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Assessing shoulder strength in elite sitting volleyball athletes: An isokinetic analysis of rotator cuff muscles

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Abstract: The nature of sitting volleyball (SV) involves repeated overhead activities and rapid movement across the court using the upper limbs. Consequently, these technical demands necessitate optimal glenohumeral muscle performance, especially among professional athletes. This study aimed to investigate the shoulder rotators' isokinetic strength profile of elite SV players. Sixteen male SV national team players participated in this study. They were preparing for the Tokyo 2022 Paralympic Games, with an average age of Mean = 27.1, SD = 6.5 years, height of Mean = 188.2, SD = 17.1 cm, weight of Mean = 88.1, SD = 21.7 kg, and a BMI of Mean = 24.9, SD = 7.6 kg/m2. We used an isokinetic dynamometer to measure the peak torque, angle of peak torque, total work, and average power of the external rotator (ER) and internal rotator (IR) muscles in the dominant limb. Measurements were taken at a velocity of 60°/s in a concentric/concentric mode. The upper body Wingate anaerobic test was conducted on a modified electro-magnetically braked cycle ergometer. The IR muscles showed significantly higher values for peak torque (p = .04), total work (p = .01), and average power (p = .05) compared to the ER muscles. There was no difference in angle of peak torque (p = .31) between IR and ER muscles. This study's results may serve as a reference standard for assessing the performance of SV players, with a focus on the rotator cuff muscles in their dominant limb, aiming to enhance their quality and efficiency.

Keywords: Paralympic, isokinetic strength, glenohumeral muscles, professional athlete

Introduction

Sitting Volleyball (SV) is known as a prominent instance of an accessible, inclusive Paralympic team sport, characterized by its widespread popularity and engagement (Ahmadi et al., 2019). This sport requires participants to execute floor movements predominantly with their upper limbs, demanding rapid reflexive responses for effective positioning and play (Cavedon et al., 2022). In SV, athletes are compelled to exhibit significant agility, encompassing acceleration, deceleration, and multidirectional shifts, in response to dynamic stimuli such as the trajectory of the ball and the actions of opposing players (Jeoung, 2017). This adaptability is paramount, requiring comprehensive proficiency in omni-directional locomotion, including anterior, posterior, lateral, and multidirectional movements. In this context, the shoulder joint assumes a pivotal role,

attributed to its intricate anatomical structure that facilitates extensive mobility coupled with dynamic stabilization capabilities (Lucena et al., 2022).

To ensure optimal stability amid the intense forces exerted on the shoulder girdle complex, it is crucial for the shoulder muscles to be well-coordinated and synchronized (Van Cingel et al., 2006; Ahmadi et al., 2020a). The ballistic movement of sitting through the acceleration phase is marked by strong concentric internal rotation (IR) and adduction at the shoulder joint, followed by a significant increase in the external rotators' (ER) eccentricity during the follow-through phase (Ahmadi et al., 2020b). During the deceleration phase, the ER muscles are subjected to high eccentric forces, potentially increasing their risk of injury (Van Cingel et al., 2006).

Muscular strength and performance are crucial for sports achievement and overall health and fitness (Fashi & Ahmadizad, 2021). However, identifying the most effective methods to enhance strength and muscle performance remains a key focus for athletes, coaches, and scientists. In this domain, the isokinetic dynamometer is recognized as the benchmark for measuring muscle strength (Ahmadi et al., 2020b; Ahmadi & Uchida, 2021). In recent years, its use has significantly increased in sports science research, attributed to its reliability and validity in assessing shoulder joint function, thereby making it a popular tool among researchers. According to Ahmadi et al. (2020a), shoulder isokinetic profiles are invaluable for assessing the performance of SV players. Despite these advancements, there is still a lack of information regarding the evaluation of shoulder rotator muscle function and the upper body's anaerobic capacity in elite SV players, especially among Paralympic champions (Ahmadi & Uchida, 2021). This gap underscores the need for comprehensive assessments, setting a standard for other athletes and teams. Given this context, our study aims to fill the existing gap by evaluating the isokinetic strength profile of the shoulder rotators in world-class elite SV players.

Materials and Methods

Sixteen male Iranian SV national team players participated in this study, during the final stage of the Tokyo 2022 Paralympic preparation camp in August 2022. Subjects abstained from any resistance training for 48 hours before the study began. After becoming acquainted with the study's procedures and protocols in the first session, participants underwent body composition analysis using the Inbody S10, specifically designed for physically disabled individuals. Subsequently, they completed the arm ergometry Wingate test to assess upper-body anaerobic power during their second visit. Within the following 48 hours, participants were asked to return to the laboratory for an assessment using the isokinetic test. Informed consent was obtained from each participant, and the research protocol was approved by the ethical committee of the University of Shahid Beheshti. The study was conducted in accordance with the Declaration of Helsinki.

Linear dimensions, including height and body mass, were quantified utilizing a measuring tape with a resolution of 0.01 meters and an electronic weighing apparatus with a precision of 0.01 kilograms, respectively. Body Mass Index (BMI) was calculated according to the formula: BMI = body mass (kg) / (height (m))^2. Brachial circumference was measured halfway between the acromion and olecranon processes while the arm was relaxed.

Upper Body Wingate Anaerobic Test (WAnT) assessment was executed employing a modified electro-magnetically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands), which was affixed to a stationary table to obviate any displacement during the evaluation. A braking force corresponding to 5% of the subject's body mass was utilized, conforming to established protocols (Bar-Or, 1987; Walker, 2016). Each trial initiated with a warm-up period lasting five minutes at an intensity of 50 Watts, incorporating three bouts of 10-second maximal sprints, followed by a five-minute recuperation phase. Subsequently,

participants underwent a stretching regimen for approximately three minutes before initiation of the WAnT. Subjects were instructed to execute the cycling task with maximal velocity following a three-second preparatory countdown, subsequent to which the predetermined resistance was engaged. Power outputs during the WAnT were documented using Wingate version 1.0.7 software (Lode, Groningen, Netherlands), encompassing Peak Power (ascertained every 0.5 seconds), Average Power, and Mean Power throughout the 30-second evaluation period. All measurements were conducted consistently by expert personnel within a specialized exercise physiology laboratory setting.

Isokinetic assessments adhered to the protocols defined by Cools et al. (2007), focusing on concentric movements (concentric/concentric mode) of the IR and ER muscles at angular velocities of 60 degrees per second (60°/s) using a Biodex System 4 apparatus (Biodex Medical Systems Inc., Shirley, NY, USA). The dominant limb was assessed, with each testing sequence comprising five repetitions. The evaluated isokinetic parameters included peak torque, total work, average power, and angle at peak torque of the shoulder musculature. All procedures were conducted by the same skilled examiner, maintaining a coefficient of variation for the isokinetic testing below 10 percent (Waller et al., 2017). Before the isokinetic evaluation, participants completed a two-minute warm-up consisting of unloaded shoulder IR and ER motions. To reduce unnecessary movements, participants were securely fastened to the apparatus with straps around their trunk, pelvis, and thigh. The range of motion was delimited to 90 degrees to preclude joint hyperextension, with full knee extension denoted as 0 degrees. Participants were instructed to keep the contralateral limb stationary and apply maximal effort during all test repetitions. Participants received verbal encouragement to optimize their performance.

The Shapiro-Wilk test confirmed the normality of the data. A power analysis, conducted using G*Power software version 3.1.9.2, determined that a sample size of n = 16 was sufficient to detect a statistically significant difference, given a power of .75, an alpha error of .05, and an effect size of .6. All statistical analyses were carried out using GraphPad Prism version 6 software. Independent t-tests were used to compare the dominant external to internal rotator tests and the arm circumference measurements. The level of significance for all statistical analyses was set at $p < .05$.

Results

Participant characteristics are summarized in Table 1. The study included 16 elite male athletes who successfully completed all tests. Their mean age was 27.1 years (SD = 6.5), with a BMI of 24.9 kg/m² (SD = 7.6), and their body fat percentage was 23.5 (SD = 6.7). Performance metrics revealed a peak power of 417.4 W (SD = 25.9), average power relative to body weight of 4.7 W/kg (SD = 1.3), and a power drop of 68.2% (SD = 10.4). The dominant arm distribution among participants was 11 right arms and 5 left arms.

Table 1. Characteristics data of the 16 male Sitting Volleyball players.

Variables	Mean	SD	Numbers
Age (years)	27.1	6.5	-
Height (cm)	188.2	17.1	-
Body mass (kg)	88.1	21.7	-
Body mass index (kg/m^2)	24.9	7.6	-
Body fat (%)	23.5	6.7	-
Peak power (W)	417.4	25.9	
Average power (W/Kg)	4.7	1.3	
Power drop (%)	68.2	10.4	
Dominant arm (right, left)	-		(11, 5)

Note: M: Mean; SD: Standard deviation.

For arm circumference, no significant difference was observed between the dominant (Mean = 35.08, SD = 5.85 cm) and non-dominant (Mean = 31.60, SD = 6.11 cm) arms (p = 0.11), as shown in Figure 1.

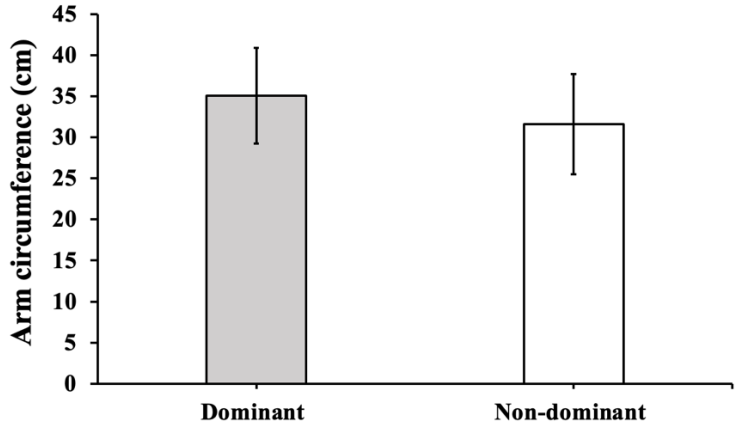

Figure 1. Comparison of circumference measurements between dominant and non-dominant arms showing no significant difference.

The comparison of peak torque, total work, average power, and angle of peak torque between internal and external rotators at 60°/s angular velocity is presented in Table 2. Significantly higher values were observed in the IR muscles compared to the ER muscles for peak torque (p = .04), total work (p = .01), and average power (p = .04), as detailed in Table 2. However, no significant difference was found in the angle of peak torque between the IR and ER muscles (p = .31).

Table 2. Comparison of peak torque, total work, average power, and angle of peak torque between internal and external rotators at 60°/s angular velocity.

Variables	ER (N/m)		IR (N/m)		t	p
	Mean	SD	Mean	SD		
Peak torque (N-M)	45.89	7.32	53.77	9.12	1.21	.04
Total work (J)	909.73	54.98	988.07	44.97	0.61	.01
Average power (W)	30.93	8.79	29.64	7.04	0.25	.04
Angle of peak torque (deg)	21.50	4.31	38.93	8.36	14.48	.31

Note. ER: external rotators, IR: internal rotators

Discussion

The purpose of this study was to explore the isokinetic strength profile of the dominant-limb shoulder rotators in world-class elite SV players. The results provide information on the physical characteristics and performance metrics of these athletes, as well as differences in strength between shoulder internal and external rotators.

Our results indicated significantly higher strength parameters in the IR muscles compared to the ER muscles at a 60°/s angular velocity. This is consistent with previous research suggesting that athletes, particularly those involved in overhead activities, tend to develop greater strength in their IR muscles (Ahmadi et al., 2020b; Işildak, 2021). These findings could inform targeted strength and conditioning programs aimed at addressing this imbalance to improve performance and reduce the risk of injury (Ahmadi et al., 2020a). However, the lack of significant difference in the angle of peak torque between the IR and ER muscles suggests that while there is a strength disparity, the functional range at which this strength is applied remains similar between the two muscle groups (Mayer et al., 1994). This could have implications for rehabilitation and training programs, emphasizing the need

to not only increase strength but also to ensure that the strength is functional across the shoulder's range of motion.

The Iranian male national SV team has consistently demonstrated exceptional performance in international competitions, securing gold medals and championships in almost every event except for the 2004 Athens and 2012 London Paralympics (World Paravolley, 2024). Consequently, the anthropometric assessments and performance metrics of this team could serve as a benchmark for other global teams aiming to elevate their performance levels. However, in the realm of sports science, there is a notable absence of data on shoulder isokinetic variables for SV players, despite the widespread application of isokinetic testing to evaluate shoulder muscle performance in healthy athletes (Ahmadi et al., 2020b; Ahmadi & Uchida, 2021). Isokinetic variables such as peak torque, total work, and average power are integral to understanding a muscle's capacity for strength generation and are interrelated, although they assess different muscle capabilities (Van Cingel et al., 2006). Specifically, peak torque measures the maximum force exerted by the shoulder rotators, correlating with average power, which together highlight the muscle group's ability to produce force swiftly and efficiently (Vargas et al., 2020). Total work, influenced by torque and the shoulder's range of motion, provides insight into muscle behavior throughout its movement, offering a broader perspective than peak torque alone (Simpson et al., 2019).

Our findings revealed that the shoulder IR muscles exhibited significantly higher values in peak torque, total work, and average power compared to the ER muscles. These differences underscore the critical role of IR muscle strength in various aspects of SV, particularly in offensive and spike positions. Therefore, enhancing the ER muscles in the dominant limb could potentially improve players' quality and efficiency. This study introduces the first report of peak power, average power, and power drop metrics for elite SV players using the 30-second WAnT. These metrics, although lower when compared to those of non-disabled volleyball players, should be considered in light of the athletes' disabilities and their remarkable achievements in international and Paralympic contests.

Comparative research, such as the study on Polish elite-level SV players, has highlighted the dependency of physical fitness and game performance on athletes' anthropometric characteristics (Marszalek et al., 2015). Moreover, studies have demonstrated that elite volleyball athletes, including those in the study by Işildak (2021), exhibit high anaerobic power and significant muscle mass around the arms, crucial for effective service delivery. Our findings of a dominant arm circumference of 35.08 cm align with these observations, indicating superior physical condition, which is likely attributable to the elite status and rigorous training of the Iranian national team members.

The limitations of this study include the small sample size and the focus on elite athletes, which may limit the generalizability of the findings to the general population or athletes from other sports. However, our sample size was the extent of the entire male Iranian national SV team at the time of the study who were available or were without injury. Future research should aim to include a larger and more diverse cohort of athletes to validate these findings. Additionally, longitudinal studies could provide insight into how these strength profiles change over time and in response to different training regimens.

Conclusions

Findings of this study revealed that the IR muscles of elite SV players exhibit significantly greater peak torque, total work, and average power than the ER muscles. These findings underscore the enhanced strength and performance capabilities of the IR muscles in these athletes. This information is critical for designing targeted rehabilitation and conditioning programs aimed at balancing muscle strength and optimizing performance in SV athletes.

Perspectives

This study presents the isokinetic strength profiles of elite SV players and identifies a notable strength imbalance between internal and external shoulder rotators. This discrepancy underscores the need for targeted training programs aimed at boosting performance and minimizing injury risks. Intriguingly, the strength variation does not affect the functional application across the shoulder's range of motion. Leveraging data from the renowned Iranian male national SV team, this research fills a significant void in sports science and highlights the potential for elevating athlete performance through specialized strength conditioning. It also has broader implications for setting benchmarks and refining training protocols in elite SV.

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Conflicts of Interest: The authors declare no conflict of interest.

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