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ORIGINAL RESEARCH

# The contribution of upper or lower extremity of male athletes differs as distances of overhead volleyball pass increase

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**Abstract**

This study aimed to assess the roles and contributions of various joint (ankle, knee, hip, shoulder, elbow and wrist) during overhead volleyball passing across different distances. Eight male college volleyball players performed passes into a floating target set at 2.53 meters height from three different distances (2.5, 5 and 7.5 meters) with their feet remaining on the ground. Motion and force data were collected from three successful passes per player. Using inverse dynamics methods, we analyzed kinetic variables at each joint to determine energy generation and transfer. The findings revealed that the energy transfer through the shoulder joint to the arm varied with distance, with significant differences in the upper limb energy generation between the short and medium distances ($p < 0.001$). The study concluded that precise control and adjustment of the upper limb are crucial for short and medium distance passes, while lower limb contributions, including stabilization and extension play a vital role in executing long-distance passes.

**Keywords**

Volleyball; Overhead pass; Energy flow; Distance; Joint kinetics

## 1. Introduction

Volleyball is a team sport that emphasizes unity and cooperation, through techniques such as serving, receiving, passing, spiking and blocking. Although passing does not directly score points, its effectiveness plays a crucial role in the offensive success of the spiker and ultimately impacts match outcomes [1–3]. Passes must be executed at varying distances depending on the situation, with accuracy generally diminishing as the distance increases [4, 5]. The passing action, which takes approximately 100 milliseconds to complete, requires precise control to position the ball optimally [6]. Understanding how the body's joints adapt to different passing distances is beneficial for beginners learning the skill and coaches teaching it.

Baseball pitches, tennis serves, cricket bowls, volleyball serves and spike all rely on kinetic chain [7–11]. In these movements, force generated by the larger muscle groups in the proximal end segments and then gradually transferred to the smaller muscle groups in the distal segments [12, 13]. Skilled volleyball players exhibit a proximal-distal sequence in their upper limbs during overhead passes [6]. This coordination enables elite players to effectively pass the ball by harnessing the elastic potential energy stored in the tendons of the upper limb [13–15].

The release parameters of the ball including release speed and the energy required to release it increase with pass distance. Yu Ozawa *et al.* [4] investigated volleyball passing at various distances and observed that the elbow extension angular velocity increased with distance, indicating a more rapid extension of the elbow joint to produce greater propulsive force. However, the upper limbs are limited in force generation due to the smaller muscle groups involved [16, 17]. While their study also recorded the vertical velocity of the pelvis, it did not include specific kinematic parameters for the lower extremity joints. As result, the exact role and contribution of the lower extremity joints to passing at different distances remain unclear.

Similar to the volleyball overhead pass, the basketball shot also relies on extending the lower body to generate more energy for longer distances [18, 19]. In the kinetic chain, the lower limbs serve as the primary source of force [20, 21]. However, while the lower limb, generate this force, the distal joints of the arm such as the wrist must remain relatively stable to maintain consistent ball release parameters [4, 22]. Thus, the energy required for a longer pass is primarily generated by the lower extremities and then transferred upwards through the trunk to the upper limbs. Recent research by Nobuyasu Nakano *et al.* [21] analysed mechanical energy flow during basketball shots from various distances and quantified the contribution of the upper and lower extremities to the shot [21, 23, 24]. Although the volleyball pass shares similarities with the basketball shot, a quantitative analysis of the energy involved in volleyball passing is lacking. Understanding how the upper and lower extremities adapt to the increased passing distance can provide valuable insights for both beginners and

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coaches.

This study aims to examine the contribution of the upper and lower extremity joints to energy generation and transfer in male volleyball athletes as the passing distance increases.

## 2. Materials and methods

### 2.1 Participants

Eight male college volleyball players were recruited to participate in the experiment. The demographic information was as follows (mean ± standard deviation): Height: 185.8 ± 2.31 cm, weight: 76.88 ± 6.4 kg, age: 21.13 ± 2.03 years, and training period: 9.13 ± 1.36 years.

### 2.2 Procedure

An experienced volleyball coach accurately passed the volleyball to the participant's head. If the ball did not land within reach, the session's data were excluded. Participants aimed to pass the ball into a circle 2.53 meters high and 0.92 meters in diameter from three different distances, achieving three successful passes at each distance. The distances were short (2.5 meters), medium (5 meters) and long (7.5 meters) based on previous studies that identified these as typical passing ranges [25]. The sequence was organized as follows 2.5 meters (three passes), 5 meters (three passes), 7.5 meters (three passes). This progressive distance increase was designed to accommodate the challenge of adapting to greater passing distances, which could affect passing skills. Participants were instructed to stand and perform a pass as closely as possible to a real-game scenario. Prior to the experiment, all subjects were informed about the procedure and 57 reflex markers were attached to their bodies after they removed loose clothing and changed into shorts (Fig. 1) [26, 27]. The coach passed the ball to the participants, who practiced without a time limit until signaling readiness to start the experiment. Additionally, participants stood on a force plate for 2 seconds before the experiment to record static movements for creating a static model in the Visual3D software (v2022.9.1 software, C-Motion, Inc., Germantown, MD, USA) and to document height and mass.

### 2.3 Data collection

Five markers were attached to the volleyball: four symmetrically placed in two pairs along the center line, and one asymmetrically positioned as an offset marker to aid in identifying the other markers.

Thirteen infrared cameras (Prime17w, OptiTrack, Corvallis, OR, USA) recorded the coordinates of attached reflective markers at a sampling frequency of 240 Hz. Two force platforms (OR6-6-2000, Advanced Mechanical Technology, Inc., USA) measured ground reaction forces during movement performance at a sampling frequency of 1200 Hz. A motion capture system device (Motive 2.2, OptiTrack, Corvallis, OR, USA) was connected to synchronize the kinematic and kinetic data (Fig. 2). Kinematic and kinetic data were analyzed in Visual3D (C-Motion, MD, USA) software with a Butterworth low-pass filter applied at cutoff frequencies of 40 Hz and 20 Hz, respectively.

### 2.4 Data analysis

A global coordinate system was defined as follows: z-axis pointed vertically upwards, the y-axis towards the target, and the x-axis was perpendicular to the plane formed by the z- and y-axes.

In Visual3D software, a full-body model was created with the pelvic coordinate system defined using CODA (pelvis segment model used by Charnwood Dynamics) pelvic coordinate system (Charnwood Dynamics Ltd, UK). The CODA system automatically determined the hip joint centers using the Bell and Brand regression equations [28]. The torso model was developed according to International Society of Biomechanics (ISB) guidelines, with the joint centers of the ankle, knee, elbow and wrist defined as the midpoints between the medial and lateral markers [29, 30]. For model simplification, the reaction force of the ball was not included in the analysis.

The centre of the volley was determined by calculating the coordinates of the markers attached to the ball to minimize $\beta$, as defined by Eqn. 1. This approach ensured an accurate determination of the ball's center by optimizing the marker positions relative to the defined criterion.

$$\beta = \sum_i^n \left\{(x_i - X)^2 + (y_i - Y)^2 + (z_i - Z)^2 - R^2\right\}^2 \tag{1}$$

Where $(X,Y,Z)$ is the center position of the ball, $(x_i,y_i,z_i)$ is the position of the ith marker on the ball, $R$ is the radius of the ball, and $n$ is the number of markers attached to the ball. The ball's center is calculated using Matlab software (R2018a, MathWorks, Natick, MA, USA).

Energy generation and transfer during volleyball overhead passing were analyzed using the segmental power analysis method developed by Robertson and Winter [23]. This method can estimate energy transfer from joint forces and energy production from joint torque. An inverse dynamics approach was used to calculate the forces and torques at each joint on both sides. The direction of energy transfer, generation and absorption was determined by the positive and negative signs of the work done by the joint forces and torques.

The rate of energy transfer through known as joint force power (JFP) was defined as the scalar product of the joint force and the linear velocity of the joint (Eqn. 2). Since the joint forces of adjacent segments are equal in magnitude and opposite in direction calculating the joint forces at the proximal end of the segment suffices to determine the energy transfer rate. A positive sign indicates energy entering the segment, while a negative sign indicates energy exiting the segment.

$$JFP = \vec{F_{ij}} \cdot \vec{V_j} \tag{2}$$

In the given equation, $F_{ij}$ represents the joint force vector acting on segment $i$ at joint $j$, while $V_j$ denotes linear velocity vector of joint $j$ in the global coordinate system.

The joint torque power (JTP) quantifies joint energy generation by representing the work done by the surrounding structures. It is derived by summing the segmental torque powers (STP) at both ends of the joint (Eqn. 3). The STP is

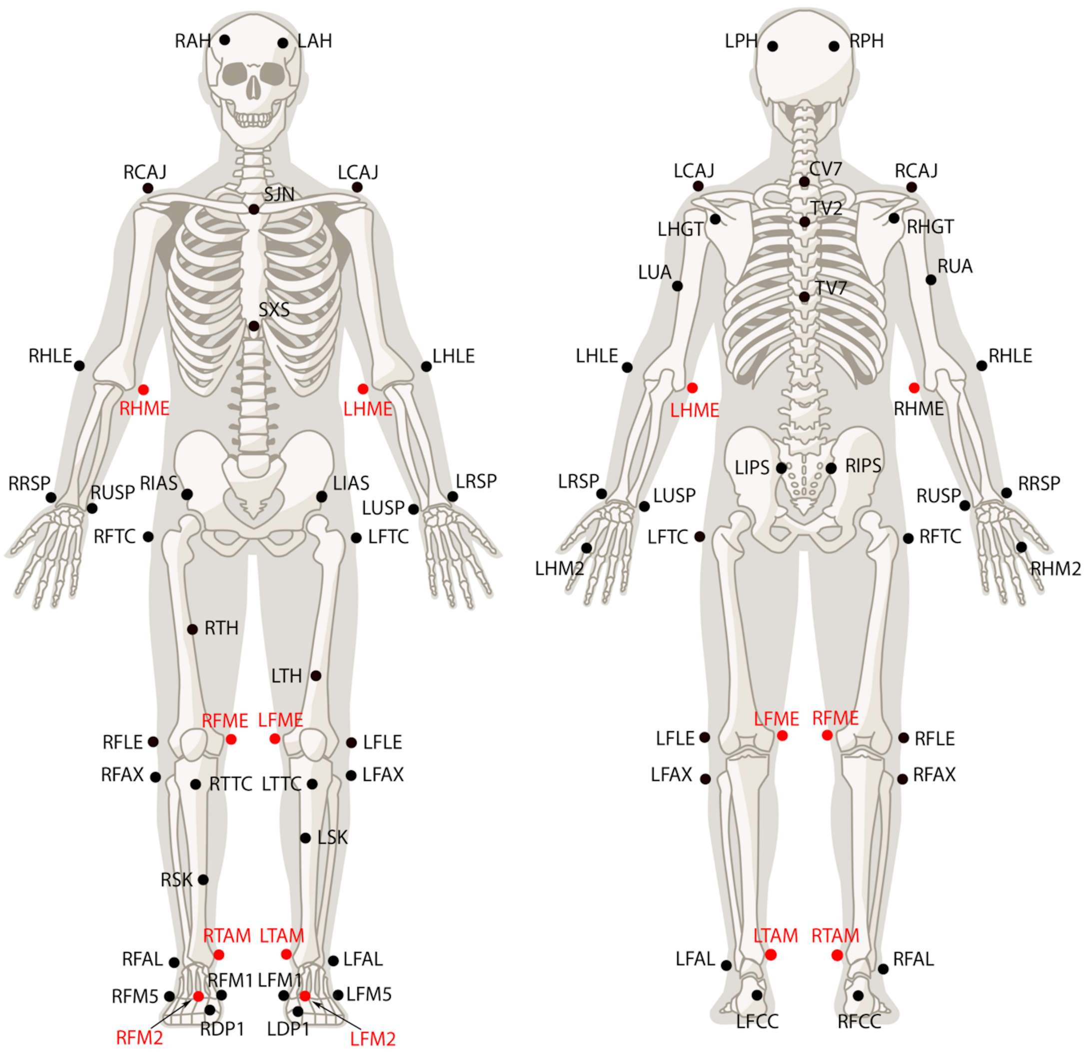



**FIGURE 1. Marker placements on the human body for biomechanical analysis during volleyball passing.** Reflective markers were strategically positioned on key anatomical landmarks, including the head, shoulders, elbows, wrists, hips, knees and ankles, to capture joint movements and measure energy contributions of the upper and lower extremities. These markers facilitated the tracking of motion in three-dimensional space, enabling the detailed analysis of joint kinematics and energy transfer during various passing distances. The calibration markers are highlighted in red. Please see **Supplementary Table 1** for a description of the anatomical markers.

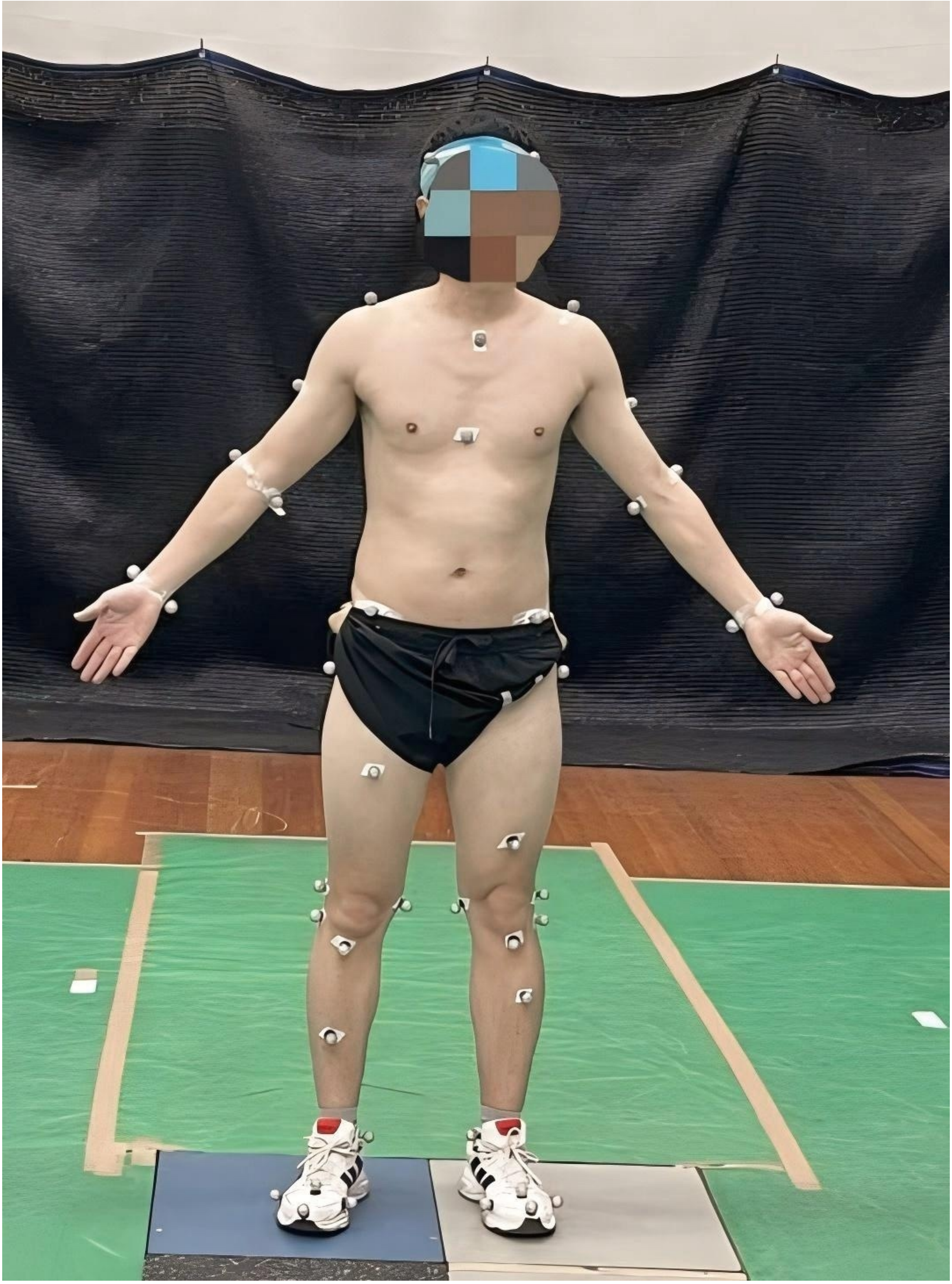
defined as the scalar product of the joint torque and the segment angular velocity vectors (Eqn. 4). Although segment torques are equal in magnitude but opposite in direction, segments have different angular velocities. While STP also indicates energy transfer, since there is minimal energy transfer during the passing action, it was not considered in this study.

$$JTP = STP_p + STP_d \tag{3}$$

$$STP = \vec{T_{ij}} \cdot \vec{\omega_j} \tag{4}$$

In the given equation, $STP_p$ and $STP_d$ represent the torque power of the proximal and distal part of the joint, respectively. Here, $T_{ij}$ is the joint torque vector acting on segment *i* at joint *j* and $\omega_j$ is the angular velocity (in radians per second) of segment *i* in the global coordinate system.

The energy generation and transfer are integrated over a specified time period for the JTP and JFP, respectively. To prevent bilateral imbalance, energy generation and transfer for each joint is averaged between the left and right sides. For the lower limb joints (hip, knee, ankle) the time domain for numerical integration is defined as the period from push-off (when the ground reaction force exceeds the body weight) to the release of the ball. For the upper limb joints, it is defined as the period from the moment the hand touches the ball (with the ball acceleration increasing from $-9.81\ m/s^2$) to the release of the ball [6]. The moment of release is identified as the point when the ball reaches its maximum vertical velocity after hand contact, beyond which vertical velocity begins to decrease due to gravity.



**F I G U R E 2. Experimental setup illustrating the target positions at distances of 7.5 meters, 5 meters and 2.5 meters from the passing athlete.** These distances were selected to evaluate the mechanics of volleyball passing across varying ranges. The athlete was instructed to aim passes at these targets while motion capture systems recorded the movements for analysis of joint kinematics and energy distribution.

## 2.5 Statistical analysis

Descriptive statistics included mean and standard deviation. Statistical analysis, using GraphPad PRISM 9.0 (Graphpad Software, Boston, MA, USA), was performed with the Tukey-Kramer multiple comparison test to compare energy generation and transfer at each joint at three distances. Statistical significance was set at $p < 0.05$. Effect sizes in multiple comparison trials were calculated as Cohen's $d$.

# 3. Results

Ball release speed increased with pass distance, and significant difference were observed between each condition. The ball's projectile angle decreased as the pass distance increased with a significantly greater angle in the short distance condition compared to the long distance condition ($p = 0.024$, $d = 0.82$) (Table 1).

The energy generated in the upper extremities was significantly higher in both the medium-distance condition ($p < 0.001$, $d = 1.69$) and long-distance condition ($p < 0.001$, $d = 2.71$) compared to the short-distance condition (Table 2). Specifically, energy generation in the shoulder joint was significantly greater at medium-distance condition ($p < 0.001$, $d = 1.21$) and long-distances condition ($p < 0.001$, $d = 1.60$) compared to short distances (Table 2). For elbow joint, energy generation was significantly higher at medium-distances ($p < 0.001$, $d = 1.40$) and long-distances ($p < 0.001$, $d = 2.15$) than at short-distances (Table 2). Similarly, wrist joint energy generation was significantly higher at medium-distances ($p = 0.04$, $d = 0.86$) and long-distances ($p < 0.001$, $d = 1.88$) than at short-distances condition (Table 2).

For each joint of the upper extremity, the analysis period was defined as the interval from when the hand touched the ball until the ball was released. For each joint of the lower extremity, the analysis period was defined as the interval from push-off to ball release. Both the upper and lower limbs were analyzed as the sum of the energy generated across their three respective joints.

In terms of energy generated in the lower limbs, significant differences were observed among the three distances (short *vs.* medium: $p = 0.001$, $d = 1.32$, short *vs.* long: $p < 0.001$, $d = 2.60$, medium *vs.* long: $p < 0.001$, $d = 1.19$) (Table 2). The energy generation of the ankle joint are significant differences among the three distances (short *vs.* medium: $p = 0.005$, $d = 1.21$, short *vs.* long: $p < 0.001$, $d = 2.05$, medium *vs.* long: $p = 0.001$, $d = 0.90$) (Table 2). The energy generation of the knee joint are significant differences among the three distances (short *vs.* medium: $p = 0.002$, $d = 1.32$, short *vs.* long: $p < 0.001$, $d = 2.60$, medium *vs.* long: $p < 0.001$, $d = 1.25$) (Table 2). The hip joint energy generation was significantly higher at long-distances compared to short-distances ($p = 0.003$, $d = 0.92$) and medium-distances ($p = 0.047$, $d = 0.58$) (Table 2).

As distance increased, energy transfer to the hand also progressively (Table 3). Significant increase in energy transfer were observed at the knee (short *vs.* medium: $p = 0.023$, $d = 0.86$, short *vs.* long: $p < 0.001$, $d = 2.43$, medium *vs.* long: $p < 0.001$, $d = 1.33$) and hip (short *vs.* medium: $p = 0.02$, $d = 0.47$, short *vs.* long: $p < 0.001$, $d = 0.92$, medium *vs.* long: $p < 0.001$, $d = 0.58$) across all conditions. Additionally, energy transfer to the hand through the shoulder (short *vs.* medium: $p = 0.029$, $d = 1.21$, short *vs.* long: $p < 0.001$, $d = 1.60$, medium *vs.* long: $p < 0.001$, $d = 0.27$), elbow (short and medium: $p = 0.001$, $d = 1.40$, short *vs.* long: $p < 0.001$, $d = 2.15$, medium *vs.* long: $p < 0.001$, $d = 0.25$) and wrist (short *vs.* medium: $p < 0.001$, $d = 0.86$, short *vs.* long: $p < 0.001$, $d = 1.89$, medium *vs.* long: $p < 0.001$, $d = 0.20$) also showed significant differences across all distances (Table 3).

Vertical velocities at the shoulder and wrist joints which reflect energy transfer from the trunk to upper extremities, and both variables were also calculated. The results indicated that these vertical velocities differed significantly across all three distances (Table 4).

# 4. Discussion

This study is significant as it quantifies the contribution of both the upper and lower extremities during volleyball passing movements at various distances. While previous research has primarily focused on upper limb kinematics and electromyography [6, 31, 32], this study investigates mechanical energy flow throughout the body. It illustrates how increasing passing distance affects energy generation and transfer at each joint. The key findings are that, as passing distance increases, the increase in ball speed largely depends on the energy transferred from the lower extremities and trunk to the passing arm, particularly at long distances.

## 4.1 Adjustment of energy flow due to increased passing distance

In both short-distance and medium-distance conditions, work done by the upper and lower extremities increases significantly. For short-distance passes, the lower limb joints contribute minimal energy (Table 2) with athletes primarily relying on the shoulder and elbow to accurately deliver the ball [4]. At medium-distance, joint extension enhances energy transfers from the lower extremities to the upper extremities, leading to greater energy generation in the upper limb joints. This finding aligns with Yu Ozawa's study, which reported a gradual increase in elbow joint angular velocity with passing distance [4]. Additionally, previous studies highlighting differences in triceps brachii activation between short and medium-distances underscore the greater reliance on elbow extensors during volleyball passing movements [4].

In medium-distance and long-distance conditions, the energy produced by the lower limbs was significantly higher, while energy generated in the upper limbs remained consistent (Table 2). This finding aligns with research on basketball shooting, which suggest that, like in long-distance volleyball passing, energy is transferred from the lower extremities to the arms rather than being generated directly by the arm joints [21]. Increased energy from the lower limb accelerates upward body rotation, enhancing energy transfer to the upper shoulders. Lower limb energy is primarily generated in the knee and ankle joints (Table 2), likely because excessive flexion of the hip joint is restricted during volleyball passes. Additionally, as

**TABLE 1. Ball kinematic parameters according to passing distance.**

| | Passing distance | | | $F$-value |
|---|---|---|---|---|
| Ball parameters | Short | Medium | Long | |
| Speed (m/s) | $5.70 \pm 0.36^{b,c}$ | $7.35 \pm 0.51^{a,c}$ | $8.94 \pm 0.45^{b,c}$ | 313.90 |
| Projectile angle (°) | $53.29 \pm 6.40^{c}$ | $49.68 \pm 6.37$ | $47.91 \pm 6.60^{a}$ | 3.78 |

*Ball kinematic parameters, including speed and projectile angle, measured at short, medium and long passing distances. The F-values indicate the statistical significance of differences observed across distances. Notably, speed increased significantly as passing distance increased, while the projectile angle decreased. Significant differences between specific distances are indicated by $^{a,b}$ and $^{c}$ ($p < 0.05$), where "a" denotes short, "b" denotes medium, and "c" denotes long distances.*

**TABLE 2. Energy generated by joints of the upper and lower extremities according to passing distance.**

| | Passing distance | | | $F$-value |
|---|---|---|---|---|
| Variable (J/kg) | Short | Medium | Long | |
| Shoulder | $0.017 \pm 0.008^{b,c}$ | $0.032 \pm 0.016^{a}$ | $0.036 \pm 0.015^{a}$ | 13.80 |
| Elbow | $0.031 \pm 0.013^{b,c}$ | $0.058 \pm 0.025^{a}$ | $0.064 \pm 0.018^{a}$ | 20.76 |
| Wrist | $0.005 \pm 0.001^{b,c}$ | $0.006 \pm 0.002^{a}$ | $0.006 \pm 0.001^{a}$ | 9.06 |
| Upper Limb | $0.052 \pm 0.190^{b,c}$ | $0.097 \pm 0.032^{a}$ | $0.106 \pm 0.021^{a}$ | 32.69 |
| Hip | $0.020 \pm 0.021^{c}$ | $0.039 \pm 0.052^{c}$ | $0.082 \pm 0.093^{a,b}$ | 6.25 |
| Knee | $0.024 \pm 0.038^{b,c}$ | $0.143 \pm 0.122^{a,c}$ | $0.316 \pm 0.154^{a,b}$ | 38.79 |
| Ankle | $0.076 \pm 0.065^{b,c}$ | $0.244 \pm 0.187^{a,c}$ | $0.437 \pm 0.240^{a,b}$ | 24.32 |
| Lower Limb | $0.120 \pm 0.104^{b,c}$ | $0.425 \pm 0.310^{a,c}$ | $0.835 \pm 0.374^{a,b}$ | 37.52 |

*Energy generated (J/kg) by the joints of the upper and lower extremities at short, medium and long passing distances. The F-values indicate the statistical significance of the observed differences across distances. Significant differences between specific distances are indicated by $^{a,b,c}$ ($p < 0.05$), where "a" denotes short distance, "b" denotes medium distance, and "c" denotes long distance.*

**TABLE 3. Energy transfer by joints of the upper and lower extremities according to passing distance.**

| | Passing distance | | | $F$-value |
|---|---|---|---|---|
| Variable (J/kg) | Short | Medium | Long | |
| Shoulder | $0.021 \pm 0.025^{b,c}$ | $0.051 \pm 0.042^{a,c}$ | $0.099 \pm 0.043^{a,b}$ | 23.21 |
| Elbow | $0.029 \pm 0.016^{b,c}$ | $0.056 \pm 0.025^{a,c}$ | $0.091 \pm 0.029^{a,b}$ | 35.21 |
| Wrist | $0.018 \pm 0.008^{b,c}$ | $0.034 \pm 0.012^{a,c}$ | $0.051 \pm 0.012^{a,b}$ | 45.91 |
| Hip | $0.123 \pm 0.178^{b,c}$ | $0.343 \pm 0.333^{a,c}$ | $0.642 \pm 0.356^{a,b}$ | 25.68 |
| Knee | $0.116 \pm 0.162^{b,c}$ | $0.312 \pm 0.262^{a,c}$ | $0.607 \pm 0.276^{a,b}$ | 32.39 |
| Ankle | $0.062 \pm 0.047^{c}$ | $0.132 \pm 0.107^{c}$ | $0.263 \pm 0.12^{a,b}$ | 22.07 |

*Energy transfer (J/kg) by the joints of the upper and lower extremities at short, medium and long passing distances. The F-values indicate the statistical significance of the differences observed across distances. Significant differences between specific distances are denoted by $^{a,b,c}$ ($p < 0.05$), where "a" represents short distance, "b" represents medium distance, and "c" represents long distance. The analysis period for each upper extremity joint was defined as the interval from hand contact with the ball until its release, while for lower extremity joints, it was from push-off to ball release. The data show that energy transfer increases with passing distance, particularly in the hip and knee joints.*

shown in Fig. 3, the hip joint absorbs more energy during long passes, likely due to the increased horizontal velocity required, stabilizing the trunk by and enabling quicker shoulder and elbow movement. This stabilizing energy absorption is similar to the stride leg's role in baseball pitching [20]. Variability in hip joint energy might be due to different passing strategies among athletes.

As passing distance increases, the wrist joint absorbs more energy post-contact, potentially enhancing the stretch-shortening cycle (Fig. 3) [4]. Excluding the volleyball's mass from the model may underestimate the actual energy dynamics at the wrist joint, which likely absorbs and generates more energy over longer distances. This occurs because lower limb and elbow extensions begin before contact, requiring the wrist to absorb additional energy to stabilize and control the ball for subsequent actions (Table 4) [6]. The model simplification likely affected the accuracy of energy calculations at the wrist joint.

**TABLE 4. Vertical velocity of the left shoulder and wrist centers at the ball contact according to passing distance.**

| | Passing distance | | | $F$-value |
|---|---|---|---|---|
| Variable | Short | Medium | Long | |
| Shoulder velocity (m/s) | $0.14 \pm 0.13^{b,c}$ | $0.45 \pm 0.27^{a,c}$ | $1.18 \pm 0.30^{a,b}$ | 34.23 |
| Wrist velocity (m/s) | $0.98 \pm 0.32^{b,c}$ | $1.52 \pm 0.25^{a,c}$ | $2.16 \pm 0.25^{a,b}$ | 13.20 |

*Vertical velocity (m/s) of the left shoulder and wrist centers at the moment of ball contact for short, medium and long passing distances. The F-values indicate the statistical significance of differences observed across distances. Significant differences between specific distances are denoted by superscripts $^{a,b,c}$ ($p < 0.05$), where "a" represents short distance, "b" represents medium distance, and "c" represents long distance.*

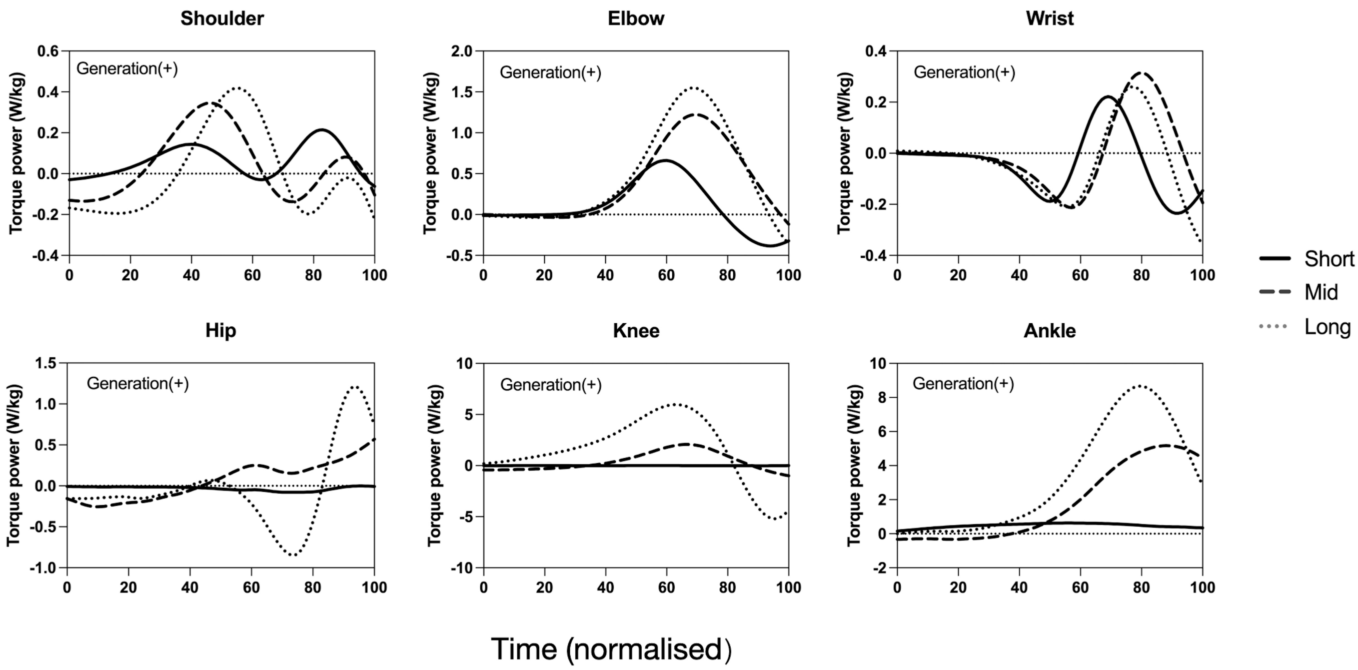



**FIGURE 3. The joint torque power of the left side of each joint for a representative participant.** The solid, dashed and dotted lines represent the short, medium and long distance conditions respectively. In the lower limbs, 0% corresponds to push-off and 100% represents ball release. In the upper limbs 0% represents the moment hand touch the ball 100% represents ball release. This figure illustrates the variation in torque power across different passing distances, highlighting the dynamic changes in joint contributions during the volleyball passing motion. Mid: Medium.

## 4.2 The role of upper limb joints and lower limb joints

In summary, ball speed is primarily driven by increased energy output from the lower extremities, while stable passing relies on consistent release parameters in the upper extremities. At medium distance, there's a notable increase in energy generated by the elbow joint. Given the variety of tactics in a volleyball game, setters must master control with different speeds, directions and curves [33]. Practicing long-distance passes helps setters refine their upper limb control. Due to the smaller muscle size and denser nerve distribution in the upper extremities, fine-tuning muscle contraction force is more manageable [34, 35]. When not using full capacity, athletes rely on the upper limbs for precise control and adjustment [36].

The work done by the joints of the lower body increased significantly in the long-distance conditions, while no such difference was observed in the upper limbs. This disparity may be attributed to the fact that the upper limbs reach their maximum effort during long passes and must also compensate for the greater variability in the lower limbs. This strategy aligns with the compensation mechanisms observed in the kinematic chain in previous studies [37, 38]. Since the variability in skeletal muscles force is proportional to the average force exerted, the distal joint (wrist) remains stable to counterbalance significant changes in the proximal joint (lower extremity), thereby ensuring the accurate release parameters [39]. In summary, during long-distance passes, the lower limbs need to be fully extended to generate the necessary energy for the ball release, while the upper limbs maintain relative stability to manage the increased variability in the lower extremities.

It is important to note that during the volleyball passing action, both hands make contact with the volleyball for only a brief time (approximately 100 milliseconds). During this time, the wrist joint must absorb the kinetic energy of the falling volleyball and then push the ball out quickly during the follow-through phase. The wrist flexors are stretched and then actively contracted throughout this phase, emphasizing the importance of training the stretch-shortening cycle effectively. Future research could explore how distance affects energy flow during jump passes, and the interval between take-off and ball release could be another factor influencing the energy dynamics of the pass.

## 4.3 Limitation

One of the limitations of this study is its small sample size, consisting of only 8 college volleyball players. The research aimed to examine how varying passing distances—set at 2.5 meters, 5 meters and 7.5 meters—affect energy flow. However, the 7.5 meters distance may not represent the maximum effort of players, as maximum effort is often assessed based on maximum ball speed in overhead throws [4, 40].

The strategies for passing the ball over various distances examined in this study may vary based on participants' skill levels [41]. It remains uncertain if all athletes employed the same strategies. While our participants were college players with extensive training, the strategies of more experienced players, such as setters, are not well understood. Furthermore, the study focused on overhead passes with both feet grounded; professional players might use jumping passes. Future research should explore how passing distance affects the energy dynamics of jumping passes.

## 4.4 Practical implication

Our findings emphasize that increased lower extremity energy as the primary source for effective passing movements, aligning with the consensus that players should use leg extension to generate more energy [41]. However, it is crucial to underscore the significant role of the upper extremities, particularly their ability to control the elbow and wrist joints, across varying passing distances.

# 5. Conclusions

This study provides critical insights into the mechanics of volleyball passing by quantifying the energy contributions of both upper and lower extremities at varying distances. The findings demonstrate that as passing distance increases, the lower limbs become crucial in transferring energy to the upper body, particularly during long-distance passes. This is evidenced by the significant energy output from the lower extremities, which supports upward body rotation and enhances the energy transfer to the shoulders and arms. While the upper limbs maintain a stable contribution throughout, they rely on this energy transfer to deliver accuracy and power. The effective control and adjustment of passing techniques are vital, especially at medium- and long-distance scenarios, where the dynamics of energy absorption and generation shift notably. Moreover, the brief contact time of approximately 100 milliseconds during passing highlights the need for training focused on optimizing the stretch-shortening cycle of the wrist, further emphasizing its role in effective ball release. Future research should delve into additional variables influencing energy dynamics, such as jump passes and the duration between take-off and ball release, to further elucidate the complex interplay of biomechanics in volleyball performance. This comprehensive understanding of energy flow is essential for improving training regimens and enhancing overall athletic performance in volleyball.

## AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

## AUTHOR CONTRIBUTIONS

MLD, JHL, CJW and SK—designed the research study; wrote the manuscript. MLD, JW, YJX and CJW—performed the research. JHL and SK—provided help and advice on the present study. MLD, JW and CJW—analyzed the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

## ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Ethics Committee of Jeonbuk National University (JBNU2022-01-004-002). All subjects signed an informed consent form before the experiment.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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jomh.org/files/article/1851531697878646784/attachment/Supplementary%20material.docx.

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