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Identifying the Most Important Biomechanical Indicators of Handball Goalkeepers and Their Relationship with Defensive Response Efficiency During Deceptive Throws

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ABSTRACT
Backgroud: This study aimed to identify the most important biomechanical indicators of handball goalkeepers and examine their relationships with defensive response efficiency during the defense of deceptive throws. It also sought to compare goalkeepers' responses to direct throws with their responses to deceptive throws. Because deceptive throws disrupt temporal organization and place the goalkeeper in a misleading decision-making situation, their analysis requires a quantitative approach that extends beyond subjective observation to the precise measurement of the temporal and kinematic indicators underlying successful or unsuccessful defensive responses.
Methods: A descriptive research design employing correlational and comparative approaches was used. The sample consisted of 10 advanced-level handball goalkeepers selected purposively. Nine biomechanical indicators were measured using a high-speed motion-capture system and a force platform. The data were analyzed using Pearson's correlation coefficient and the paired-samples t-test.
Results: The results showed that reaction time, motor response time, horizontal center-of-mass velocity, and time to reach the save point were the indicators most strongly associated with defensive response efficiency. The findings also demonstrated that deceptive throws resulted in longer response times and lower velocity and defensive efficiency, with statistically significant differences compared with direct throws.
Conclusions: The researcher concluded that the effectiveness of defending against deceptive throws is governed primarily by temporal velocity indicators rather than angular indicators. Accordingly, goalkeeper preparation should emphasize the development of rapid reaction and perceptual motor response capabilities

Keywords: Biomechanical indicators; Handball goalkeeper; Defensive response efficiency; Deceptive throws; Reaction time; Handball.

INTRODUCTION

The handball goalkeeper represents the final link in the defensive system and the critical boundary between team success and failure, as decisive moments in a match may depend on the goalkeeper's response. The nature of the game requires the goalkeeper to combine maximal speed with accurate decision-making within an extremely limited time frame. The flight time of the ball during long-range throws may be less than half a second, requiring the goalkeeper to interpret the thrower's cues and initiate a response before the ball is released or immediately thereafter.

The task becomes even more demanding when the thrower employs a deceptive throw, in which the direction or timing of the shot is disguised to disrupt the goalkeeper's judgment and induce a premature response in the wrong direction. Under these circumstances, defensive performance becomes more than a simple motor reaction; rather, it represents a complex perceptual motor process in which the speed of information processing interacts with the

efficiency of motor execution. Accordingly, quantitatively and accurately understanding what occurs within the goalkeeper's body during this critical moment represents a key to improving performance, an objective facilitated by modern biomechanical analysis.

Goalkeeper performance can be conceptualized as a sequential chain of processes beginning with the detection of the thrower's movement cues, followed by their perception and processing, selection of the direction and timing of the save, initiation of the response, and execution of the movement until the save is completed. Any disruption at one stage of this sequence may produce a delay in subsequent stages. Deceptive throws specifically interfere with the perceptual and decision-making stages by introducing a misleading cue that may induce an incorrect premature response. The goalkeeper must then inhibit the initial movement and redirect it, thereby consuming valuable response time. The significance of the present study lies in its shift from descriptive assessment of goalkeeper performance based primarily on the coach's subjective impression toward objective quantitative measurement of the temporal and movement-related indicators underlying defensive-response effectiveness. It also seeks to determine which of these indicators are most closely associated with defensive-response efficiency. Previous international studies have shown that expert goalkeepers initiate their movements approximately 193 ms before ball release and achieve success rates several times higher than those of less-experienced counterparts (Rojas et al., 2012). Furthermore, the ability to read the thrower's kinematic cues has been identified as a key component of successful anticipation (Huesmann et al., 2023), while deceptive throws represent particularly challenging situations because they exploit response biases in the goalkeeper (Cañal-Bruland & Schmidt, 2009).

The value of this approach is particularly relevant in the Iraqi sporting context, where the use of motion analysis in goalkeeper preparation remains limited despite the availability of such technologies. Arab studies have highlighted the importance of incorporating biokinematic variables into the training of handball goalkeepers (Ghazi & Abd Al-Khaliq, 2021).

Several Arab studies have addressed the perceptual and defensive aspects of handball goalkeeper performance. Abd Al-Hadi (2022) examined the effect of perceptual exercises on the development of goalkeepers' cognitive abilities and defensive skills. Mutaib et al. (2024) investigated the development of sensorimotor perception and saving skills through feedback, whereas Al-Masalmah (2000) examined the relationship between sensorimotor perception and skill level in handball. Despite the value of these studies, most have focused on developing abilities through training interventions rather than quantitatively measuring goalkeeper biomechanical indicators and determining which are most closely associated with defensive-response efficiency, particularly when facing deceptive throws, which have rarely been examined as an independent quantitative problem.

Accordingly, the present study seeks to address this gap by providing a quantitative profile of the most important goalkeeper biomechanical indicators and their relationships with defensive-response efficiency when responding to deceptive throws. This approach is intended to provide coaches with a scientific basis for directing goalkeeper preparation according to quantified performance indicators rather than relying solely on general observational impressions.

Biomechanical Indicators

Biomechanical Indicators: Quantitative kinematic and kinetic variables describing the goalkeeper's movement during defensive responses, including temporal variables, velocities, displacements, joint or segmental angles, and ground-reaction forces. These variables are used to characterize and evaluate the biomechanical features of defensive performance (Al-Fadhli, 2016).

Defensive-Response Efficiency

Defensive-Response Efficiency: A quantitative indicator representing the goalkeeper's ability to successfully defend against throws. Operationally, it is calculated as the proportion of successfully defended attempts relative to the total number of attempts within the testing situation. It constitutes the dependent variable in the present study.

Deceptive Throw

Deceptive Throw: A throw in which the thrower deliberately disguises the intended direction or timing of the shot through a deceptive movement preceding the actual execution, with the aim of inducing the goalkeeper to initiate a premature response in the wrong direction.

Research Problem

Through observing handball matches and training sessions, the researcher noted that a substantial proportion of goals are scored from deceptive throws that goalkeepers are unable to defend effectively. Goalkeeper preparation continues to rely largely on experience and repetition, without sufficient quantitative analysis to diagnose specific deficiencies in defensive responses. Furthermore, goalkeeper performance is often assessed visually, which may fail to capture subtle differences in the temporal and velocity-related characteristics that distinguish successful saves from unsuccessful ones.

The problem is further compounded by the limited body of literature particularly Arabic literature examining goalkeeper biomechanical indicators specifically during deceptive throwing situations. Existing research has predominantly focused either on descriptive aspects of goalkeeper performance or on the shooting skill from the thrower's perspective. Consequently, the question of which goalkeeper indicators are most strongly associated with defensive-response efficiency when facing deceptive throws remains insufficiently addressed quantitatively.

Although several studies have emphasized the central role of reaction speed in goalkeeper performance and have sought to improve it through training for example, Ghanem (2021), who examined the relationship between improving handball goalkeepers' reaction speed and counterattacking effectiveness, and Belfritis (2019), who proposed specialized tools for developing goalkeepers' reaction speed these efforts have not simultaneously examined a set of goalkeeper indicators to determine their relative associations with saving efficiency. Nor have they systematically compared goalkeeper responses to direct and deceptive throws. This constitutes the central research problem addressed by the present study.

Accordingly, the research problem can be formulated through the following questions:

1. What are the quantitative values of the biomechanical indicators of handball goalkeepers during defensive responses to deceptive throws?
2. Which biomechanical indicators are most strongly associated with defensive-response efficiency?
3. Do goalkeeper responses and their biomechanical indicators differ significantly between direct and deceptive throws?

Research Objectives

1. To identify the quantitative values (descriptive statistical characteristics) of the biomechanical indicators of handball goalkeepers during defensive responses to deceptive throws.
2. To determine the biomechanical indicators most strongly associated with the goalkeeper's defensive-response efficiency.
3. To determine the statistical significance of differences in goalkeeper indicators and defensive-response efficiency between responses to direct throws and deceptive throws.

Research Hypotheses

1. There are statistically significant correlations between the goalkeeper's biomechanical indicators and defensive-response efficiency when responding to deceptive throws.
2. There are statistically significant differences in goalkeeper indicators and defensive-response efficiency between direct and deceptive throws, in favor of the direct-throw condition.

Scope of the Study

1. Human scope: Ten (10) advanced-level handball goalkeepers registered with the Iraqi Central Handball Federation, selected using purposive sampling.
2. Temporal scope: March 14, 2026 to May 26, 2026.
3. Spatial scope: The indoor sports hall in Al-Kut, Wasit, Iraq.

METHODS

Research Design

A descriptive research design employing correlational and comparative approaches was adopted because it was considered appropriate to the nature of the research problem. The correlational approach was used to examine the relationships between the biomechanical indicators and defensive-response efficiency, whereas the comparative approach was used to compare goalkeeper responses to direct and deceptive throws. This methodological choice is consistent with the principles of research methodology in physical education, which emphasize the need to align the research design with the nature of the research problem and its objectives (Al-Shawk & Al-Kubaisi, 2004).

Research Population and Sample

The research population comprised advanced-level handball goalkeepers registered with the Iraqi Central Handball Federation. A purposive sample of ten (10) goalkeepers was selected. Homogeneity was examined with respect to the participants' basic characteristics to assess the distributional characteristics of the sample, as presented in Table 1.

Table 1. Homogeneity of the Basic Characteristics of the Research Sample (n = 10)

Variable	Unit of Measurement	Mean	SD	Skewness
Age	Years	26.40	2.80	0.44
Height	Cm	188.50	4.90	−0.21
Body mass	Kg	86.20	5.70	0.38
Training age	Years	9.30	1.90	0.52

As shown in Table 1, the skewness coefficients ranged between −1 and +1, which was considered indicative of an approximately symmetric distribution of the sample's basic characteristics.

Equipment, Instruments, and Measurement Tools

The following equipment and instruments were used:

1. Two high-speed cameras operating at 240 frames per second (fps), positioned in the sagittal and frontal planes and used with a calibration reference.
2. Force platform for measuring ground-reaction force during the goalkeeper's defensive movement.
3. Computer and contemporary motion-analysis software for extracting joint landmarks and the center of mass and for calculating temporal, velocity, and angular variables.
4. Throwing device or ball launcher to standardize the stimulus conditions, together with a regulation handball goal divided into designated target zones.
5. Data-recording forms and a graded assessment scale for quantifying defensive-response efficiency.

Pilot Study

A pilot study was conducted on three (3) handball goalkeepers who were not included in the main research sample. The pilot study aimed to determine the appropriate camera positions, establish the calibration and synchronization settings with the force platform, verify the clarity of the anatomical landmarks, assess the consistency of defensive-response efficiency scoring, and estimate the time required for testing each goalkeeper. The pilot study consequently helped minimize potential sources of measurement error and establish optimal conditions for the main experiment.

Main Experiment, Experimental Procedures, and Measurement Protocol

The responses of each goalkeeper to direct and deceptive throws were recorded using the two synchronized cameras, while ground-reaction force was simultaneously recorded using the force platform. The recorded video sequences were subsequently processed to extract the relevant anatomical landmarks and track the trajectory of the goalkeeper's center of mass. The biomechanical indicators were then calculated automatically across the different phases of the defensive response, as illustrated in Figure 1.



Figure 1. Workflow for Analysing Goalkeeper Biomechanical Indicators

Nine biomechanical indicators were identified for measurement: reaction time, motor response time, anticipatory time before movement, horizontal center-of-mass velocity, lateral center-of-mass displacement, ground-reaction force, knee-flexion angle at the instant of the defensive push-off, limb reach distance, and time to reach the save point. Defensive-response efficiency represented the dependent variable. The following procedures were adopted:

1. The motion-capture system was spatially calibrated to convert pixel coordinates into real-world units and was temporally synchronized with the force platform.
2. The instant of ball release, the onset of the goalkeeper's movement, and the instant of the save were automatically identified from the motion and force curves.
3. Temporal variables were calculated from the differences between the corresponding events; velocities were calculated from the first derivative of displacement; angles were calculated from vector relationships; and ground-reaction force was obtained from the force platform.
4. Defensive-response efficiency was calculated for each goalkeeper as the percentage of successfully saved attempts, and the resulting values were organized for statistical analysis.

Tests and Measurement Procedures

Each goalkeeper performed a series of saving attempts distributed equally between direct and deceptive throws from the 9-m line and 7-m line. The trials were recorded and digitally analyzed to extract the nine biomechanical indicators and calculate defensive-response efficiency under each of the two conditions. The measurement form is provided in Appendix 1.

Statistical Methods

The data were processed using the Statistical Package for the Social Sciences (SPSS). The statistical procedures included the arithmetic mean, standard deviation, coefficient of skewness, coefficient of variation, Pearson's correlation coefficient, paired-samples t-test, percentage of improvement, and effect size.

RESEARCH RESULTS

Quantitative Description of the Biomechanical Indicators

To address the first research objective, the means, standard deviations, and coefficients of variation of the measured indicators are presented in Table 2. Figure 3 illustrates the coefficients of variation as an indicator of the degree of homogeneity within the sample.

Table 2. Descriptive Statistics of the Biomechanical Indicators and Defensive-Response Efficiency (n = 10)

Indicator	Unit of Measurement	Mean	SD	Coefficient of Variation (%)
Reaction time	s	0.240	0.030	12.50
Motor response time	s	0.420	0.050	11.90
Anticipatory time before movement	s	0.190	0.040	21.10
Horizontal center-of-mass velocity	m/s	1.850	0.220	11.90
Lateral center-of-mass displacement	m	0.620	0.080	12.90
Ground-reaction force	× body weight	1.900	0.250	13.20
Knee-flexion angle at push-off	degrees	118.00	7.50	6.40
Limb reach distance	m	0.940	0.090	9.60
Time to reach the save point	s	0.380	0.050	13.20

Defensive-response efficiency	%	58.40	9.20	15.80

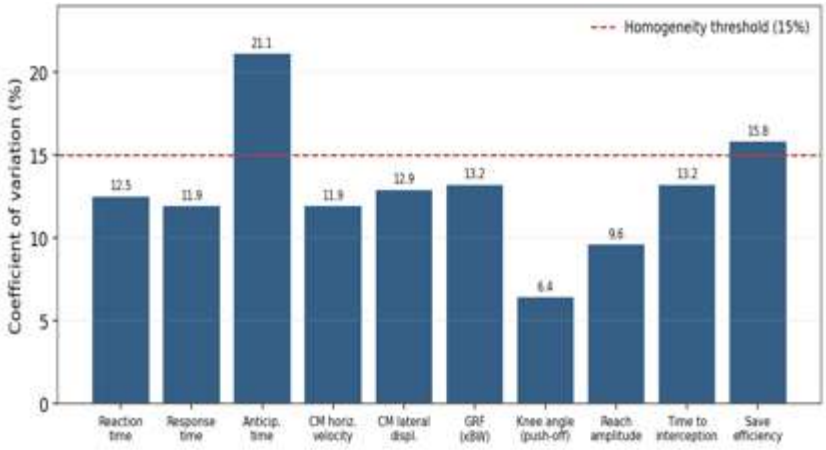

Figure 2. Coefficient of Variation of the Goalkeeper Indicators

As shown in Table 2 and Figure 2, the coefficients of variation for the biomechanical indicators were below 15%, indicating a relatively high degree of homogeneity in the sample's performance across these variables. In contrast, defensive-response efficiency showed a slightly higher coefficient of variation (15.80%), suggesting greater inter-individual variability in the ability to respond effectively to deceptive throws.

The greatest variability was observed for anticipatory time before movement (21.10%). The researcher attributes this variation to differences in the goalkeepers' response strategies, with some preferring to delay movement while reading the thrower's cues, whereas others tend to initiate movement earlier. This interpretation is broadly consistent with the findings of Rojas et al. (2012), who reported that expert goalkeepers tend to delay movement longer than less-experienced goalkeepers.

Identification of the Biomechanical Indicators Most Strongly Associated with Defensive-Response Efficiency

To address the second research objective and test the first hypothesis, Pearson's correlation coefficient was calculated between each biomechanical indicator and defensive-response efficiency, as presented in Table 3 and Figures 4 and 5. With n = 10 and therefore 8 degrees of freedom, the reported critical correlation values are 0.632 at $\alpha = 0.05$ and 0.765 at $\alpha = 0.01$.

Table 3. Correlations Between Biomechanical Indicators and Defensive-Response Efficiency (n = 10)

Biomechanical Indicator	Correlation Coefficient (*r*)	Direction of Association	Statistical Significance
Reaction time	−0.82	Negative	Significant at 0.01
Motor response time	−0.78	Negative	Significant at 0.01
Horizontal center-of-mass velocity	0.75	Positive	Significant at 0.05
Time to reach the save point	−0.73	Negative	Significant at 0.05
Lateral center-of-mass displacement	0.69	Positive	Significant at 0.05
Limb reach distance	0.66	Positive	Significant at 0.05
Ground-reaction force	0.64	Positive	Significant at 0.05
Anticipatory time before movement	0.58	Positive	Not significant
Knee-flexion angle at push-off	0.41	Positive	Not significant

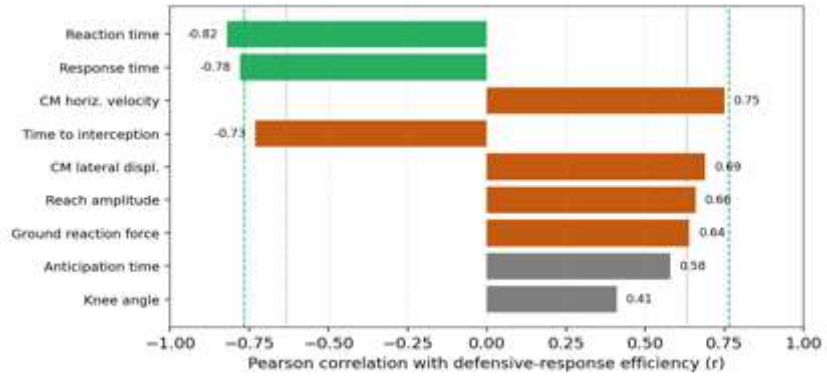

Figure 3. Correlation of Biomechanical Indicators with Save Efficiency

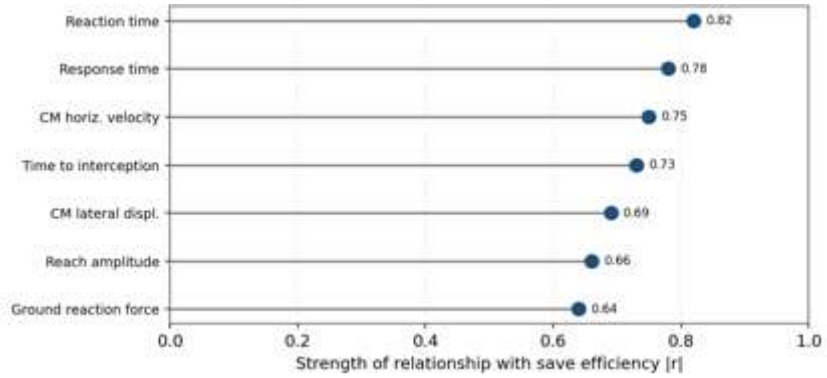

Figure 4. Ranking of the Most Important Goalkeeper Indicators

The findings indicate that the biomechanical indicators most strongly associated with defensive-response efficiency, ranked according to the magnitude of the correlation, were reaction time ($r = -0.82$) and motor response time ($r = -0.78$), both statistically significant at the 0.01 level. These were followed by horizontal center-of-mass velocity, time to reach the save point, lateral center-of-mass displacement, limb reach distance, and ground-reaction force, all of which were statistically significant at the 0.05 level. In contrast, anticipatory time before movement and knee-flexion angle did not reach statistical significance.

The associations were negative for the temporal indicators, indicating that shorter response times were associated with higher defensive-response efficiency, whereas positive associations were observed for velocity-, reach-, and force-related indicators, indicating that higher values of these variables were associated with greater defensive-response efficiency.

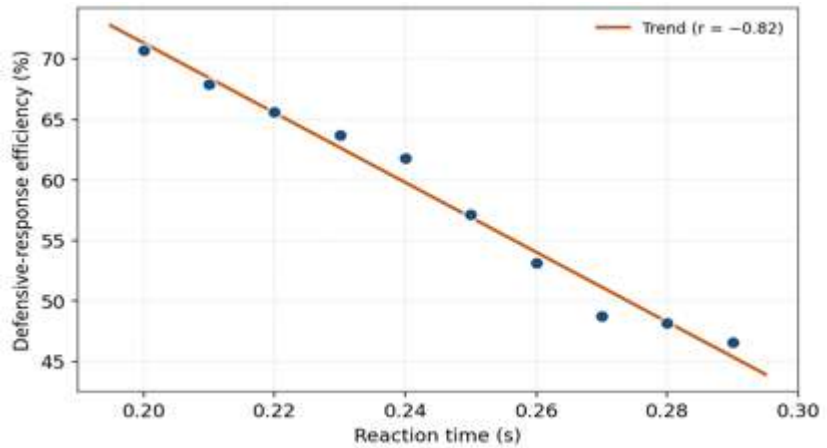

Figure 5. Reaction Time vs. Save Efficiency Against Deceptive Throws

The researcher attributes the predominance of the temporal indicators to the short flight time of the ball, which leaves the goalkeeper with only a narrow margin for response. Consequently, gaining fractions of a second in reaction and response time may determine the difference between a successful save and failure, particularly during deceptive throws, which consume part of this limited temporal margin through the need to correct the initial response. Figure 6 illustrates this relationship, showing a consistent decline in defensive-response efficiency as reaction time increases.

This finding is consistent with previous research emphasizing the importance of rapidly perceiving relevant cues and responding to them for successful anticipation (Huesmann et al., 2023; Rojas et al., 2012). It is also consistent with the findings of Horníková et al. (2021), who reported a substantial contribution of reaction time to reactive-agility performance in handball players. The researcher further suggests that the relatively weak association of joint angle indicates that defensive-response efficiency may be governed more strongly by temporal and velocity-related dimensions than by any single angular position. Accordingly, the first hypothesis was supported.

This finding is also consistent with the direction adopted by Arab studies that have focused on reaction speed as a key determinant of goalkeeper performance. Ghanem (2021), for example, reported that improving the reaction speed of handball goalkeepers positively influences their subsequent performance effectiveness. This finding provides training-oriented support for the present study's correlational results from a measurement perspective.

The researcher concludes that ranking the indicators according to the strength of their associations provides coaches with a clear hierarchy of priorities, beginning with reaction speed and motor response, followed by the velocity of center-of-mass displacement and the time required to reach the save point. Such a hierarchy would be difficult to establish through observational assessment alone.

Differences Between Direct and Deceptive Throws

To achieve the third objective and test the second hypothesis, differences between the goalkeeper's responses to direct and deceptive throws were examined using a paired-samples t-test, as presented in Table 4 and Figure 7. The critical t value at 9 degrees of freedom was 2.262 at the 0.05 significance level.

Table 4. Differences Between Direct and Deceptive Throws in Goalkeeper Biomechanical Indicators (n = 10)

Indicator	Direct Throws (Mean ± SD)	Deceptive Throws (Mean ± SD)	*t*	Significance
Reaction time (s)	0.20 ± 0.03	0.24 ± 0.03	4.10	Significant
Motor response time (s)	0.37 ± 0.05	0.42 ± 0.05	3.80	Significant
Horizontal center-of-mass velocity (m/s)	2.05 ± 0.20	1.85 ± 0.22	3.30	Significant
Lateral displacement (m)	0.55 ± 0.07	0.62 ± 0.08	2.90	Significant
Time to reach the save point (s)	0.34 ± 0.04	0.38 ± 0.05	3.05	Significant
Defensive-response efficiency (%)	74.20 ± 7.50	58.40 ± 9.20	6.20	Significant

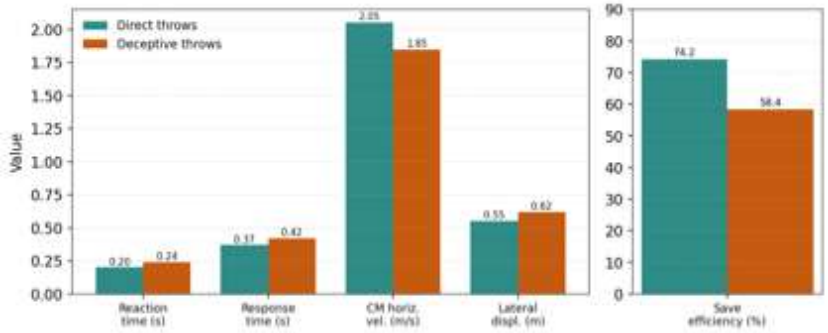

Figure 6. Goalkeeper Indicators Direct vs. Deceptive Throws

As shown in Table 4, all calculated t values exceeded the critical value, confirming the presence of statistically significant differences between the two conditions, in favor of direct throws. Deceptive throws prolonged reaction time, motor response time, and time to reach the save point, reduced horizontal center-of-mass velocity, and increased lateral displacement as a consequence of delayed directional correction. Collectively, these changes were accompanied by a decline in defensive-response efficiency from 74.20% during direct throws to 58.40% during deceptive throws.

Figure 8 illustrates this overall deterioration through a comparative representation of the performance profile across the two conditions. The performance profile for deceptive throws shows a clear contraction relative to that observed for direct throws across all indicator axes. Figure 9 presents the magnitude of the relative change induced by deception in each indicator, with the largest changes observed in defensive-response efficiency, which decreased by approximately 21%, and reaction time, which increased by approximately 20%.

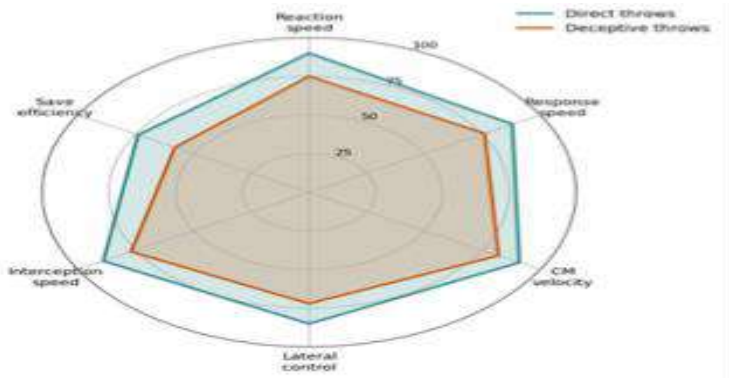

Figure 7. Goalkeeper Performance Index Direct vs. Deceptive Throws

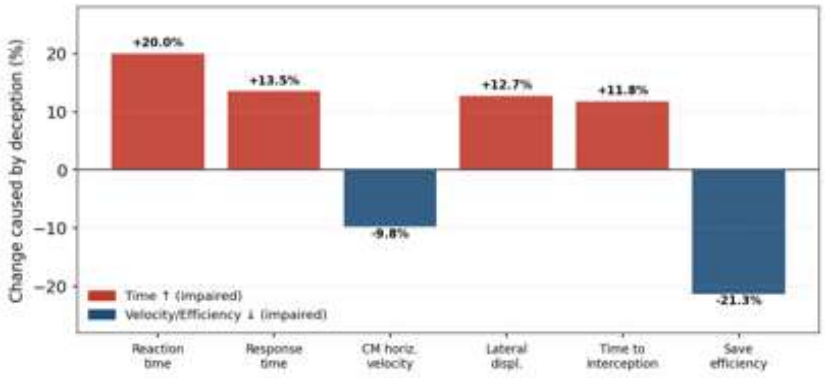

Figure 8. Magnitude of Change in Indicators Caused by Deception

DISCUSSION

The researcher explains these findings by suggesting that deception introduces an additional perceptual process in which the goalkeeper must identify the actual cue after being exposed to a misleading cue. Consequently, valuable portions of response time are consumed by inhibiting the initial movement and redirecting it. This is particularly evident in the increased lateral displacement, which may reflect delayed directional correction. This finding is consistent with Cañal-Bruland and Schmidt (2009), who indicated that deceptive movements generate a response bias that is difficult to avoid, and with Cañal-Bruland et al. (2011), who demonstrated that anticipatory judgments are sensitive to local kinematic changes in the thrower's movement.

The findings further indicate that the difficulty imposed by deception is fundamentally temporal and perceptual in nature, reinforcing the correlational finding that temporal indicators

were the most strongly associated with defensive-response efficiency. Accordingly, the second hypothesis was supported.

This finding highlights that addressing the effects of deception should not rely solely on developing muscular capacity, but should also incorporate the perceptual processes that precede movement. This perspective is supported by Arab studies that have directed training toward the perceptual and defensive abilities of goalkeepers, including Abd Al-Hadi (2022), who examined the development of cognitive abilities and defensive skills, and Mutaib et al. (2024), who investigated the development of sensorimotor perception and saving skills through feedback.

The researcher considers the present findings to complement these efforts by quantitatively identifying the indicators that should be prioritized in such training. This approach shifts goalkeeper preparation from general development of physical and perceptual abilities toward targeted development of the factors most closely associated with defensive-response efficiency.

The researcher concludes that a goalkeeper's ability to respond effectively to deceptive throws is based on an integrated system centered on rapid temporal response, supported by rapid center-of-mass displacement and greater reach distance. Developing this system requires training that targets reaction speed and perceptual reading of the thrower's cues alongside the muscular capacity required for rapid movement initiation. Such characteristics are difficult to diagnose and target appropriately without the quantitative biomechanical assessment adopted in the present study.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The biomechanical indicators of the goalkeepers included in the study sample showed relatively high homogeneity, whereas defensive-response efficiency demonstrated greater individual variability when responding to deceptive throws.
2. The indicators most strongly associated with defensive-response efficiency were reaction time and motor response time, both showing strong negative associations, followed by horizontal center-of-mass velocity and time to reach the save point.
3. The angular indicators showed relatively weak associations with defensive-response efficiency, suggesting that performance may be more closely related to temporal and velocity-related dimensions than to a single angular position.
4. Deceptive throws were associated with statistically significant changes in the goalkeeper's biomechanical indicators and defensive-response efficiency compared with direct throws, as reflected by lower defensive-response efficiency and greater lateral displacement, which may be related to delayed directional correction.

Recommendations

1. Goalkeeper training should prioritize the development of reaction speed and perceptual motor responses to the thrower's cues, given their relatively strong associations with defensive-response efficiency.
2. Quantitative biomechanical assessment, including high-speed video recording, force-platform measurements, and motion analysis, should be incorporated periodically into goalkeeper evaluation to identify and monitor performance limitations.
3. Specific exercises should be designed to train goalkeepers to respond to deceptive throws, identify the relevant cue, and inhibit premature responses.
4. Similar studies should be conducted in other goalkeeper situations, such as 7-m throws and close-range saves, using larger samples and three-dimensional biomechanical analysis.

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