

**ORIGINAL ARTICLE**

Motor Response Time and Biomechanical Factors in Stationary Handball Shooting Accuracy Among University Players

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Accepted June 25, 2025.**KEYWORDS***Response Time,
Biomechanics Phenomena,
Motor Skills,
Sports Performance.***ABSTRACT**

Background. Handball is a team sport that demands quick reflexes and precise motor skills, particularly in shooting. Players' ability to shoot accurately and swiftly while stationary makes upper limb reaction time crucial for success. **Objectives.** The research objective is to investigate the relationship between the motor time of the arm muscles and the accuracy index of shooting from a stationary position in fourth-stage handball players. **Methods.** The researchers employed the descriptive method because it is a commonly used method in research on a sample of students from the fourth stage of the College of Physical Education and Sports Sciences. The sample consisted of 29 male students from the community of origin and 43 students. **Results.** It is showed that the variables under study have significant direct correlations with the accuracy variable of shooting from stability, where the correlation of the motor response time was $r=0.73$ ($p=0.047$), the speed of movement of the arm $r=0.87$ ($p=0.380$), the maximum decrease in the knee angle variable $r=0.77$ ($p=0.360$) and the maximum decrease in the center of mass of the body was $r=0.79$ ($p=0.380$). In contrast, the degree of elbow angle during the ball's exit was variable, $r=0.62$ ($p=0.560$), and the degree of wrist angle during the ball's exit was variable, $r=0.79$ ($p=0.380$). **Conclusion.** The study found that motor response speed, knee angle, and body center of mass have a significant impact on skill accuracy. These factors balance the player and maintain the movement path, resulting in an integrated skill. The accuracy of shooting from consistency in handball is primarily determined by the angle taken at each stage, particularly during the exit phase of the ball.

INTRODUCTION

The significant advancements in scientific development that have occurred among global populations can be attributed to the adoption of contemporary and sophisticated scientific methodologies to achieve established goals and objectives (1). Consequently, sports have experienced notable progress through enhancing athletic standards, resulting from systematic and strategic planning. Among the various sports, handball has undergone a remarkable evolution

and secured a distinguished position among nations worldwide due to its exceptional capacity for thrill and excitement, in addition to being played by individuals of both genders (2, 3).

Handball constitutes a collective athletic endeavor that requires rapid response times and precise motor performance (4, 5). A pivotal element differentiating handball participants is their capacity to aim accurately and swiftly while maintaining a static posture (6). The reaction time

of the musculature in the upper limbs represents a crucial determinant influencing shooting efficacy (7).

Shooting is one of the fundamental skills in handball (8), serving as the key mechanism through which players can successfully reach their objectives and ultimately win matches (9). Notably, many tactical offensive strategies rely on this critical action (10, 11). Shooting plays a crucial role in boosting the psychological confidence of both individual athletes and the team, while also applying pressure on the opposing team's mental state (12), which may cause them to change their defensive setups. Additionally, shooting is closely connected to the motor response time of the arm muscles, which is crucial for enhancing shooting accuracy and improving overall performance effectiveness in the game (13).

Shooting with steadiness in handball involves accurately and powerfully directing the ball towards the goal while maintaining a firm, motionless position. This ability depends on body balance, ball control, and hand-eye coordination to achieve a successful shot (14).

The significance of this particular skill is underscored by its foundational role in the successful attainment of objectives within distinct scenarios that arise during a competitive match, particularly when the player finds themselves in a stationary position while enduring the intense pressure exerted by opposing defenders, or alternatively, when they are situated in a stable and advantageous attacking stance (15). Achieving a high level of proficiency in executing shots from a position of constancy plays a crucial role in enhancing the precision and accuracy of the shots taken. It serves as a vital cornerstone for the progressive development of additional shooting techniques, including those involving dynamic movement or shooting while in a state of jumping (16). This study is characterized by its direct correlation between the motor response time of the upper limb and the accuracy of shooting from the steady position of the handball, by analyzing the moment of the ball's exit using precise biomechanical variables such as the angle of the elbow and wrist joint, and the decrease in the knee angle. Despite the importance of previous studies in the field of motor response and accuracy of shooting from constancy in handball, recent studies reveal a clear lack of analysis of biomechanical factors in non-elite groups (17,

18). For example, Vila et al. (2023) highlighted the need for accurate biomechanical analysis, but did not identify the gaps that the studies concerned with university categories address. Recent studies indicate that these factors are present in college handball players, especially at the stage of shooting consistency (19). For example, the Asan study (2023) did not find a statistically significant relationship between grip strength or neuromuscular control and aiming accuracy in elite players, suggesting that technical performance may be more influential (20). Karim et al. (2024) also demonstrated a correlation between specific biomechanical variables and shooting accuracy during a high jump; however, this was not addressed during the shooting phase of consistency (21). Recent kinematic analyses have shown that average handball players who maintained elbow angles within the range of 100–110° exhibited a 15% increase in goal accuracy compared to those with a suboptimal joint position. However, these results have not yet been tested at a student level. Society, neuromuscular maturation, and movement strategies may differ (22). This study addresses an existing scientific need: to develop an accurate understanding of the factors affecting the accuracy of static shooting in this category, which is often subjected to training programs that are not customized or based on the standards of elite players. The first objective of this study was to measure the motor response time of the upper limb as a fundamental physiological indicator characterizing the speed of reaction to visual stimuli. Especially since previous results suggested that this variable may account for a significant portion of the variation in aiming accuracy. The second objective is to study variables such as the angle of the elbow joint, the angle of the wrist joint, the maximum degree of knee flexion, and the center of gravity of the body mass. These measurements aim to identify the motor characteristics most closely related to the aiming accuracy, building an accurate quantitative picture of ideal performance. Based on the results of these two axes (physiological and biomechanical), the study also aims to analyze the predictive relationship between these variables and the accuracy of static aiming, thereby contributing to the construction of an analytical model that can be used to interpret performance and guide training interventions.

This goal represents a fundamental step towards the transition from descriptive analysis to

quantitative forecasting, which can be used scientifically to design accurate training plans. Ultimately, these goals aim to achieve a broader objective of providing a practical training framework based on measurement and analysis results, specifically targeting university students and addressing the shortcomings of current training programs by focusing on scientifically scalable factors, such as response time, consistency of articulation angles, and dynamic balance efficiency.

In this way, the study enriches scientific literature and provides tools that are directly applicable in the university training environment. Consequently, the significance of research in which biomechanical variables exert a critical influence on athletic performance efficacy is underscored. By understanding the impact of these variables on both motor response time and targeting precision, coaches can refine their training regimens to develop player competencies and enhance the accuracy of targeting from a stationary position.

This investigation accentuates the essential role of motion analysis and the application of biomechanical metrics in enhancing handball performance. Modern research in sports science focuses on professional or elite players, while biomechanical and physiological data of university players is a relatively understudied area, despite these players often receiving less personalized and applied training programs. Systematic reviews, including the Lee study (2024), have indicated a clear research gap specific to this category, which calls for studies focused on university players to provide practical and applicable recommendations.

In this context, the current study aims to analyze one of the most important indicators affecting performance, which is the motor response time, which represents the speed of signal transmission from the sensory input to the muscular action and is a key indicator of the effectiveness of interaction with stimuli, especially in handball sports (23).

Salem and Ghunaim (2025) demonstrated that response time accounts for 53% of the variation in shooting accuracy among university players ($r^2 = 0.53$, $p = 0.047$), highlighting its significance as a central variable in this field. The articular angles, particularly at the elbow and wrist, determine the ball's trajectory and stability during the throw (24). Moreover, researchers have

assumed there is a statistically effect of the motor response time of the upper limb on the accuracy of shooting from the stationary position in the light of the biomechanical variables under consideration (The angle of the elbow during the exit of the ball, The angle of the wrist during the exit of the ball, Maximum decrease of the center of mass of the body during shooting, Maximum decrease of the knee angle during shooting) in university handball players. Shooting in handball requires the rapid generation of force and precise coordination of multiple joints. According to Newton's second law ($F = m*a$), the acceleration of the throwing arm depends on the net muscular force delivered through the elbow and shoulder joints; insufficient acceleration may damage the speed of the shot and trajectory. Moreover, the principle of impulse momentum ($\text{Impulse} = \Delta p$) asserts that a longer force application time (via optimal joint angles and controlled preparatory movement) can enhance the speed of the ball without sacrificing accuracy.

MATERIALS AND METHODS

The study used a descriptive Associative Design because it was convenient for analyzing the relationships between physiological and biomechanical variables and shooting accuracy among university players. The sample was intentionally selected from the research community, which consisted of fourth-year students in the faculties of physical education and sports sciences at the University of Baghdad. These students share similar technical and training characteristics, ensuring a level of homogeneity necessary for accurately analyzing the relationships between variables. Although this type of sampling restricts the generalization of the findings, it allows for studying the phenomenon within a realistic applied environment and is justified in research focused on specialized communities.

Study Design. The research included a preliminary exploratory experiment on March 11, 2024, during which the main obstacles were identified and the capabilities of the assistant work team were assessed. Subsequently, the main experiment was conducted on November 12, 2024, with the research sample, where the core test was performed, and the variables under consideration were determined (Figure 1).

Participants. The sample was intentionally selected to match the nature of descriptive

research, initially comprising 29 male students out of 43 students representing the research community. However, statistical analysis was performed on only 25 of them after four cases were excluded due to non-compliance with performance requirements or technical malfunctions that prevented complete recording of motor data. This step was taken before analysis to ensure the accuracy of biomechanical measurements and the validity of the results. The sample was selected to ensure a normally distributed representation, focusing on healthy students with good health. Regarding potential overlapping variables, such as gender and sports experience, the study was limited by restricting the sample to males with similar training and university competition experience. Although the study did not employ stratified analyses or multi-level statistical models,

the relative homogeneity of the sample helped reduce the influence of these factors on the results.

Participants' Demographic data, including age, height, and weight, were collected according to standard norms in sports studies. The demographic characteristics are shown in [Table 1](#).

A normal distribution check was conducted to verify the sample's representation. However, the absence of randomization may limit the generalization of the results. Future studies should employ random or stratified sampling to minimize selection bias.

A power analysis conducted with G*Power ($\alpha = 0.05$, power = 0.80, effect size = average) indicated that a sample of 21-24 participants is sufficient for the planned correlational analyses, supporting the chosen sample size.

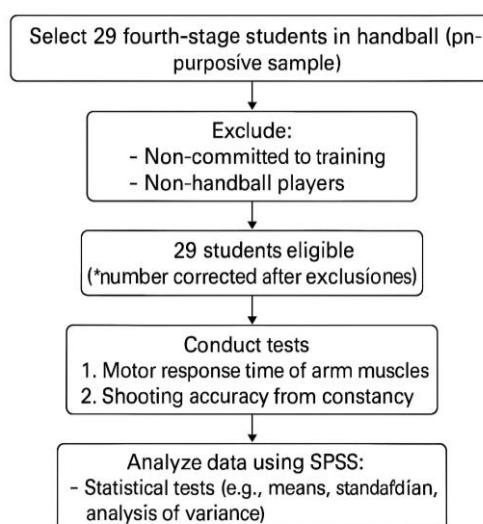


Figure 1. A flowchart representing the procedures for selecting a study sample, testing, and data analysis.

Table 1. Demographic variables of the study sample.

The variable	M	SD
Age (year)	24	1.5
Height (cm)	175	7
Weight (kg)	72	8

M: Mean; SD: Standard deviation.

Inclusion Criteria. The participants met specific conditions, including being enrolled in the fourth stage of the handball program, being free from muscular injuries or neurological issues, attending practical sessions regularly, being physically healthy and suitable for performance tests, and having no prior experience at elite or professional levels of handball.

Managing Confusion. To minimize the discrepancy, all participants were from the same academic level and specialty, ensuring a similar educational background and skills. However, gender and previous play experience were not fully controlled and were identified as potential confounding variables that should be addressed in future studies using stratified analysis or matching methods.

The exclusion criteria involved removing students with illnesses or injuries that hinder their participation and those who are not committed or unable to perform research-related tests. Additionally, four students were excluded for not complying with the final form and the established exam procedures. As a result, the final sample size was 25 students, representing 58.13% of the research population. The theoretical normal distribution and the theoretical distribution were also compared with the actual distribution derived from real data. This comparison helps evaluate how well the data align with the theoretical model and identify any discrepancies in the actual data. These steps were taken to ensure the quality and accuracy of the results, aligning with the objectives of descriptive research and accurately representing the study community.

Instruments. A Sony high-speed camera, capable of recording 1000 frames per second, was used to capture kinematic movements during a shooting accuracy test. To ensure precise biomechanical measurements, the camera was calibrated using a lens deformation correction method to maintain accurate geometric dimensions and properly align with the target area. The camera was positioned 1.5 meters above the floor to ensure accurate recording of movement.

Reliability of the Assessment. Kinovea software was used to analyze biomechanical

movements during shooting performance. To ensure the reliability of the evaluation among the evaluators, the reliability coefficients (ICC) were calculated, which showed high consistency (ICC = 0.92), confirming that the measurements are dependable and repeatable.

Testing the Accuracy of Shooting for the Constancy. Figure 2 illustrates the method for testing shooting accuracy from constancy, including the necessary tools, the camera position during the test, and all measurements and dimensions required. The purpose of the test was to assess shooting accuracy from constancy. Tools included eight handballs and four squares, each measuring 40 x 40 cm. The procedure involved: a) The tester stands behind a throw line 7 meters away, holding the ball; b) When the signal is given, the player aims at Square 1, 2, 3, and 4; and c) repeats the process. Grammar considerations included: a) maintaining the constancy of one of the player's feet without moving it during the throw; and b) playing the ball within three seconds of hearing the signal (25).

Guidance and recording. One point is awarded for each shot made within the designated area. Zero is given if the player commits an offense, such as moving their fixed feet or failing to shoot within three seconds of hearing the signal.

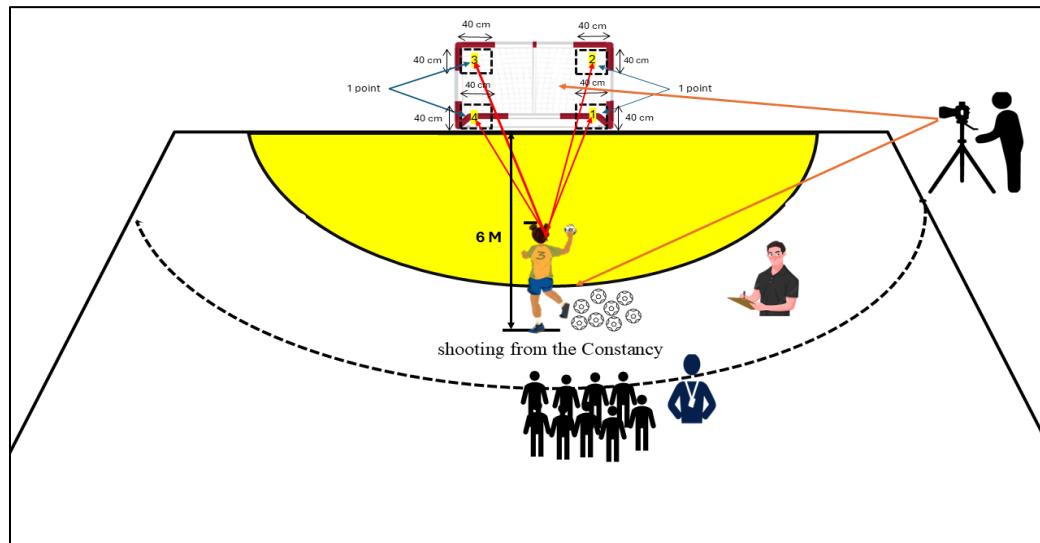


Figure 2. The accuracy test of shooting from constancy position.

Data Collection. The data were gathered during the main experiment, where they were recorded by testing the accuracy of shooting from a stable position and capturing photographic evidence of the

test method. Then, the data was analyzed and uploaded to the data registration form.

Camera position and angle: To accurately record shooting movements, a high-speed camera

(≥ 120 frames/sec) must be mounted on a fixed stand at a lateral angle (90° relative to the arm's trajectory). The cameras were also placed at a height roughly parallel to the shoulder joint (1.5 meters) and at least 3 meters away from the shooting line to minimize visual distortion.

Reliability of the test: To ensure data accuracy, each participant undergoes eight attempts, with a 3-second interval between each attempt. The Intraclass Correlation Coefficient (ICC) is calculated between the three attempts to confirm a value ≥ 0.85 , which indicates high reliability. The average of the three attempts was used in the final analysis to minimize random variation.

Data Analysis. The data was entered and organized into Excel tables, then transferred to SPSS version 26 for statistical analysis. Calculations included arithmetic averages (Mean), standard deviation (SD), and percentages (%). A simple correlation coefficient test (Pearson's r) was also performed to assess the strength of the relationship between motor response time and shooting accuracy, and to determine the contribution ratio of the explained variability. A significance level of $\alpha = 0.05$ was adopted, with results considered statistically significant if $p < 0.05$.

RESULTS

The test of shooting accuracy from a stable position was conducted on a sample of 25 university players, with each player making three shooting attempts. Their performance scores were recorded for each attempt. The arithmetic mean for each player was then calculated to represent their overall skill, as shown in [Table 2](#), which displays the raw scores of the study sample. The averages ranged from 4.33 to 7.67, indicating variation in shooting accuracy levels among the players. Player 19 achieved the highest average of 7.67, reflecting a high level of accuracy and stability in performance. Conversely, players 6 and 16 recorded the lowest average of 4.33, suggesting they may benefit from customized training interventions to improve their performance.

The results are shown, outlining the sample selection process, starting from the original community ($n=43$) and ending with the exclusion of 14 students who did not meet the inclusion and testing criteria, resulting in the final sample ($n=29$).

Motor Response Time. The analysis results showed a strong correlation between motor

response time and shooting accuracy in handball, with a correlation coefficient of $r = 0.73$, indicating a strong positive relationship. However, the p -value ($p = 0.047$) did not meet the accepted threshold of statistical significance (0.05), indicating that the relationship is not statistically significant. Nevertheless, the value of the coefficient of determination ($r^2=0.53$) suggests that 53% of the variation in shooting accuracy can be explained by response time. This finding underscores the importance of response time in skill performance and aligns with recent trends highlighting the link between response speed and accurate skill execution in team sports. As shown in [Table 3](#).

Maximum Decrease of the Center of Mass of the Body During Aiming. The results showed a strong correlation between the maximum decrease in the body's center of mass during shooting and shooting accuracy ($r = 0.87$); however, the relationship was not statistically significant ($p = 0.380$). The contribution ratio was $r^2 = 0.60$, indicating that this variable can explain 60% of the variation in shooting accuracy. Interestingly, this finding was unexpected, as many previous studies suggest that lowering the body's center of mass is a mechanical factor that improves motor stability and control during complex skills, such as aiming, which was expected to produce a statistically significant relationship. This variation may be due to individual differences in how the skill is executed or to varying learning styles among players, highlighting the need for additional research that considers the qualitative aspects of movement, not just quantitative angles. As shown in [Table 4](#).

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Table 2. Shows the raw scores of the study sample to test the shooting skill from constancy.

The player	Attempt 1	Attempt 2	Attempt 3	Mean
1	6	7	6	6.33
2	5	6	5	5.33
3	7	6	7	6.67
4	8	7	7	7.33
5	6	5	6	5.67
6	5	5	4	4.67
7	6	6	6	6
8	7	7	6	6.67
9	4	5	4	4.33
10	6	7	7	6.67
11	7	6	7	6.67
12	5	5	6	5.33
13	6	6	6	6
14	6	7	7	6.67
15	5	6	5	5.33
16	4	5	4	4.33
17	7	7	6	6.67
18	5	5	5	5
19	8	7	8	7.67
20	6	6	5	5.67
21	5	6	6	5.67
22	7	8	7	7.33
23	6	6	6	6
24	5	5	6	5.33
25	7	6	7	6.67

Table 3. Biomechanical variables of the shooting skill from constancy.

No	Biomechanical variables	Unit of measurement	The shooting skill of constancy		
			M	SD	r
1	The motor response time	S	0.56	0.051	0.73

M: Mean; SD: Standard deviation; R: Correlation coefficient; P: p-value.

Maximum Decrease of the Center of Mass of the Body During Aiming. The results showed a strong correlation between the maximum decrease in the body's center of mass during shooting and shooting accuracy ($r = 0.87$); however, the relationship was not statistically significant ($p = 0.380$). The contribution ratio was $r^2 = 0.60$, indicating that this variable can explain 60% of the variation in shooting accuracy. Interestingly, this finding was unexpected, as many previous studies suggest that lowering the body's center of mass is a mechanical factor that improves motor stability and control during complex skills, such as aiming, which was expected to produce a statistically significant relationship. This variation may be due to individual differences in how the skill is executed or to varying learning styles among players, highlighting the need for additional research that considers the qualitative aspects of movement, not just quantitative angles. As shown in [Table 4](#).

Maximum Lowering of the Knee Angle During Aiming. The results showed a strong correlation between the maximum decrease in knee angle during shooting and aiming accuracy ($r = 0.77$), although it did not reach statistical significance ($p = 0.360$). The contribution ratio was $r^2 = 0.59$, indicating that 59% of the variance in accuracy is attributable to this variable. This suggests that the knee plays a crucial role in controlling posture during shooting; however, individual differences in motor execution techniques likely reduce the likelihood of achieving uniform statistical significance in a small sample. As shown in [Table 4](#).

The Angle of the Elbow During the Moment of Exit of the Ball. The correlation coefficient between the elbow angle at the moment of ball release and shooting accuracy was $r = 0.62$, indicating a medium-strength relationship, but it was not statistically significant ($p = 0.560$). The

contribution ratio was $r^2=0.38$. This finding is somewhat surprising, as the literature suggests that the elbow angle at the moment of release is directly related to guidance accuracy and ball trajectory control. This result likely reflects the influence of other variables, such as trunk angle or arm speed, which were not isolated in this study. It highlights the importance of analyzing movements as a whole complex rather than just as separate joints, as shown in [Table 5](#).

The Angle of the Wrist During the Moment of Exit of the Ball. The results showed a strong correlation between the wrist angle at the moment

of the ball's exit and shooting accuracy ($r = 0.79$), but this relationship was not statistically significant ($p = 0.380$). The contribution ratio has reached $r^2 = 0.62$, indicating a notable effect of this variable on improving shooting quality and reflecting its role in the final touch that determines the trajectory and accuracy of the ball. Moreover, although statistical significance was not achieved, the high value of the correlation coefficient suggests the importance of this variable, which warrants further research to confirm its role using larger samples and more extensive study designs. As shown in [Table 5](#).

Table 4. Shows the correlation between the accuracy index of shooting in handball and the maximum decrease in the center of body mass and knee angle during shooting.

No	Biomechanical variables	Unit of measurement	The shooting skill of constancy		
			M	SD	r
1	Maximum decrease of the center of mass of the body during shooting	cm	90	2	0.87 0.380
2	Maximum decrease in the knee angle during shooting	cm	108	12.58	0.77 0.360

M: Mean; SD: Standard deviation; R: Correlation coefficient; P: p-value.

Table 5. Shows the correlation between the accuracy index of shooting in handball and the angle of the elbow and wrist during the ball's exit.

No	Biomechanical variables	Unit of measurement	The shooting skill of constancy		
			M	SD	r
1	The angle of the elbow during the exit of the ball	Degree	141	3.21	0.62 0.560
2	The angle of the wrist during the exit of the ball	Degree	162	3	0.79 0.380

M: Mean; SD: Standard deviation; R: Correlation coefficient; P: p-value.

DISCUSSION

It is clear from the previous [Table 3](#) that there is a relationship and a centrifugal orientation between motor response time and shot accuracy in handball, where the quick interaction between neuromuscular response and shot accuracy is essential for optimal player performance. Research shows that improvements in motor response time lead to better shooting accuracy, as players with quick responses can make critical decisions faster (26), reducing the chance of errors during shooting. This relationship is supported by studies indicating that increasing neuromuscular strength through targeted exercises can significantly boost shooting accuracy (27). Şimşek's research (2018) further elucidated the link between electrical activity in the upper arm muscles and shot precision,

demonstrating that players with higher muscular engagement tend to achieve better goal accuracy, especially in handball, which involves tight angles that challenge the attacker. The study suggests that increased muscle electrical activity enhances the recruitment of motor units and improves neuromuscular communication, enabling muscles such as the triceps and biceps to generate the correct force and adjust contraction timing. The physiological mechanism behind this involves greater muscle involvement, which increases shoulder and elbow stability and reduces motor oscillation during the pushing and releasing phases. This improves the adjustment of throw angles and directions under defensive pressure and tight spaces, leading to more consistent and accurate shots (28). The link between motor response latency and shooting

accuracy depends on how quickly the neuromuscular system responds and how well the player performs controlled movements. Motor response latency refers to the time it takes for a player to process visual or motor cues (such as a ball or defenders' movements) and react accordingly, which directly impacts shooting accuracy (29, 30). Training should target this variable as a key factor in skill performance. This can be achieved through visual and auditory response exercises, such as those in Blazepods, which utilize light effects to prompt quick responses. For example, placing light modules around a region where they turn on randomly, and the player is tasked with moving toward and touching the lit module quickly before returning to the starting point, repeating several rounds. These exercises aim to improve response speed, agility, and eye-hand coordination. Mohammed's study (2024) on handball students at Minya University, involving 8 weeks of BlazePod training, showed significant improvements in response speed and defensive skill levels. The study confirmed that performing such exercises three times a week for eight weeks could improve response time by up to 12%, positively impacting overall performance. This progress likely results from improved neuromuscular coordination, as repeated light-response training speeds up visual signal processing in the brain's motor cortex and its rapid transfer to motor units, enhancing muscle recruitment for joint stability and interception movements. The underlying process relies on neural plasticity, which creates faster connections between visual and motor areas, as well as improves motor attention and reduces decision-making times. This makes responses more automatic and boosts overall defensive skills (31). Although some variables, such as the stability of the center of mass and joint angles (knee: 90-110 degrees, elbow: 90-120 degrees), did not reach statistical significance, their practical importance encourages exploring specific training strategies to determine how customized interventions could affect them. For instance, dynamic balance exercises on tools like BOSU or vibrating boards, with three sets of 45 seconds each, can stimulate motor control and help stabilize the center of gravity. Regarding the knee angle, exercises involving vertical jumps, with landings at approximately 100 degrees, monitored using motion analysis tools, can help ensure proper technique. Incorporating these exercises into

weekly training can help track performance improvements over time (32).

Results show a direct correlation between the maximum decrease in the body mass center during shooting and the accuracy index of shooting. The correlation indicates that a decrease in the body mass center enhances consistency and control during shooting. The lower the center of mass, the more balanced the body becomes (33), which allows force to be effectively transferred from the lower to the upper body, thereby improving shooting accuracy. The form constancy of the body during shooting, which depends on the center of mass remaining stable, plays a crucial role in enhancing performance. If the center of mass is high or unstable, this can cause imbalance and reduce shooting accuracy. A lower center of mass provides a greater support base and increases the vertical thrust of the legs, contributing to better body control and shooting precision. The (Sadeq) 2024 study indicated that players who can lower their body's center of mass during shooting have better movement control, positively affecting shooting accuracy. This study suggests that lowering the body's center of gravity during the throw enhances the dynamic stability of the joints (knee, pelvis, and ankle), which reduces shear forces and lateral vibrations during movement. This mechanical stability enhances neuromuscular coordination by providing a uniform activation pattern of the participating muscles.

Regarding the physiological mechanism, it is based on proprioception: the lowered body position enhances joint position sense and activates sensory receptors in ligaments and tendons, reducing brain processing time for motor information and improving neuromuscular planning and movement execution. This increases shooting accuracy and decreases the lateral deflection of the ball (34). The Krosshaug study (2007) showed that lowering the body's center of gravity improves players' balance and enhances the accuracy of motor performance in handball. A lower center of gravity broadens the imaginary support base and reduces torque on the joints, increasing stability and decreasing the need for momentary adjustments. Consequently, the sensitivity of postural receptors (proprioceptors) improves, and neuromuscular corrections decrease; aiming becomes smoother and steadier in direction (35).

It was found that there is a direct correlation between the maximum decrease in knee angle

during shooting and the accuracy index of shooting. The relationship between the maximum decrease in knee angle and shooting accuracy stability in handball centers on the mechanical effect of the angle on force generation and consistency during shooting, especially when the knee angle is correct and low enough for players to generate more force from their leg muscles. This force can then be transferred to the shoulders and arms during the shot. However, if the knee angle is too low or insufficient, it may lead to a lack of body balance, which can negatively impact shooting accuracy (36).

A comprehensive investigation by Christensen (2020) conclusively demonstrates that the specific angle of the knee joint during flexion significantly affects the body's balance and the force required to shoot accurately while maintaining consistency. The study's scientific interpretation indicates that selecting the optimal knee flexion angle helps center the body's gravity within the support base of the legs, reducing unwanted tilt and stabilizing the body during shooting. This right angle also allows the player to smoothly transfer weight from the back leg to the front, improving the stability of the fulcrum and directing force accurately toward the shot. This is due to, first, the placement of muscles around the knee (quadriceps and hamstrings) in a length-tension range that boosts their contractile ability; second, increased torque at the joint thanks to the correct length of the force lever; third, enhanced sensory feedback (proprioception) that speeds up neuromuscular adjustments to maintain stability; and fourth, better pressure distribution and joint stability during weight transfer and aiming, leading to more precise and effective ball handling (37). Numerous scientific studies have confirmed that the ideal knee angle, typically between 90 and 110 degrees, is crucial for optimizing strength and consistency during shooting. This range balances the body's natural flexibility and ability to generate the necessary force for effective performance. A study by Jo (2015) similarly emphasizes that maintaining the knee joint at a specific angle can significantly enhance overall athletic performance. It suggests that fixing the knee between about 30° and 45° of flexion enhances force production and movement stability, as the muscle fiber length aligns better with the tension-length curve, thereby boosting force transfer efficiency.

Additionally, proprioceptor response in the knee improves, reducing the need for adjustments. The optimal angle also helps absorb shocks and store elastic energy for recovery during explosive movements, which reduces energy expenditure and delays fatigue, thereby enhancing overall performance, particularly in terms of shooting accuracy. However, it is essential to note that excessive increases or decreases in the knee angle can disrupt the body's balance, negatively impacting shooting precision (38).

The variants under study may be significantly impacted by muscle fatigue caused by repeated exertion or prolonged play. A study by Rigozzi et al. (2023) suggests that fatigue affects the accuracy of joint movements, leading to motor coordination dysfunction that reduces the stability of joint postures during performance and, consequently, impacts shooting accuracy. It can be understood that fatigue decreases the precision of joint movements and disrupts motor coordination through two main mechanisms: first, the buildup of metabolic products (such as lactic acid) and glycogen deficiency slows nerve impulse transmission and reduces the effective recruitment of muscle units; second, central fatigue causes a decrease in stimulation of the motor cortex and sensitivity of postural receptors, impairing joint stability and increasing errors in motor angles, which negatively impacts aiming accuracy (39).

Fatigue can also disrupt the body's balance and alter the position of the body's center of mass, which impacts the dynamic balance at the moment the ball exits (19). According to Pantelis (2024), fatigue diminishes the effectiveness of motor control and increases the likelihood of a change in movement mechanics, particularly in quick and precise movements, such as aiming from a stationary position (40, 41).

There is a direct correlation between the angle of the elbow during ball release and shooting accuracy, as this relationship depends on the precise mechanics of arm movement and muscle coordination during the shooting process. Since the elbow angle directly influences the ball's trajectory and speed, an incorrect or imprecise elbow angle can result in an inaccurate trajectory, thereby affecting shooting accuracy. Scientific studies suggest that the ideal elbow angle during ball release is between about 90 and 120 degrees to maximize strength and accuracy, as this range

promotes optimal muscle coordination, which helps control the ball's trajectory and speed (42). The study by van den Tillaar (2009) showed that adjusting the elbow angle can significantly impact shooting accuracy; players who maintain a consistent elbow angle tend to be more accurate. This stability reduces arm oscillation, resulting in a more uniform ball trajectory during launch. Mechanically, maintaining an optimal elbow angle improves coordination between the biceps and triceps, enhances shoulder stability, and enables a more efficient transfer of energy from the trunk to the arm, ultimately leading to more accurate shots (43) (Table 5).

Results show that there is a direct correlation between the angle of the wrist during the ball's exit and shooting accuracy, as the relationship between wrist angle and shot precision in handball mainly depends on motor control and force direction. The wrist angle plays a crucial role in directing the ball's trajectory, as precise control of this angle influences both the height and direction of the shot. When the wrist angle is optimal, it allows the ball to exit with a straight and fast trajectory, enhancing accuracy. Scientific studies in biomechanics have shown that the timing and precision of wrist movements during ball launch can enhance players' overall performance (44). The study by Wagne (2011) demonstrated that the final wrist movement during ball exit is significantly related to shooting accuracy (45), with players who better controlled their wrist angle during release being more accurate. This is because the optimal wrist angle enables precise guidance of the thrust and release angle, which improves the ball's trajectory toward the target. Regarding the possible mechanism, motor adjustments of the wrist enhance the coordination of hand movement with the axis of the throw, reducing angular oscillation at release and increasing the stability of the motor trajectory, which produces more accurate and stable shots (46).

The speed of motor response is a key factor that greatly influences shooting accuracy in handball, particularly among university players. Aiming in handball requires precise neuromuscular coordination in a minimal amount of time to adjust the ball's course and execute movements correctly. The quicker the player reacts, the better they can control the angles of the elbow and wrist, ensuring the ball's final trajectory aligns with the intended goal. Studies indicate that delayed motor responses lead to muscle timing dispersion and reduce

throwing accuracy. Therefore, response speed training should be a vital component of training programs for university players, as improving overall performance involves minimizing neuromuscular delays and increasing the available time for accurate aiming (47).

The psychological factor directly influences the accuracy of aiming in university students, as stress and anxiety are linked to decreased motor control and joint posture stability during performance. Muntianu et al. (2022) emphasized the significance of the interaction between psychological traits and psychomotor skills in improving sports performance. In steady handball shooting, psychological factors such as self-discipline and motivational perseverance can improve accuracy by increasing focus and decision-making. Concurrently, psychomotor skills impact the execution of precise movements (48), with a study by Shalar et al. (2019) emphasizing the role of psychological readiness in enhancing sports performance. In continuous handball shooting, psychological preparedness—such as self-confidence and motivation—can influence a player's ability to shoot accurately under competitive pressure.

Additionally, mental disorders may alter the angles of the elbow and wrist during ball release, affecting its trajectory and accuracy (49). The inability to lower the body's center of mass due to psychological stress also impairs balance, which is crucial for a precise throw. Since university students often lack extensive experience in competition, incorporating psychomotor training programs is necessary to improve stability and accuracy in performance (50). Several limitations in this study should be addressed. First, the sample consists of lower-year students in the early stages of their university education, which limits the ability to generalize the findings to professional or youth handball players. Second, biometric standards related to speed, such as the rate of angular movement, have not been examined. For a more detailed analysis, potential external factors, such as fatigue, previous training load, or psychological variables like attention and decision-making under pressure, have not been controlled, which could influence motor response time and handball accuracy.

CONCLUSION

The study concluded that motor response speed is strongly linked to the accuracy index of

shooting in handball, suggesting that a 53% variation in shooting accuracy can be explained by response speed. This is because accurate neuromuscular interaction with the correct trajectory and a little time is necessary to perform the skill with high precision. The variables of the maximum knee drop and the center of mass of the body play significant roles in determining shooting accuracy. Although the results showed a strong correlation with the accuracy index, this relationship did not reach statistical significance; however, the high explanatory power indicates that this variable makes a significant contribution to interpreting shot performance. This highlights the importance of considering biomechanical factors when training and suggests that further studies with larger sample sizes are needed to confirm these findings. While not all of these correlations reached the traditional significance level ($p < 0.05$), they indicate strong relationships between biomechanical variables and shot accuracy. Additionally, in handball, shooting accuracy from a stable position mainly depends on the angles of the wrist and elbow joints at each stage of the shot, especially during the ball's exit phase, which is considered the final stage of the skill.

APPLICABLE REMARKS

- Training includes dynamic balance exercises to enhance the stability of the center of gravity and techniques to improve the optimal knee angle (90-110°) using jumps.
- Players are also trained to control elbow and wrist angles (90-120°) to improve aiming accuracy through guided exercises and kinesthetic analysis tools.

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AUTHORS' CONTRIBUTIONS

Study concept and design: Abbas Hussein Khalifa. Acquisition of data: Mustafa Ahmed Obaid. Analysis and interpretation of data: Abbas

Hussein Khalifa. Drafting the manuscript: Mustafa Ahmed Obaid. Critical revision of the manuscript for important intellectual content: Teeba Saleem Abd. Statistical analysis: Abbas Hussein Khalifa. Administrative, technical, and material support: Teeba Saleem Abd. Study supervision: Mustafa Ahmed Obaid.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

FINANCIAL DISCLOSURE

We hereby declare that we have no relevant financial interests or conflicts of interest related to the content of this manuscript. We have not received any research funding or compensation from institutions or organizations in the past years or for the future. Additionally, we have no financial ties or personal relationships that could have influenced the substance or outcomes of this research.

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ETHICAL CONSIDERATION

This study followed the ethical guidelines of the University of Baghdad, College of Physical Education and Sports Sciences, Baghdad, Iraq. All participants were informed about the testing process, made aware of potential risks, and given their written consent to participate. All personal information from the research sample was kept strictly confidential. These procedures were submitted for review, and the Ethical Committee approved the study.

ROLE OF THE SPONSOR

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ARTIFICIAL INTELLIGENCE (AI) USE

No artificial intelligence tools or techniques were used in this manuscript's design, analysis, or

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