

**ORIGINAL ARTICLE**

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

<sup>1</sup>Abbas Hussein Khalifa , <sup>1</sup>Mustafa Ahmed Obaid \*, <sup>1</sup>Zahraa Adnan Hadi 

<sup>1</sup>College of Physical Education and Sports Sciences, University of Baghdad, Baghdad, Iraq.

\*, Corresponding Author: Mustafa Ahmed Obaid; E-mail: [mostafa.a@cope.uobaghdad.edu.iq](mailto:mostafa.a@cope.uobaghdad.edu.iq)

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**KEYWORDS**

*Response Time,  
Biomechanic 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 study the relationship between the motor time of the muscles of the arms and the index of accuracy of shooting from constancy in fourth-stage students in handball. **Methods.** The researchers used the descriptive method because it is one of the methods used in the research on a sample of students of the fourth stage of the college of Physical Education and Sports Sciences, where the sample consisted of 29 male students from the community of origin, 43 students. **Results.** The results 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 significantly impact 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. This study stands out with novelty for its focus on university handball players, providing an accurate biomechanical analysis of this category of students, which has not been studied. The analyzed variables included elbow angle, wrist angle, knee flexion, and center of body mass during different shooting phases. In addition, using a non-random sample is a limitation that may affect the generalizability of the results.

**INTRODUCTION**

The significant advancements in scientific development that have transpired among global populations can be attributed to adopting 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 remarkable evolution and has secured a distinguished position among nations worldwide due to its exceptional capacity

for thrill and excitement, in addition to being engaged in by individuals of both genders (2, 3).

Handball constitutes a collective athletic endeavor that necessitates rapid response times and elevated precision in 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 essential for improving shooting accuracy and increasing 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, control of the ball, 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) pointed out the need for accurate biomechanical analysis, but did not identify the gaps the studies concerned with university categories fill. Recent studies indicate these factors in college handball players, especially at the shooting stage of 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) study also showed a correlation between some biomechanical variables and the shooting accuracy during a high jump, but it was not addressed during the shooting phase of constancy (21). Recent kinematic analyses showed that average handball players who kept the elbow angles in 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 comes to meet an existing scientific need, which is the 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. So, the first objective of this study was to measure the motor response time of the upper limb as one of the fundamental physiological indicators characterizing the speed of reaction to visual stimuli, especially since previous results indicated that this variable may explain a large percentage 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, which contributes to constructing 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. Finally, these goals serve a broader goal of providing a practical training framework based on the results of measurement and analysis, which is specifically targeted at the university students, and addresses the shortcomings of current training programs, by targeting 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 wherein biomechanical variables exert a critical influence on the efficacy of athletic performance is underscored. By comprehending the impact of these variables on both motor response time and the precision of targeting, coaches can enhance training regimens aimed at cultivating player competencies and augmenting the proficiency 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 university players' biomechanical and physiological data is a little-studied area, although these players often receive 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) showed that the response time explains 53% of the variation in shooting accuracy among university players ( $r^2=0.53$ ,  $p=0.047$ ), reflecting its importance 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 rapid force generation and precise coordination of multiple joints. According to Newton's second law ( $F = m \cdot a$ ), 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 based on the research community, which was limited to 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 03-11-2024, during which the main obstacles were identified and the capabilities of the assistant work team were assessed. Subsequently, the main experiment was conducted on 12-11-2024 with the research sample, where the core test was performed, and the variables under consideration were determined (Figure 1).

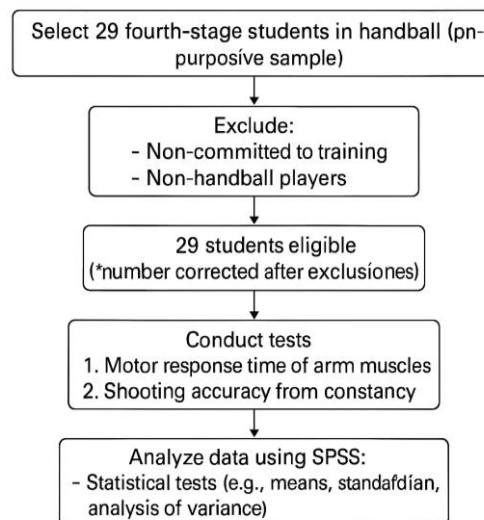
**Participants.** The sample was selected intentionally to match the nature of descriptive research, initially including 29 male students out of 43 students representing the research community. However, statistical analysis was performed on only 25 of them after four cases were excluded due to non-compliance 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 normally distributed to ensure a balanced representation, focusing on healthy students with good health. Regarding potential

overlapping variables like gender and sports experience, they were limited by restricting sample characteristics 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) showed that a sample of 21-24 participants is adequate for the planned correlational analyses, supporting the chosen sample size.



**Figure 1.** A flowchart representing the procedures for selecting a study sample, their 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 conditions such as 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 handball levels.

**Managing Confusion.** To minimize the discrepancy, all participants were from the same academic level and specialty, ensuring similar educational background and skills. However, gender and previous play experience were not fully controlled and were identified as potential confounding variables to be addressed in future studies with 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 fit the theoretical model and identify any discrepancies in the real 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.

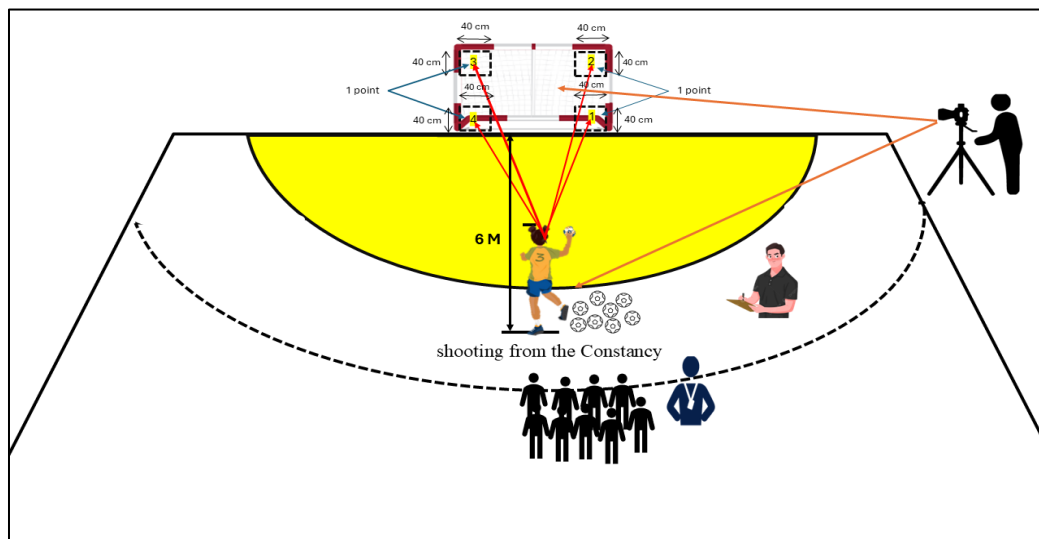
**Instruments.** A Sony high-speed camera that recorded 1000 frames per second was used to capture kinematic movements during a shooting accuracy test. To ensure precise biomechanical measurements, the camera was calibrated using a lens deformation correction method to maintain

accurate geometric dimensions and properly align with the target area. The camera was positioned 1.5 meters above the floor to ensure accurate movement recording.

**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 measuring 40 x 40 cm each. 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.

**Data Collection.** The data was gathered during the main experiment, where it was 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 ( $\geq 120$  frames/sec) must be mounted on a fixed stand at a lateral angle ( $90^\circ$  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 test includes 8 attempts per participant, with a 3-second interval between attempts. The Intraclass Correlation Coefficient (ICC) is calculated between the three attempts to confirm a value  $\geq 0.85$ , 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 for the amount of 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 stability was conducted on a study sample of 25 university players, with each player making three shooting attempts and their performance scores 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 the correlation coefficient reaching  $r=0.73$ , indicating a strong positive relationship. However, the  $p$ -value ( $p=0.047$ ) did not meet the accepted threshold of statistical significance (0.05), meaning 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 like 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](#).

**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	p
1	The motor response time	S	0.56	0.051	0.73	0.047

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

**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	p
1	Maximum decrease of the center of mass of the body during shooting	cm	90	2	0.87	0.380
2	Maximum decrease of the knee angle during shooting	cm	108	12.58	0.77	0.360

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

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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 like 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 the knee angle during shooting and aiming accuracy ( $r=0.77$ ), but 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 an important role in controlling posture during shooting, but individual differences in motor execution techniques likely reduce the chance 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 the ball's 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 during the moment of the ball's exit and the shooting accuracy ( $r=0.79$ ), but this relationship is 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 this variable's importance, which warrants further research to confirm its role using larger samples and more extensive study designs. As shown in Table 5.

**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	p
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 explained the link between electrical activity in the upper arm muscles and shot precision, showing that players with higher muscular engagement tend to have 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, allowing muscles like the triceps and biceps to generate the correct force and adjust contraction timing. The physiological mechanism behind this involves greater muscle involvement increasing shoulder and elbow stability and reducing motor oscillation during pushing and releasing phases. This improves 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 is 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 affects shooting accuracy (29, 30). Training should target this variable as a key factor in skill performance. This can be done through visual and auditory response exercises, like those in Blazepods that use light effects to motivate 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 their rapid transfer to motor units, enhancing muscle recruitment for joint stability and interception movements. The underlying process relies on neural plasticity, creating faster connections between visual and motor areas, along with better motor attention and shorter decision-making times. This makes responses more automatic and boosts overall defensive skills (31). Although

some variables, like 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 see how customized interventions could affect them. For instance, dynamic balance exercises on tools like BOSU or vibrating boards, with 3 sets of 45 seconds each, can stimulate motor control and stabilizing the center of gravity. Regarding the knee angle, exercises involving vertical jumps landing at approximately 100 degrees, monitored with motion analysis tools, can help ensure proper technique. Incorporating these exercises into weekly training can help track performance improvements over time (32).

Results show that there is a direct correlation between the maximum decrease in 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 decreases, 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 decrease in the center of mass, plays an important 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 interprets that lowering the body's center of gravity during the throw enhances the dynamic stability of joints (knee–pelvis–ankle), which reduces shear forces and lateral vibrations during movement. This mechanical stability improves neuromuscular coordination through 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 more steady 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 less than necessary, it may lead to a lack of body balance, which can negatively affect shooting accuracy (36).

A comprehensive investigation by Christensen (2020) conclusively shows that the specific angle of the knee joint during flexion significantly affects the body's balance and the force needed to shoot accurately while keeping consistent. 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). Many scientific studies have

clarified that the ideal knee angle, generally between 90 and 110 degrees, is essential for maximizing 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 stresses that maintaining the knee joint at a specific angle can greatly improve overall athletic performance. It suggests that fixing the knee between about 30° and 45° flexion enhances force production and movement stability, because the muscle fiber length aligns better with the tension–length curve, boosting force transfer efficiency, and 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 lowers energy use and delays fatigue, thereby improving overall performance, especially shooting accuracy. However, it is important to note that too much increase or decrease in the knee angle can upset the body's balance, negatively affecting 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) indicates that fatigue affects the accuracy of joint movements and leads to motor coordination dysfunction, which reduces the stability of joint postures during performance and, as a result, affects 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 cause a disruption in 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 raises the chances of a change in movement mechanics, especially 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 shooting. 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 to 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 indicated that the timing and precision of wrist movements when launching the ball can improve players' overall performance (44). The study by Wagne (2011) proved that the final wrist movement during ball exit is significantly related to shooting accuracy (45), with players who better controlled their wrist angle during the 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 adjustment of the wrist enhances the coordination of hand movement with the axis of the throw and reduces angular oscillation at release, increasing the stability of the motor

trajectory and producing 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 demands precise neuromuscular coordination in minimal 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 cause muscle timing dispersion and reduce throw 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 stability of joint postures during performance. Muntianu et al. (2022) highlighted the importance of the interaction between psychological traits and psychomotor skills in enhancing 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 the study by Shalar et al. (2019) emphasizing the role of psychological readiness in boosting 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 university, limiting the ability to generalize 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 more detailed analysis, potential external factors like fatigue, previous training load, or psychological variables such as 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 ( $p=0.360$ ); however, the high explanatory power ( $r^2=0.59$ ) indicates that this variable greatly contributes to interpreting shot performance. This underscores the importance of considering biomechanical factors when training and suggests that further studies with larger samples 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

- Development of motor performance and accuracy of shooting in handball: the training program aims to improve motor response using interactive exercises supported by technology (such as placebos), while tracking progress with accurate measuring devices. Such training includes dynamic balance exercises to enhance the stability of the center of gravity and techniques to improve the optimal knee angle ( $90-110^\circ$ ) using jumps. Players are also trained to control elbow and wrist angles ( $90-120^\circ$ ) 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 gave 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

The College of Physical Education and Sports Sciences provided practical support for this study by helping recruit participants and giving access

to their facilities for data collection. Additionally, it had no role in the study's design, conduct, data analysis, or the preparation, review, and approval of the manuscript.

### ARTIFICIAL INTELLIGENCE (AI) USE

No artificial intelligence tools or techniques were used in this manuscript's design, analysis, or writing. All aspects of the research and manuscript preparation were conducted solely by the authors.

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