} = \overline{BR}'$, $\overline{L'G} = \overline{GR}$ such that $\overline{LG}'' = \overline{G''R'}$.

Point G' is the intersection of \overline{LR} and \overline{BG}'' such that $\angle LG'G'' = \angle RG'G$.

GR and LG'' are horizontal such that $\triangle LG'G''$ and $\triangle RG'G$ are similar.

Further, $\overline{LG}'' > \overline{GR}$ such that $\overline{LG}' > \overline{G'R}$.

Points C and G located in the middle of the segment LR do not match. The “straight line between the centre of the goal line and the ball”, which most handball textbooks refer to, implies a dotted line (Line BC in Figure 2), which does not divide the scope of defence in half.

In general, the middle of the goal line is known as the centre of the range that the goalkeeper must defend. However, the straight line connecting the centre point of the goal line and the shot ball does not divide the range that the actual goalkeeper must defend in half. If the goalkeeper's defence range is divided into both sides based on the straight line connecting the centre of the goal line and the ball, the defence range in the direction close to the ball is wider than that in the direction far from the ball. In other words, the centre of the range the goalkeeper must defend should be slightly biased towards the goalpost in the direction close to the ball based on the centre of the goal line.

Defining the Goalkeeper's Last Defence Line

The goalkeeper blocks the ball from entering the net. The goalkeeper's defence range depends on the size of the net and the relative position of the ball and goalkeeper.

If the ball is located at the front and the goalkeeper is standing at the centre of the goal line, the goalkeeper must defend an area similar to the size of the net and the final defence line will be the goal line (Figure 3. Front). When defending a shot from the side, the

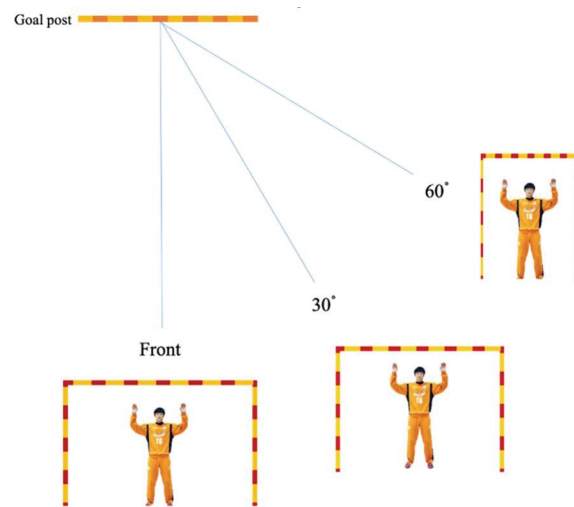


Figure 3. Goalkeeper's defending area according to the shooting angle

goalkeeper defends a narrower area than when defending from the front (Figure 3. 30° and 60°).

The goalkeeper's defensive position is determined by two factors. The first is the left and right position information based on the position of the ball being shot, and the second is the front and rear position information on the distance to be travelled in front of the goal line to block the ball. If the shot is made from the front, the goalkeeper's left and right positions will be at the middle of the goal line, and the last position that the goalkeeper can block the ball is on the goal line. If the goalkeeper defends from a position that is far towards the back when the shot is made from the side (Figure 4.a), the goalkeeper may block the ball from behind the goal line. Therefore, the goalkeeper's final defence position should be located on the same line (Figure 4.b) as the near goal post or in front of the goal post (Figure 4.c) when the goalkeeper moves left and right. Hence, the goalkeeper's last defence line to defend the shot from the side must pass through the near goal post (i.e. the red dotted line shown in Figure 5), and the goalkeeper's defence position must be located on a line (i.e. the green solid line shown in Figure 5), extending from the centre of the goalkeeper's last defence line.

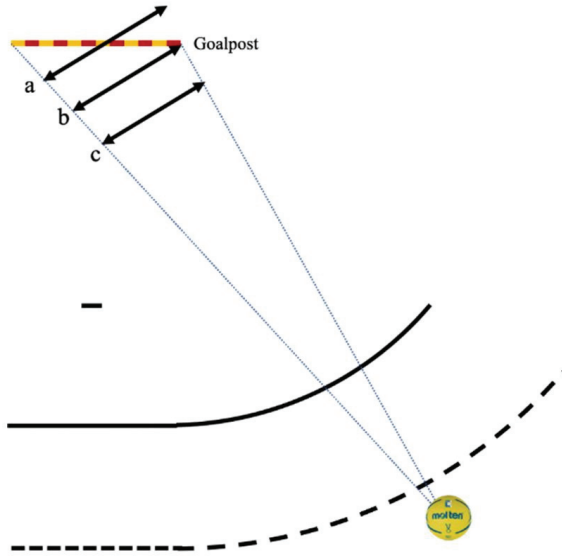


Figure 4. Example of left and right movement according to the goalkeeper's defensive position in a diagonal shooting situation

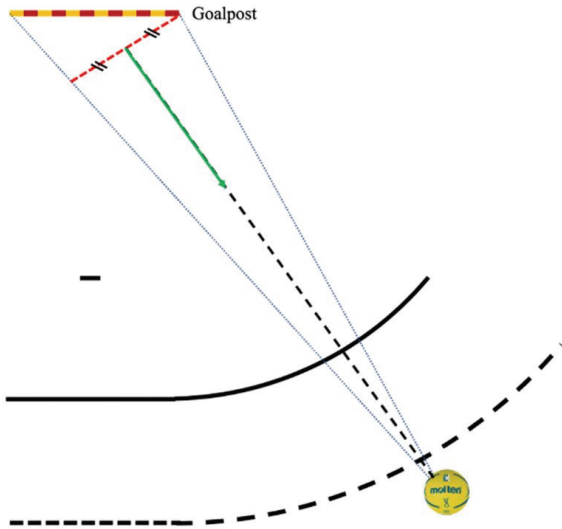


Figure 5. Goalkeeper's last defence line and position in a diagonal shooting situation

Formula of Goalkeeper's Last Defence Position

If the solid green line in Figure 5 is expressed on the coordinate plane, it becomes a straight line connecting the point G and the point S in Figure 6.

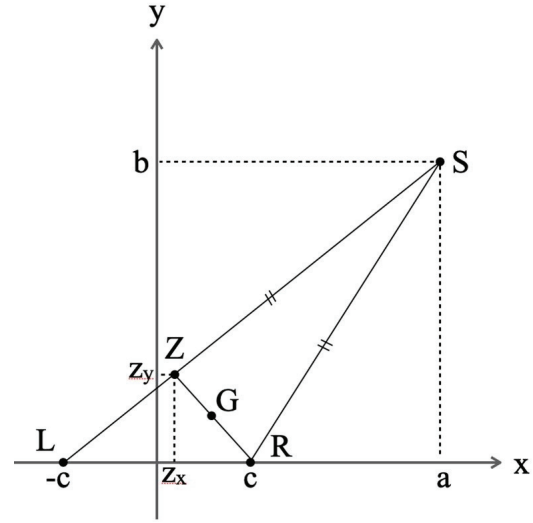


Figure 6. Graph for the goalkeeper's last defence position. $S(a, b)$: Shooting position, $R(c, 0)$: Right Goalpost, $L(-c, 0)$: Left Goalpost, $Z(z_x, z_y)$: Position that satisfies $\overline{SR} = \overline{SZ}$, $G(z_x, z_y)$: goalkeeper's last defence position, only $a > 0, b > 0, c > 0$

This line is a straight line that divides the inner area in the left and right directions when the goal is viewed from the shooting point, and at this time, the goalkeeper can most efficiently defend the shot.

The formula for the position of the handball goalkeeper's last defence (G in Figure 6) is as follows:

$$|\overline{RS}| = \sqrt{(a-c)^2 + b^2} = |\overline{SZ}|, \tag{1}$$

$$|\overline{LS}| = \sqrt{(a+c)^2 + b^2}. \tag{2}$$

Point Z exists above $|\overline{LS}|$.

$$Z_y = \frac{b}{a+c}(Z_x + c) \tag{3}$$

$$|\overline{LZ}| = \sqrt{(Z_x + c)^2 + Z_y^2} = \sqrt{(Z_x + c)^2 + \left\{ \frac{b}{a+c}(Z_x + c) \right\}^2} \tag{4}$$

$$\begin{aligned} |\overline{LZ}| &= |\overline{LS}| - |\overline{SZ}| = |\overline{LS}| - |\overline{RS}| \\ &= \sqrt{(a+c)^2 + b^2} - \sqrt{(a-c)^2 + b^2} \\ &= (Z_x + c) \sqrt{1 + \left(\frac{b}{a+c} \right)^2} \end{aligned} \tag{5}$$

$$Z_x = \frac{\sqrt{(a+c)^2+b^2} - \sqrt{(a-c)^2+b^2}}{\sqrt{1+(\frac{b}{a+c})^2}} - C \quad (6)$$

$$Z_y = \frac{b}{a+c} \times \frac{\sqrt{(a+c)^2+b^2} - \sqrt{(a-c)^2+b^2}}{\sqrt{1+(\frac{b}{a+c})^2}} \quad (7)$$

The point G in Figure 6 (the position of the handball goalkeeper's last defence) is determined as follows:

$$g_x = \frac{x_z + r_x}{2} = \frac{\sqrt{(a+c)^2+b^2} - \sqrt{(a-c)^2+b^2}}{2\sqrt{1+(\frac{b}{a+c})^2}} \quad (8)$$

$$g_x = \frac{z_y + r_y}{2} = \frac{b}{a+c} \times \frac{\sqrt{(a+c)^2+b^2} - \sqrt{(a-c)^2+b^2}}{\sqrt{1+(\frac{b}{a+c})^2}} \quad (9)$$

In general, when blocking a ball from the diagonal, the goalkeeper defended on an imaginary line connecting the center of the goalpost and where the shot was made. This is not a method of dividing the area inside the goalpost from left to right when calculated mathematically ($|\overline{GS}|$ in Figure 6), but an inefficient method in which the defensive area toward the goalpost close to the shooting point is set slightly wider.

Goalkeeper's Last Defence Line and the Actual Handball Game Situation

According to the formula for the goalkeeper's last defence position previously mentioned, Figure 7 shows lines that corresponds to the goalkeeper's last defence position when shooting from 6 m and 9 m away from the outermost goalpost. The green line refers to the goalkeeper's last defence position when the ball is being shot from 6 m away from the outermost goalpost, and red line refers to the goalkeeper's last defence position when the ball is being shot from 9 m away from the outermost goalpost. As shown in Figure 7, there is a slight difference between the last defence position for the 9-m shot and that for the 6-m shot; however, in general, they exhibit a similar pattern. The goalkeeper's last defence line takes the form of two semicircles with the centre of the goal line and the left and right goalposts as a diameter. Through calculations, the last defence line is obtained as 0.75 m in front of the goal line.

Figure 8 shows 231 jump shots measured near the 9-m line for seven men's handball qualifiers at the 99th National Sports Festival in South Korea. The goalkeeper's defence position (Yang & Kwon, 2021) and their final defence line are indicated. These data were obtained through the observed shooting of nine

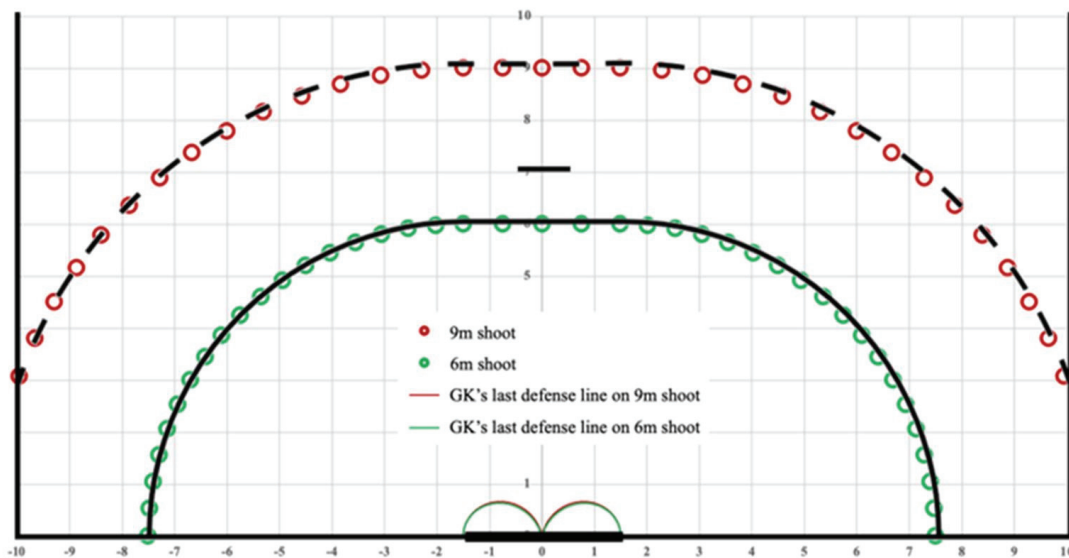


Figure 7. Last defence line for 6- and 9-m shots

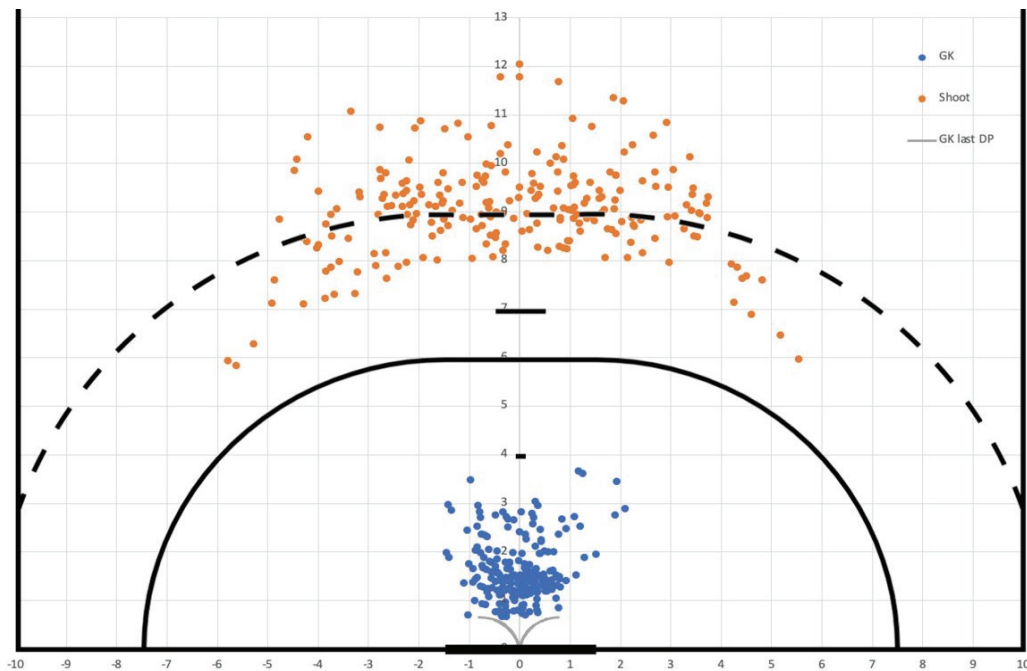


Figure 8. Actual 9-m jump shot and goalkeeper defence position

matches. In addition, video analysis of the matches filmed at 1440×1080 resolution was performed. After calculating the three-dimensional coordinates of the image data using the direct linear transformation method (Walton, 1981), it was used to compute the variables. From Figure 8, it is evident that the goalkeepers' actual defence positions are located ahead of the final defence line.

Effective Goalkeeper Movement Strategy to Defend a 9-m Jump Shot

According to Yang & Lee (2016), the optimal defence position of a South Korean male goalkeeper is 1.5 m in front of the goal line; thus, it would be advantageous to go one step forward (approximately 0.75 m) from the goalkeeper's final defence line and defend. Earlier, when the goalkeeper defended a shot flying from the side, he knew that he had to defend while being a little more biased in the direction of the close goal post and not the line connecting the ball and the middle of the goal line. The closer the goalpost and the ball are, the greater the difference. Additionally, the farther the ball moves from the goalpost, the smaller

the difference. These results indicate that the goalkeeper should set a different standard for positioning based on the shooting distance.

From previous studies, we can infer the goalkeeper's position in the left–right, and front–rear directions is a key factor in improving the goalkeeper save performance. Previously, we checked where the handball goalkeeper's last defence line was, and we identified that blocking the ball at approximately 1.5 m in front is the best defence position.

The three coloured lines suggested in Figure 9 show different strategies in goalkeeper movement in various situations. The red semicircular line (Line a in Figure 9) is an estimated line based on the estimation that the goalkeeper save performance can be enhanced when they defend 1.5 m away from the goal line. The double semicircular line (Line c in Figure 9) shows the mathematically calculated final defence line. The line (Line b in Figure 9) connecting each quarter circular line at the end of each goalpost (moving along the last defence line) mends the deficiency of the double semicircular line (marked “c”) of moving backwards toward the goal line, thereby placing the goalkeeper in the front.

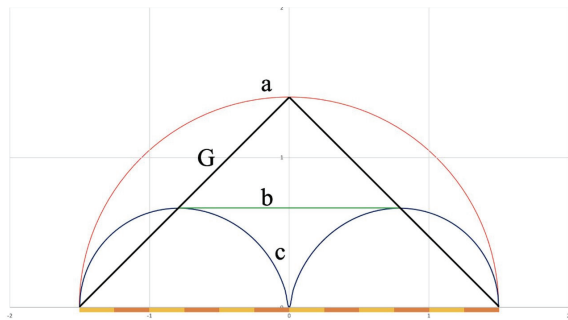


Figure 9. Various examples of goalkeeper movement strategies

Goalkeepers can follow various movement strategies to defend the ball in handball games. First, the goalkeeper knows that he has the highest save performance at 1.5 m in front of the goal line; thus, he can take a semicircular movement strategy (Line a in Figure 9) that passes 1.5 m in front. This offers the advantage of being able to defend the ball at the position with the highest goalkeeper save performance; however, the goalkeeper cannot quickly respond to the rapidly changing position of the ball, since the movement range is too long. In fact, if the handball goalkeeper has a movement strategy (Line a in Figure 9) from one goalpost to the other goalpost, the goalkeeper must move a distance of 4.71 m.

On the other hand, it is also possible to follow the strategy (Line b in Figure 9) and move along the last defence line. In this case, the total travel distance is 3.86 m, which can reduce the travel distance to approximately 81.8% of the total travel distance of Line a in Figure 9 (which is 4.71 m). However, Line b in Figure 9 is different being 1.5 m away from the goal line (which has the highest goalkeeper save performance). Thus, it takes one more step to reach an advantageous defence position. Considering the shooters' various shooting forms and timing, it is expected to be very difficult to take a step forward to reach 1.5 m from the goal line and take a defensive posture in time before the shooter takes the shot. However, if the ball is blocked on the last line of defence without moving forward, the goalkeeper save performance will be reduced.

Lines a and b in Figure 9 have curved sections.

As the handball court does not mark the last defence line, or 1.5 m and a half circle, it is difficult to move while accurately measuring the exact defence position and maintaining the curved movement line in an intense game situation. Therefore, a new goalkeeper movement strategy is required to reduce the shortcomings of the two strategies.

Line G in Figure 9 is similar to Line a in Figure 9, but it is in a straight line rather than a curve. The advantage of movement along Line G is that it is very close to the ideal defence position (1.5 m) and has a shorter travel distance than the movement along Line a. In addition, since the shape of the movement line is straight, it is relatively easy to follow without moving away from it. The total travel distance is 4.24 m, which is 90.0% of that in Line a. However, in the case of the Line G movement, there is a disadvantage that a route to the back of the last defence line occurs in the outer area of 45° left and right, but a 9-m jump shot rarely occurs in the outer area. If a shot occurs in that area, the Line G strategy of rapidly approaching the goal post through straight movement may be advantageous because the strategy of sticking to the net as quickly as possible and setting the goalkeeper's defence range in one direction is advantageous.

In actual handball games, various variables such as the type of the shot and the position of the striker and defender affect between the goalkeeper's defensive behavior that blocks the shot. Therefore, in this study, it is unclear how effective the mathematical calculation method using only the point where the shot is made and the position of the goalkeeper to improve the goalkeeper's defense ability is when applied to real situations. In the future, follow-up studies are needed on how goalkeeper movements based on mathematical calculations affect goalkeeper defense improvement in real games. Nonetheless straight movements, such as Line G movement strategies, minimise unnecessary movements of goalkeepers and maximise efficiency. Because the ball moves on the court until the shot is made in a handball game, it is very important for the goalkeeper to efficiently move to take a defensive posture and quickly respond to the striker's shot. This is because the goalkeeper's position in advance and

preparing for the attack is a major factor in increasing the goalkeeper save performance.

Conclusion

In this study, we determined errors in the conventional approach in which the centre of the goal line is the centre of the goalkeeper's defence range and corrected them appropriately. Moreover, a new movement strategy was proposed that allows the goalkeeper to move to a position favourable to defence as efficiently as possible and focus only on the movement of the ball. If goalkeeper training is conducted using this goalkeeper movement strategy (Line G in Figure 9), it can increase the goalkeeper save performance in actual games and be useful in other sports, such as football and hockey, where goalkeepers exist.

Author Contributions

Jonghyun Yang conceived and planned the experiments. All authors developed performed the experiments/calculations/simulations, analysed the data and wrote the manuscript. Junwoo Kwon contributed to the final version of the manuscript. Jonghyun Yang were in charge of overall direction.

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Conflict of Interest

The authors have no competing interests to declare that are relevant to the content of this article.

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