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Analysis of the Relationship between Certain Biokinematic and Goniometric Variables of the Linear Smash with Explosive Force Upwards, Forwards, and in Volleyball Shooting

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This study aimed to investigate the biokinematic and goniometric variables associated with a linear smash in volleyball, and their relationship with explosive strength. Eleven female volleyball players from the Sanharib Club participated in this study. Physical tests assessed explosive strength through vertical/forward jumps and medicine ball throw. Biokinematic variables included center of mass elevation/displacement, arch depth, movement time, and velocities, while goniometric variables measured the joint angles during execution. The video analysis software extracted variable values during players' smash attempts. Significant inverse correlations were identified between explosive vertical jump strength and horizontal center-of-mass distance (-0.911) and between explosive medicine ball throw strength and horizontal distance (0.891). Additionally, a positive correlation existed between medicine ball throw strength and shoulder joint angle at the maximum arch (0.82). The vertical center of mass elevation was inversely correlated with the forward jump distance (-0.776). Strong but insignificant relationships emerged between variables such as horizontal speed/medicine ball throw and takeoff-landing distance/jump time. The results demonstrate the importance of the explosive strength for upward/forward propulsion and proper joint angles for efficient energy transfer during linear smashing. Recommendations include focusing on correlated variables through targeted training, utilizing joint ranges of motion, and incorporating additional biodynamic factors. This study offers insights into optimizing linear smash through biomechanical analysis and training interventions.

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Public Interest Statement

This study explored the relationship between biokinematic and goniometric variables and explosive strength in linear volleyball smashes by analyzing 11 female players from the Sanharib Club. By assessing vertical/forward jumps and medicine ball throws, along with joint angles and motion metrics, significant correlations were identified, indicating targeted training strategies to optimize performance.

Introduction

The volleyball game demands a high level of physical and technical proficiency from its players, with the linear smash being a critical element that can significantly influence the outcome of a match. Among the various attack techniques, the linear smash, or jump smash, is a potent and frequently employed maneuver that combines power, accuracy, and strategic placement to challenge the receiving team. This explosive skill involves the intricate coordination of various body segments and efficient transfer of energy from the lower extremities to the upper extremities through a precise kinetic chain (Lobietti et al., 2010).

The analysis of biokinematic and goniometric variables has become crucial for understanding and optimizing linear smash. Biokinematic variables encompass the study of human motion and associated kinematic principles, providing insights into factors such as joint angles, segment velocities, and temporal parameters. These variables were meticulously analyzed to identify the optimal movement patterns and techniques for maximizing the effectiveness of a smash (Lees, 1999; S∅rensen et al., 1996). On the other hand, goniometric variables focus on the measurement of joint angles throughout the smash motion, shedding light on the range of motion and precise positioning of body segments during the execution of the skill (Elliott, 2006; Lees, 1999).

Numerous studies have explored the relationship between these variables and explosive power generated in various directions, including upward, forward, and volleyball shooting. Tillman et al. (2004) investigated the biomechanical factors contributing to jump smash velocity in collegiate volleyball players. They found that certain kinematic variables, such as shoulder and trunk rotation as well as knee and hip extension, significantly influenced the speed and accuracy of the smash. Similarly, Wagner et al. (2009) examined the relationship between lower-body kinematics and smash performance in elite beach volleyball players, revealing that greater knee and hip flexion during the preparatory phase, followed by rapid extension during execution, contributes to increased smash velocity and power.

Analysis of goniometric measurements has also provided valuable insights into the optimal joint angles and ranges of motion required for efficient energy transfer during smash motion. JoãTo et al. (2010) analyzed the joint kinematics of the upper extremities in elite volleyball players during the jump smash. Their findings indicated that greater shoulder external rotation and elbow extension during ball release are associated with increased smash velocity and accuracy. Teu et al. (2006) investigated the relationship between upper-body kinematics and smash performance, highlighting the importance of proper trunk and shoulder positioning for generating maximum power and control.

The relationship between the biokinematic and goniometric variables and the explosive power generated in different directions has been a subject of significant interest. Upward explosive power, generated through the vertical displacement of the body during the jump, is crucial for achieving the maximum height and creating a favorable position for the smash (Sheppard et al., 2008). The forward explosive power, on the other hand, contributes to the horizontal displacement and overall momentum of the smashing motion, influencing the speed and trajectory of the smash (Lobietti et al., 2010).

In a comprehensive study, Forthomme et al. (2005) investigated the kinematic chain during a jump smash in elite volleyball players, revealing that the coordination and timing of lower-body joint actions, such as hip and knee extension, played a significant role in generating both upward and forward explosive power. Additionally, they highlighted the importance of proper upper-body mechanics, including shoulder and elbow kinematics, in effectively transferring this power to the ball during a smash execution. Similarly, Sheppard et al. (2008) explored the kinematic and kinetic characteristics of jump smashes in elite female volleyball players, emphasizing the crucial role of lower-body joint mechanics in generating vertical and horizontal force vectors for an effective smash.

Furthermore, the analysis of biokinematic and goniometric variables has been extended beyond the smash itself, encompassing other volleyball skills and techniques. Ozawa et al. (2021) investigated the relationship between lower-body kinematics and jump height in volleyball players and provided insights into optimizing vertical explosive power for various offensive and defensive movements. Likewise, Teu et al. (2006) examined upper-body kinematics during spiking and blocking, highlighting the importance of proper joint positioning and range of motion for generating power and precision in these crucial skills.

The integration of these findings has led to the development of training methodologies and interventions aimed at enhancing linear smashes and overall volleyball performance. Buscà et al. (2012) explored the effects of a plyometric training program on smash velocity and biomechanical parameters in volleyball players, demonstrating significant improvements in explosive power and smash performance. Additionally, Sheppard et al. (2008) proposed a comprehensive training approach incorporating biomechanical analysis, strength and conditioning, and skill-specific drills to optimize linear smash in elite athletes.

In summary, the analysis of biokinematic and goniometric variables has provided invaluable insights into the mechanics and biomechanical factors influencing linear smash in volleyball. By understanding the relationships between these variables and the explosive power generated in various directions, researchers and coaches can develop more effective training strategies and interventions to enhance performance and the overall athletic prowess in this dynamic sport.

This study aimed to investigate the biokinematic and goniometric variables related to linear smashes in volleyball. It focuses on identifying the specific values of these variables and exploring how certain physical measures, such as explosive strength in vertical and forward jumps, influence the performance. By establishing correlations between biokinematic and goniometric variables and explosive strength during execution, this study sought to uncover relationships that could help refine training strategies. The research hypothesis suggests that significant correlations exist between these variables and explosive strength measured through vertical and forward jumps, as well as medicine ball throws. Female volleyball players from the Sanharib Club were the chosen sample, and data were collected in the volleyball stadium of the Sanharib Club team between June 1 and November 2, 2023. These findings are expected to provide valuable insights into optimizing the linear smash technique by improving joint angles, refining propulsion methods, and enhancing the physical conditioning of athletes.

Literature Review

A linear smash, often executed as a powerful jump smash, is widely regarded as one of the most potent offensive weapons in volleyball. This disrupts the opposing team's defense and creates significant scoring opportunities. However, executing an effective linear smash requires a complex interplay of biomechanical factors and precise techniques. Researchers have extensively studied the biokinematic and goniometric variables associated with this skill to unravel the intricate mechanics that contribute to its explosive power and success rate.

2.1 Upper-body kinematics and goniometric analysis

While lower-body mechanics play a crucial role in linear smashes, the efficient transfer of energy to the upper extremities is equally important. JoãTo et al. (2010) analyzed the joint kinematics of the upper extremities in elite volleyball players during the linear smash, focusing on goniometric measurements. Their findings indicated that greater shoulder external rotation and elbow extension during ball release are associated with increased smash velocity and accuracy.

Teu et al. (2006) further explored the importance of upper-body kinematics and goniometric variables, emphasizing the role of proper trunk and shoulder positioning in generating maximum power and control during smashing. They conducted a comprehensive analysis of the range of motion and joint angles during volleyball spiking and blocking movements, providing insights into the optimal kinematics for these skills, which share similarities with linear smash. Reeser and Bahr (2017) also examined upper-body mechanics in volleyball shooting, highlighting the potential risk factors for shoulder and elbow injuries, and the importance of proper techniques and training to mitigate these risks.

2.2 Upper-body kinematics and goniometric analysis

While lower-body mechanics play a crucial role in jump serve, the efficient transfer of energy to the upper extremities is equally important. JoãTo et al. (2010) analyzed the joint kinematics of the upper extremities in elite volleyball players during the jump serve, focusing on goniometric measurements. Their findings indicated that greater shoulder external rotation and elbow extension during ball release are associated with increased serve velocity and accuracy.

Teu et al. (2006) further explored the importance of upper-body kinematics and goniometric variables, emphasizing the role of proper trunk and shoulder positioning in generating maximum power and control during serve. They conducted a comprehensive analysis of the range of motion and joint angles during volleyball spiking and blocking movements, providing insights into the optimal kinematics for these skills, which share similarities with jump serve. Reeser and Bahr (2017) also examined upper-body mechanics in volleyball serving, highlighting the potential risk factors for shoulder and elbow injuries, and the importance of proper techniques and training to mitigate these risks.

2.3 Integration of Kinematic and Kinetic Variables

Several studies have attempted to integrate the analyses of kinematic and kinetic variables to gain a holistic understanding of linear smash mechanics. Forthomme et al. (2005) investigated the kinematic chain during the linear smash in elite volleyball players, highlighting the coordination and timing of lower-body joint actions, such as hip and knee extension, in generating both upward and forward explosive power. Additionally, they emphasized the importance of proper upper-body mechanics, including shoulder and elbow kinematics, in effectively transferring this power to the ball during smash execution.

Tilp et al. (2008) focused on the role of extensor muscle activity in improving joint moment during the spike impact of a volleyball linear smash. Their findings suggested that starting with extensor muscle activity can enhance the joint moments at spike impact, potentially leading to increased smash velocity and power. Ab. Rashid (2021) also investigated the kinetic and kinematic factors influencing linear smash, emphasizing the importance of integrating technical and physical training to optimize performance.

2.4 Training Interventions and Performance Enhancement

The insights gained from biomechanical and goniometric analyses have facilitated the development of targeted training interventions aimed at enhancing linear-smash performance. Buscà et al. (2012) explored the effects of a plyometric training program on smash velocity and biomechanical parameters in volleyball players. Their results demonstrated significant improvements in explosive power, smash velocity, and biomechanical factors such as ground reaction forces and joint kinematics after the training intervention.

Sheppard et al. (2008) proposed a comprehensive training approach that integrates biomechanical analysis, strength and conditioning, and skill-specific drills to optimize linear smash in elite athletes. This holistic approach recognizes the multifaceted nature of linear smash and emphasizes the importance of addressing both physical and technical aspects to achieve optimal performance. Additionally, Forthomme et al. (2005) proposed a training program focused on improving lower-body power and core stability, which they found had a positive impact on linear smash performance in collegiate volleyball players.

2.5 Practical Applications and Future Directions

The findings of these studies have practical implications for coaching and training strategies in volleyball. By understanding the relationships between biokinematic and goniometric variables, as well as their contributions to explosive power generation in a linear smash, coaches can design more effective training programs tailored to individual athletes' strengths and weaknesses.

Additionally, the integration of biomechanical analysis tools, such as motion capture systems and force platforms, can provide real-time feedback and objective data to refine the techniques and monitor progress. This data-driven approach can enhance the coaching process and facilitate more targeted interventions for performance optimization, as demonstrated by Verma et al. (2013) in their study on the application of motion analysis technology in volleyball training.

Future research should continue to explore the intricate interplay between biomechanical factors and linear smash performance, considering variables such as skill level, sex, and playing surface (e.g., indoor vs. beach volleyball). Furthermore, longitudinal studies investigating the long-term effects of targeted training interventions on biomechanical variables and smash performance would be valuable for refining training methodologies. Emerging technologies such as wearable sensors and artificial intelligence may also provide new avenues for real-time biomechanical analysis and personalized training recommendations (Reeser et al., 2010).

In conclusion, the literature on biokinematic and goniometric variables in relation to the linear smash in volleyball has provided a wealth of knowledge and insights into the mechanics and biomechanical factors that influence this crucial skill. By integrating these findings into training and coaching practices, volleyball players and coaches can enhance their understanding of the biomechanical demands of linear smash and develop more effective strategies for performance optimization.

2.2 Previous studies

Jary and Daikh (2022) explored biomechanical distinctions in volleyball smash skills. This study sheds light on the unique physical and performance characteristics inherent to each center, arguing for the critical need for tailored training practices that cater to these differences to enhance smash effectiveness.

Telles et al. (2021) investigated the correlation between shoulder rotation range of motion (ROM) and serve speed in young male volleyball athletes. By demonstrating a link between reduced internal rotation in the dominant shoulders and ball velocity, with significant associations found with age and BMI, the study underlines the pivotal role of physical characteristics in serving performance and suggests avenues for targeted improvement.

Sultan et al. (2020) conduct a study focusing on the impact of compound exercises that incorporate light and sound stimuli, alongside the use of rubber ropes and training aids, on enhancing kinetic abilities and bio-kinematic variables. This research highlights the importance of these exercises in developing force-speed curve characteristics for youth volleyball players, suggesting that such training significantly contributes to improving spike performance by facilitating sequential skill integration under variable conditions.

Methodology

The researcher opted for a descriptive approach, given the appropriateness and nature of the study. The sample was comprised of skilled female volleyball players from the Sanharib Sports Club, specifically those who performed a right-arm smash. The sample consisted of 11 players; the specifications of the research sample are listed in Table 1.

Table 1. Specifications of the Research Sample

N.	Sample	Height (cm)	Age (years)	Mass (kg)	Vertical Jump (cm)	Long Jump (cm)	Medicine Ball Throw (3kg)
1	Ivon Dawood Raban	179	21	66	34	209	10
2	Ata Dawood Raban	172	22	72	52	205	7
3	Doreen Rommel	167	18	69	48	180	10
4	Dorz Rommel	170	23	70	54	180	6
5	Helen Omar Othman	178	24	72	54	228	8

6	Barzah Razkar Faraj	170	25	66	55	123	8
7	Breeva Razkar Faraj	174	19	61	49	186	9
8	Hero Jameel	176	20	61	51	187	7
9	Suze Bahij	170	21	62	47	185	10
10	Hamesha Hoshyar	172	22	68	53	189	6
11	Lana Youbert	169	23	67	52	190	8
	Average	172.45	21.64	66.73	49.91	187.45	8.09
	Standard Deviation	3.86	2.11	4.03	5.87	25.88	1.51
	Coefficient of Variation	2.24%	9.75%	6.04%	11.77%	13.81%	18.71%

The coefficient of variation ranged between (2.24 – 18.71%), indicating that the sample size did not exceed 30%. Consequently, it was considered a homogeneous sample. The closer the coefficient of variation is to (1%), the higher the homogeneity. If it exceeded (30%), the sample was considered to be heterogeneous.

3.1 Research instruments and equipment

The researcher employed measurement, testing, and technical observations as the data collection methods. The research tests included a vertical jump test conducted from a standstill (Pueo et al., 2018), and a long jump test from a stationary position (Aragón, 2000). Additionally, a medicine ball throw test was used, in which participants threw a 3-kilogram medicine ball overhead while standing (Stockbrugger & Haennel, 2001). Finally, the accuracy of the linear smash was assessed using a detailed test (Atkinson & Nevill, 1998).

3.1.1 Linear smash accuracy test

The measurement of the accuracy of the linear ash is depicted in Figure 1. The aim of this test was to gauge the accuracy of the straight smash. The experiment was conducted in a volleyball court with two mattresses placed 5 cm away from the sideline and end line, with one mattress positioned behind the other. The player started at position 4 and received a pass from the coach, who was stationed at location 3. The player was required to make 15 hits on the rear mattress and 15 hits on the front mattress.

The evaluation of player performance is contingent on the accuracy and consistency of the smashes, as demonstrated in the precision-based scoring system. Each successful smash that landed the ball on the mattress directly adjacent to the designated area was rewarded with four points. A smash placing the ball within the designated zone earns three points. Two points were awarded for each smash that landed the ball in areas (A) and (B). This scoring system offers a transparent and objective method for assessing player performance, and provides a clear metric for evaluation. (Source: Cactus Communications)

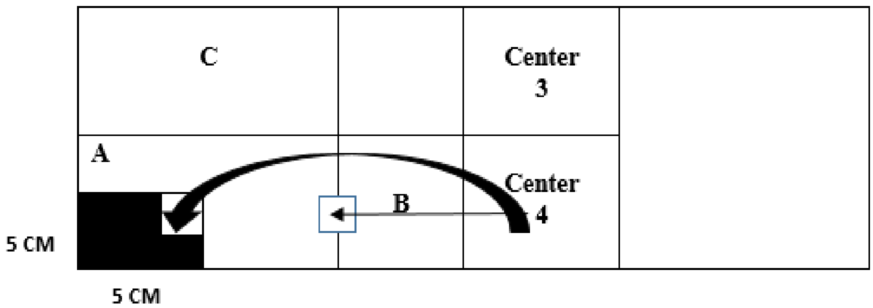

Figure 1. Measurement of the Accuracy of the Linear Smash

3.1.2 Final test explanation

After completing the physical tests, each player was allowed five attempts to execute a linear smash. The most accurate attempt in terms of reaching the intended target area was analyzed to obtain the highest possible points.

In the main experiment, each player made two attempts at smashing, and the most accurate attempt was analyzed to identify the research variables. The flight angle was determined by observing the angle from the last point of contact with the ground before takeoff to the moment immediately after takeoff. Hip angle was measured between the shoulder, trunk, and knee joints. Shoulder angle during the flight phase was calculated from the elbow, shoulder, and trunk joints.

The horizontal distance of the center of mass (CM) is the distance traveled from the first step to the moment of the smash. Vertically, CM was measured from the initial step to the highest point during smashing. The depth of the arch in the back during the flight phase was assessed by comparing the line of the back arch with the line extending from the shoulder to the knee. Movement time was measured by counting the number of frames captured during the smash and multiplying it by the time per frame. Finally, the vertical and horizontal speeds were determined by dividing the respective distances by the time required.

These variables provided comprehensive data to analyze the biomechanical aspects and performance efficiency of the smash in volleyball.

3.1.3 Selection of biokinematic research variables

The main experiment was conducted on June 1, 2023, in the Sanharib Sports Club Hall. The selected variables were carefully aligned with the study's title and objectives, emphasizing the execution of the smash and its connection to jumping and pushing. The researcher's expertise informed the choice of the variables, which also depended on what was readily available.

For the analysis, the researcher imported the recorded data onto a laptop after filming. Each player's leg length was measured to serve as a real scale, which was then converted into a virtual scale. The most accurate smash attempt closest to the net was chosen for further analysis using a combination of specialized software, including image slicing, video slicing, DART FISH, KINOVEA, and MAX TRAQ programs.

In addition, statistical tools were employed, such as MICROSOFT OFFICE EXCEL 2010 and SPSS statistical package. The relevant formulas (mean, standard deviation, coefficient of variation, and simple correlation coefficient) were applied to the data using a computer. Together, these tools provide detailed insight into the biomechanical and performance factors that underpin the smash technique.

Finding

The researcher structured the results in alignment with the research objective. The initial step involved presenting and analyzing the statistical landmarks relevant to the study. Specifically, statistical markers for physical variables related to explosive strength were outlined, focusing on vertical and forward jumps and medicine ball throws. These data are compiled and presented in Table 2, providing a clear and detailed illustration of these key performance measures.

Table 2. Displays the mean, standard deviation, and coefficient of variation for explosive strength in jumping and pushing for volleyball players

Statistic	Vertical Jump (cm)	Forward Jump (cm)	Medicine Ball Throw (cm)
Mean	52.33	197.83	8.68
Standard Deviation	8.38	38.49	1.52
Coefficient of Variation	16.01	19.45	17.56

Table 2 demonstrates that the coefficient of variation spans from a low of 1.21 to a high of 19.45, indicating the homogeneity of the sample. Additionally, Table 3 presents some statistical markers associated with the biokinematic variables of straight linear smash in volleyball players. These comprehensive data provide insights into the key biomechanical factors that influence the smash technique.

Table 3. Displays the mean, standard deviation, and coefficient of variation for the biokinematic variables of the straight linear smash for volleyball players

N.	Biokinematic Variables	Statistic		
		Mean	Standard Deviation	Coefficient of Variation
1	Highest elevation of COM above ground (cm)	139.66	3.27	2.34
2	Distance between takeoff and landing (cm)	49.23	2.10	4.27
3	Horizontal distance (cm)	179.44	3.84	2.14
4	Vertical distance (cm)	46.51	2.79	6.00
5	Total time (s)	1.85	3.27	2.34
6	Horizontal speed (cm/s)	98.56	2.42	2.46
7	Vertical speed (cm/s)	24.45	1.52	6.24

8	Depth of back arch (degrees)	14.51	1.52	10.52

The table reveals that the coefficient of variation ranges from a low of 2.14 to a high of 10.52, which demonstrates the homogeneity of the sample. Table 4 provides a detailed presentation of the statistical landmarks associated with goniometric (angle) values during straight linear smash movement in volleyball players. These measurements offer further insight into the biomechanical aspects of the smash technique.

Table 4. Displays the mean, standard deviation, and coefficient of variation for the goniometric variables during the straight linear smash for volleyball players

N.	Angles (Degrees)	Statistic		
		Mean	Standard Deviation	Coefficient of Variation
1	Flight Angle	43.6	1.8	4.14
2	Hip Joint Angle at Maximum Body Arch	212.73	4	1.88
3	Hip Joint Angle (Moment of Smash)	162.33	24.84	15.3
4	Shoulder Joint Angle at Maximum Arch	180.51	1.41	0.78
5	Ball Flight Angle at End of Smash	14.55	0.98	6.77

This study explored the correlations between explosive strength and the biokinematic and goniometric variables involved in the straight linear smash among volleyball players. The relationships between the physical variables of explosive strength and biokinematic factors are presented and discussed to determine their significance in improving the smash performance. The correlation coefficients between these measures are detailed in Table 5, providing a clear illustration of how explosive strength is linked to the biomechanical aspects of the volleyball technique.

Table 5. Shows the Correlational Relationship Between Some Biokinematic Variables and Explosive Strength for Vertical and Forward Jumps and the Straight Linear Smash for Volleyball Players

N.	Biokinematic Variable	Explosive Strength (cm)		
		Vertical jump (r) calculated value	Long jump (r) value calculated	Paying a 3 kg medicine ball for the calculated (r) value
1	Highest Elevation of COM (cm)	0,001	0,776 -	0,232
2	Distance Between Takeoff and Landing (cm)	0,085	0,418 -	0,253 -
3	Horizontal Distance (cm)	0,911 -*	0,009 -	0,891 *
4	Vertical Distance (cm)	0,96 - *	0,035	0,025 -
5	Total Time (s)	0,101	0,345 -	0,083
6	Horizontal Speed (cm/s)	0,239 -	0,239 -	0,479
7	Vertical Speed (cm/s)	0,245 -	0,245 -	0,374
8	Depth of Back Arch (degrees)	0,06 -	0,177 -	0,193

*Significant correlation at an error rate of (0.05), in front of a degree of freedom (4), and tabulated r-value (0.729).

This study revealed several noteworthy relationships between explosive strength and biokinematic variables during the execution of a straight linear smash among volleyball players. A statistically significant negative correlation was observed between the explosive strength in the forward long jump and the highest elevation of the Center of Mass (COM), with an r-value of -0.776, which exceeded the tabulated value for a degree of freedom of 4. This relationship can be attributed to volleyball players' preference for vertical elevation over forward movement. Therefore, an increase in horizontal jump distance negatively affects COM elevation due to the emphasis on vertical, rather than forward, jumps.

Similarly, a strong negative correlation exists between the explosive strength in the vertical jump and the horizontal distance of the COM, with an r-value of -0.911. This finding suggests that players aim to minimize vertical movement while maintaining their speed in order to prevent their opponents from effectively blocking the smash. A greater horizontal COM distance requires a greater pushing force to achieve a high elevation, which is consistent with the principles of dynamics.

On the other hand, a significant positive correlation was found between the explosive strength required to throw a 3 kg medicine ball forward and the horizontal distance, indicated by an r-value of 0.891. This positive relationship is due to the forward displacement of the body during the throw, where the speed depends on the distance and time the player moves in that direction. No significant correlation was found between other biokinematic variables and explosive strength or throwing tests.

Further analysis and discussion of the statistical landmarks for the correlation coefficients between the explosive strength and goniometric (angle) variables are presented in Table 6, providing additional insights into the biomechanics of the straight linear smash in volleyball.

Table 6. Correlational Relationship Between Some Goniometric Variables and Explosive Strength for Vertical and Forward Jumps and the Medicine Ball Throw for the Straight Linear Smash for Volleyball Players

N.	Angles (Degrees)	Explosive Strength (cm)		
		Vertical jump (r) calculated value	Long jump (r) value calculated	Paying a 3 kg medicine ball for the calculated (r) value
1	Flight Angle	0,5 -	0,162 -	0,315
2	Hip Joint Angle at Maximum Body Arch	0,15 -	0,307 -	0,418
3	Hip Joint Angle (Moment of Smash)	0,45 -	0,339 -	0,82 *
4	Shoulder Joint Angle at Maximum Arch	0,041 -	0,474 -	0,26
5	Ball Flight Angle at End of Smash	0,364 -	0,193 -	0,399

* A significant correlation at an error rate (0.05), against a degree of freedom (4), and a tabular r-value of (0.729) indicate meaningful statistical relationships.

Table 6 shows a significant positive correlation between the explosive strength in the forward throw of a 3 kg medicine ball and the shoulder angles, as indicated by an r-value of 0.82, exceeding the tabulated r-value for a degree of freedom of 4. This relationship can be attributed to the strength of the shoulder muscles, which is enhanced by the action of tendons in the joint. The shoulder requires substantial angular momentum to execute the smash skill as it generates a large torque. According to this equation, the angular momentum equals the moment of inertia multiplied by the angular velocity.

A larger shoulder angle results in a greater moment of inertia and lower angular velocity, given that the overall angular momentum remains significant and constant. Thus, an increase in the moment of inertia leads to a decrease in the angular velocity and vice versa. This principle aligns with the importance of this variable for explosive ball hits. Shoulder muscle strength is vital for displaying various physical attributes such as speed, agility, and flexibility, which are essential for skill performance and endurance, as highlighted by Knudson and Knudson (2007).

Discussions

The findings of this study provide valuable insights into the relationships between explosive strength and biokinematic and goniometric variables associated with the straight linear smash in volleyball. The results highlight the importance of considering these correlations when analyzing and optimizing the smash performance. To further enhance the interpretation and practical implications of these findings, it is crucial to connect them with relevant theories and prior research discussed in the literature review section.

One of the key findings of this study is the significant negative correlation between explosive strength in the vertical jump and the horizontal distance of the center of mass (COM). This relationship can be interpreted in light of the work by Forthomme et al. (2005), who investigated the kinematic chain during a linear smash in elite volleyball players. They emphasized the importance of coordinating and timing lower-body joint actions, such as hip and knee extension, in generating both upward and forward explosive power. The results of this study align with this concept, suggesting that players who exhibit greater explosive strength in the vertical jump tend to minimize the horizontal distance of the COM, possibly to maintain a more efficient kinetic chain and energy transfer during the smash movement.

Another notable finding is the significant positive correlation between explosive strength in the medicine ball throw and shoulder joint angles at the maximum arch. This result can be related to the findings of JoãTo et al. (2010), who analyzed the joint kinematics of the upper extremities in elite volleyball players during a linear smash. They found that greater shoulder external rotation and elbow extension during ball release were associated with an increased smash velocity and accuracy. The results of this study support this notion, indicating that players with greater explosive strength in medicine ball throws tend to exhibit larger shoulder joint angles at the maximum arch, which may contribute to improved smash performance.

The study also revealed a significant negative correlation between explosive strength in the forward long jump and the highest elevation of the COM. This finding can be discussed in the context of the research by Sheppard et al. (2008), who examined the relative importance of strength, power, and anthropometric measures on jump performance in elite volleyball players. They highlighted the role of lower-body joint mechanics in generating vertical and horizontal force vectors for effective smashing. The results of this study suggest that players who demonstrate greater explosive strength in the forward long jump may prioritize horizontal force production over vertical elevation of the COM, potentially influencing their smashing technique and performance.

Furthermore, the results of this study can be related to the insights provided by Tilp et al. (2008), who focused on the role of extensor muscle activity in improving the joint moment during the spike impact of a volleyball linear smash. They suggested that initiating movement with extensor muscle activity can enhance joint moments during spike impact, leading to increased smash velocity and power. The findings of this study regarding the correlations between explosive strength and various biokinematic and goniometric variables support the importance of considering muscle activity and joint moments when analyzing and training for optimal smash performance.

The practical implications of these findings can be explored in light of the training interventions and performance-enhancement strategies discussed in the literature review. Buscà et al. (2012) investigated the effects of a plyometric training program on smash velocity and biomechanical parameters in volleyball players and demonstrated significant improvements in explosive power and smash performance. The results of this study highlight the specific biokinematic and goniometric variables associated with explosive strength, providing valuable insights for designing targeted training programs aimed at enhancing smash techniques and outcomes.

The comprehensive training approach proposed by Sheppard et al. (2008), which integrates biomechanical analysis, strength and conditioning, and skill-specific drills, can be explained by the findings of this study. By understanding the relationship between explosive strength and key biomechanical variables, coaches and trainers can develop more effective and individualized training plans that address the specific needs and characteristics of each player.

In conclusion, the results of this study contribute to the growing body of knowledge on the biomechanical factors influencing straight linear smash in volleyball. By connecting these findings with the relevant theories and prior research discussed in the literature review, this study provides a more comprehensive understanding of the complex interplay between explosive strength and biokinematic and goniometric variables associated with smash performance. The insights gained from this research can inform training practices, technique optimization, and performance enhancement strategies, ultimately benefiting volleyball players and coaches in their pursuit of excellence.

Conclusions

The study identified that two biokinematic variables had a significant inverse correlation with explosive strength: horizontal distance with vertical jump (-0.911) and horizontal distance with medicine ball throw (0.891), underscoring the importance of jumping and throwing techniques. A direct correlation was also observed between the shoulder angle at the maximum arch during medicine ball throws (0.82) and explosive strength. Additionally, the vertical jump in the Center of Mass (COM) had an inverse correlation with long jumps (-0.776), emphasizing the game's need for vertical rather than forward elevation.

Several correlations, both direct and inverse, revealed strong relationships that were not statistically significant but were consistent with movement techniques, such as the link between horizontal speed and medicine ball throws, as well as the inverse relationship between takeoff and landing distance and total time in the long jump. The highest correlation recorded between the ball flight angle and medicine ball throw (-0.399) was not significant. The study also highlighted the positive impact of explosive strength on vertical jumps, which enhanced ball delivery and increased scoring opportunities.

The optimal angle for interacting with the ball during the smash is crucial to its success given its interaction with the body's explosive upward force. All inverse correlations indicate that choosing the right angle leads to the delivery of the ball to the opponent's target with appropriate speed, range, force, and accuracy. Finally, the results suggest that reducing the time required to perform the movement improves jumping strength, whether upward, forward, or during throwing, as the jumping force is a product of force and time.

Players and coaches should focus on biokinematic variables that demonstrate high correlations, whether direct or inverse, during the volleyball smash movement phases. Coaches should also emphasize improving volleyball players' explosive strength, as this technique relies on rapid, single-attempt ball movements that are closely related to explosive strength.

Maximizing the body's joint range of motion increases flexibility, allowing players to achieve a wide range of motion based on movement direction (moment of inertia), which facilitates accurate, quick, and strong smashes. Coaches should emphasize jump timing and swift ball-collision motion. Other biokinematic variables relevant to game techniques, but not explored in this research, should also be considered.

Additional biodynamic variables, such as power, energy, momentum, and work are crucial for refining the straight linear smash movement. Incorporating weightlifting exercises into training routines will enhance explosive strength in the upper and lower body. Finally, practicing smash skills in varied movement positions and heights, especially during ball collisions, will further refine players' performance.

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