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Evaluating Shoulder Rotation Strength Asymmetry in Elite Wheelchair Basketball and Sitting Volleyball Players

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SUMMARY

Background. Although an imbalanced strength profile is considered a risk factor for injury, research on asymmetry in para-athletes is limited.

Objective. This study investigated the potential unilateral and bilateral asymmetries of the glenohumeral muscles in elite male players of sitting volleyball (SV) and wheelchair basketball (WB).

Methods. Twenty-two elite SV and WB players (each group of 11 players) participated in this study. A Biodex dynamometer was used to measure the internal and external rotator of the glenohumeral muscle strength at 60°/s velocity in a concentric/concentric mode.

Results. Findings indicated that both groups exhibited bilateral strength asymmetries in internal rotation and external rotation. The SV players had higher inter-limb asymmetric values than WB players regarding IR movement. The study also revealed a unilateral ratio imbalance among the SV players (ER/IR ratio mean = 88.80, SD = 18.70 for dominant and mean = 79.45, SD = 14.65 for non-dominant). They had a significantly greater ER/IR ratio than the WB players ($p = 0.016$) and also a significant dominant side × group interaction effect ($p = 0.049$). The WB group had stronger IR muscles relative to their body weight comparing the SV group ($p = 0.018$, partial eta-squared = 0.248, large effect).

Conclusions. Participants demonstrated an asymmetrical rotational strength profile with IR strength dominance. Although this muscle imbalance has been considered a shoulder injury risk factor among overhead athletes, it may not apply to para-athletes due to their functional adaptation requirements. Therefore, specific asymmetry thresholds need to be explored among them.

KEY WORDS

Elite para-athletes; isokinetic shoulder strength; rotator muscles; wheelchair basketball; sitting volleyball.

INTRODUCTION

Shoulder injuries are common among wheelchair basketball (WB) and sitting volleyball (SV) players (1, 2). They require repetitive explosive upper limb actions, both unilaterally (such as serving and spiking/shooting) and bilaterally (such as blocking, moving across the court, and wheelchair pushing), which could eventually lead to a shoulder injury (3). Some studies suggest that SV players may experience a mechanical disadvantage, compared to wheelchair-user athletes due to moving in different directions across the court using the shoulder instead of the elbow movements required to push a wheelchair forward (4). Nevertheless differences, both sports involve asymmetrical shoulder movements, which may potentially result in strength imbalances and asymmetry between the dominant (D) and non-dominant (ND) shoulders (4, 5). Research has shown that strength ratio differences in D and ND shoulders are associated with injury in sports involving overhead activities (6, 7). Ahmadi *et al.* used isokinetic shoulder screening and highlighted - inter-limb and intra-limb strength imbalances in SV players' shoulder muscles, focusing on external rotation (ER) and internal rotation (IR) (4). Freitas *et al*. did not detect any muscle imbalances between IR and ER in paraplegic WB athletes and non-athletes with spinal cord injuries (8). Although imbalanced rotational strength probably increases the risk of shoulder injury in sports with overhead activities, setting a specific threshold is difficult due to the task-specific nature of asymmetry (9, 10). Also, limited evidence related to para-athletes' strength imbalance made it more challenging. Studies have revealed that overhead athletes face a higher risk of injury if their D shoulder exhibits more than 9% strength imbalance in IR and 14% less strength in ER as compared to their ND shoulder (11). In addition, research indicates that people with inter-limb asymmetries exceeding 15%, regardless of whether they are athletes or not, are more susceptible to injuries and diminished performance when compared to those whose asymmetries fall below this benchmark (12, 13). Moreover, shoulder injuries can be caused by an abnormal intra-limb strength imbalance between the IR and ER muscles (14). Literature suggested the unilateral strength ratios between IR and ER muscles ranging between 65% to 75% as a standard ratio (15, 16). However, research on asymmetry in para-athletes is limited (4). On the one hand, functional adaptations related to limb deficits may affect movement patterns and asymmetry threshold in this population. On the other hand, establishing a consistent threshold for asymmetry is difficult due to task differences and varying tests and metrics (17). Therefore, it is necessary to develop related literature in this population, particularly among para-athletes. This study aimed to describe the isokinetic strength profile of the shoulder muscles in elite SV and WB players, examining both inter-limb and intra-limb strength and identifying any asymmetries that may be present. The results of this research could help improve injury prevention risk assessments by providing insight into the extent of these asymmetries.

MATERIALS AND METHODS

Participants

The study included 22 male players from SV and WB national teams of Iran (11 players in each group). None of the participants had experienced any shoulder-related issues in the past six months, such as rotator cuff tears, shoulder surgery, or upper limb disabilities. All participants had a confirmed official medical/functional classification from the International Wheelchair Basketball Federation (IWBF) or World ParaVolley. Additionally, they completed a questionnaire that gathered information on their dominant hand, years of practice background, training hours, and previous shoulder injuries. All the participants had no upper limb impairment. However, as some of the participants were athletes with spinal cord injuries (SCI), special considerations were made to ensure they could complete the study's test protocol. Their clinical cases in terms of spinal injury level were reviewed, and it was confirmed that the most severe SCI athlete had an injury at the T2 level. Clinical evaluations have shown that spinal injuries from T1 to T6 allowed for full use of shoulders, arms, and fingers with normal muscle strength and range of motion (18). In addition, the SCI participants passed the clinical and functional evaluations of the International Wheelchair Basketball Federation classification and had received an official classification. Prior to the study, all participants were required to read and sign an informed consent form. The current research study was approved by the University of Tehran Ethics Committee (IR.UT.SPORT.REC.1400.043 – date of approval: December 20, 2021).

Table I provides a summary of the participants' characteristics.

Table I. Characteristics of the participants.

	SV		WB	
	Mean	**SD**	**Mean**	**SD**
Age (yrs)	31.73	6.63	31.73	7.6
Body Height (cm)	185.27	8.14	172.87	11.88
Sitting Height (cm)	95.96	4.68	97.86	8.03
Body Mass (kg)	85.00	13.71	72.49	13.82
Sport Experience (yrs)	12.27	6.83	13.56	6.13
Classification	VS1(3), VS2(8)		Class1 (2), Class2 (2), Class2.5 (2), Class3.5 (1), Class4 (4)	

SV players' classification was determined by the World Paravolley; WB players' classification was determined by the International Wheelchair Basketball Federation.

Testing procedure

To evaluate the IR and ER of the shoulder, a Biodex System 4 Pro isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, New York, USA) was utilized. All movements were performed in the concentric-concentric mode, following the protocol established by Cools *et al.* (19). The dominant side was evaluated first, followed by the non-dominant side. The dominant arm was defined as the preferred limb for throwing a ball (20). The participants were seated upright at 0° with a 5° tilt in the dynamometer and an 85° tilt in the seat back. They began with a full IR, and their shoulder was positioned at 90° abduction, resting at a 90° of elbow flexion on the rotation cuff pad. To ensure precision, we aligned the olecranon with the rotational axis of the dynamometer. The participants maintained a neutral position on their forearm and wrist by holding the input shaft by hand. We stabilized the participants' trunks by securing a belt across their chest from the opposite shoulder and fastening it with a buckle. Before the test, the participants were instructed to hold - the handgrip on the opposite side of the chair and perform IR and ER movements, commencing from an internally rotated position. A predefined range of motion of 90 degrees was established beforehand. The participants engaged in a 5-minute warm-up period with a shoulder wheel, consisting of 10 repetitions at an angular velocity of 60°/s. Before each actual test, they were asked to perform five repetitions, and throughout the test, they were verbally encouraged. Two submaximal contractions were executed to acquaint the participants with the test movements before the actual maximal test. To determine the optimum measure, the mean of the maximum torque recorded during three middle attempts was calculated.

Outcome variables

The Biodex software can determine several values, including peak torque (PT), peak torque to body weight ratio (PT/BW), and agonist/antagonist ratio. To assess intra-limb asymmetry, the ER/IR ratio provided by Biodex software was utilized (21). Inter-limb asymmetries were calculated separately for each movement using the Bishop *et al.* protocol (22). The Bilateral Strength Asymmetry (BSA) equation was used, and inter-limb asymmetry direction was measured for each participant. It was calculated for peak torque and peak torque to body weight variables as absolute and relative strength asymmetry. BSA is shown in equation 1:

BSA = [(Stronger Limb - Weaker Limb) / Stroger Limb] × 100

Normality was checked using the Shapiro-Wilk test, and the data showed a normal distribution. Separate 2-way mixed design ANOVA (with independent measures on groups and repeated measures on shoulder dominance) was used to assess differences between relative and absolute IR and ER concentric strength and relative ER/IR strength ratios. Independent measures t-tests were conducted to compare relative and absolute strength asymmetry between groups. The significance level was set at 0.05, and effect sizes were calculated using partial eta-squared (partial η^2), with 0.001, 0.06, and 0.14 classified as small, medium, and large effect sizes, respectively (23). Effects sizes (Cohen's d) were calculated to show practical differences between groups and were interpreted as: trivial (0-0.19), small (0.20-0.49), medium (0.50-0.79), and large (0.80 and greater) (24). All analyses were conducted in SPSS (version 26.0; SPSS Inc, Chicago, IL).

RESULTS

The study found significant differences in PT and PT/BW of IR muscles between the D and ND shoulders of both groups (IR PT, $p = 0.015$, partial $\eta^2 = 0.260$, large effect and IR PT/BW, $p = 0.010$, partial $\eta^2 = 0.287$, large effect). Additionally, WB players had significantly greater amounts of PT/BW of IR muscles than SV players ($p = 0.018$, partial $\eta^2 = 0.248$, large effect). However, no difference was found in the PT and PT/BW of ER muscles between D and ND shoulders in both groups (PT $p = 0.965$, partial $\eta^2 = 0.000$, no effect and PT/BW $p = 0.533$, partial $\eta^2 = 0.022$, small effect) and between groups ($p = 0.163$, partial $\eta^2 = 0.105$, medium effect). Results revealed that ER/IR ratios were significantly different between WB and SV players ($p = 0.016$, partial $\eta^2 = 0.284$, large effect) but there was no significant difference between participants' D and ND shoulders ($p = 0.209$, partial $\eta^2 = 0.086$, medium effect). Also, significant dominant side × group interaction effect was observed ($p = 0.049$, partial $\eta^2 = 0.198$, large effect). Results revealed that there were inter-limb asymmetries in IR and ER strength in both groups, ranging from 11.32% to 19.79%, and there was a significant difference between the two groups' PT and PT/BW of IR muscles asymmetry values (absolute IR, $p = 0.041$ and relative IR, $p = 0.032$). Also, the intra-limb asymmetric profile was found in the SV players' D and ND shoulders (relative ER/IR ratio mean = 88.80, SD = 18.70 for D and mean = 79.45, SD = 14.65 for ND). The statistical results for glenohumeral muscle strength and inter-limb asymmetry (%) in WB and SV players have been presented in **table II**.

Table II. Model summary for glenohumeral muscle strength results and inter-limb asymmetry (%) in wheelchair basketball and sitting volleyball players.

	WB		SV		Dominance		Group		Dominance × group	
	D	ND	D	ND	P-value	Partial η²	P-value	Partial η²	P-value	Partial η²
IR PT (Nm)	52.13 ± 11.32	49.84 ± 10.51	50.95 ± 8.97	43.91 ± 10.93	0.015*	0.260	0.397	0.036	0.193	0.083
ER PT (Nm)	36.79 ± 8.43	34.73 ± 8.29	37.74 ± 6.78	39.95 ± 8.08	0.965	0.000	0.311	0.051	0.203	0.080
IR PT/BW (Nm/kg)	73.97 ± 18.37	70.63 ± 16.16	61.34 ± 13.47	52 ± 12.07	0.010*	0.287	0.018*	0.248	0.195	0.083
ER PT/BW (Nm/kg)	51.60 ± 11.79	50.33 ± 11.03	46.75 ± 6.09	45.26 ± 6.68	0.533	0.022	0.163	0.105	0.961	0.000
ER/IR ratio	68.54 ± 8.05	70.76 ± 7.17	88.80 ± 18.70	79.45 ± 14.65	0.209	0.086	0.016*	0.284	0.049*	0.198
IR PT Inter-limb asymmetry (%)	11.32 ± 6.36		19.16 ± 10.02				0.041*	d = 0.93		
ER PT Inter-limb asymmetry (%)	13.05 ± 10.63		13.47 ± 11.72				0.930	d = 0.04		
IR PT/BW Inter-limb asymmetry (%)	11.41 ± 6.33		19.79 ± 10.27				0.032*	d = 0.98		
ER PT/BW Inter-limb asymmetry (%)	13.12 ± 10.63		15.14 ± 10.84				0.664	d = 0.19		

ER: external rotation; IR: internal rotation; PT: peak torque; peak TQ/BW: peak torque to body weight; D: dominant; ND: non-dominant; partial η²: partial eta-squared; d: cohen's d; *significant at $p < 0.05$.

DISCUSSION

This research aimed to investigate the isokinetic strength profile of the glenohumeral muscles in elite male players of SV and WB, with a focus on identifying any potential asymmetries between the D and ND shoulders.

The study found significant differences in PT and PT/BW in the IR movement between the D and ND shoulders of both groups (IR PT, $p = 0.015$, partial $\eta^2 = 0.260$, large effect and IR PT/BW, $p = 0.010$, partial $\eta^2 = 0.287$, large effect). Additionally, WB players had significantly greater amounts of PT/BW in the IR movement than SV players ($p = 0.018$, partial $\eta^2 = 0.248$, large effect). The results agree with previous literature that the D shoulder has higher IR strength than the ND shoulder in SV players (4, 25). This could be due to the explosive unilateral IR movements required in SV, such as spiking and serving. Also, given that the active propulsion movements during wheelchair use (extension-adduction-IR) are at least twice as large as the counter-movements (flexion-abduction-ER) on the same axis (26), muscle imbalance with greater IR peak torque is an expected result (27). However, the authors could not find the same or contrasting findings related to WB in the current literature. The findings suggest that playing SV and WB at an elite level can result in significant strength asymmetries between D's and ND's shoulders regarding PT and IR PT/BW. Moreover, greater IR strength may be caused by other factors such as greater focus on larger muscles such as the IRs, the latissimus dorsi, and the pectoralis major, and ignoring small external rotators during strength training (27). Additionally, WB players had stronger IR PT/BW in both shoulders than SV players, which could be attributed to the role of IR muscles in explosive bilateral movements to push the wheelchair on the game court, which is the primary feature of WB sports. Previous studies have reported that performing high repetitions of sport-specific actions is one of the leading causes of gross anatomical asymmetry in the upper extremity (28, 29). However, no difference was observed in the PT and PT/BW of ER movement between D and ND shoulders in both groups (absolute $p = 0.965$, partial $\eta^2 = 0.000$, small effect and relative absolute $p = 0.533$, partial $\eta^2 = 0.022$, small effect). These findings highlight bilateral ER weakness in both groups. External rotator muscle weakness in the D shoulder is identified as an essential modifiable internal risk factor for shoulder injuries (30). Thus, the strength of ER muscles could play a role as an asymmetry controller in SV and WB players' shoulders. Increasing the strength of the ER muscle can help modify imbalance, provide greater stability to the shoulder joint, and reduce the risk of shoulder injuries. Hence, ER strengthening exercises are included in current shoulder injury prevention programs for athletes who perform overhead activities (31, 32). In both groups, there was inter-limb asymmetry in the ER and IR movements, ranging between 13.5% to 19.8% in the SV players and 11.3% to 13.1% in the WB players. In addition, we found a statistically significant difference in inter-limb imbalance between the two groups. There was a greater asymmetry between both shoulders in the SV players compared to the WB players during IR movement. Previous studies have shown that athletes with limb asymmetry greater than 15% are more prone to sports injuries (33). In addition, to return to sports after a unilateral limb injury, some researchers recommend striving for less than 10% asymmetry (34, 35). Exceeding a certain threshold of asymmetry can negatively impact an athlete's health, but it may also be advantageous for specific athletic performances (36). However, these thresholds are still challenging in current studies and may vary between individuals and activities (37). Additionally, some studies have highlighted the task-specific nature of asymmetry (10, 38) and have challenged such thresholds (39, 40), meaning that an asymmetry measured from one test may not be consistent across different tests (17). Since asymmetry is an adaptive consequence magnified with long-term physical activity participation (9), our finding suggests that playing SV and WB at an elite level over the long term can lead to asymmetry. Also, one of the causes of bilateral asymmetry is an abnormality of the spine (41). Since SV and WB players often have a unilateral lower disability, which can affect spine alignment, the findings may be related to probable spine abnormalities in subjects. A recent study by Zwierzchowska *et al.* (2022) found the sagittal deviation of spinal curvature in SV players (42). They postulated that in SV players, the mechanism of internal compensation, activated by lower limb impairment, contributed to a change in thoracic kyphosis angle, mobility, and angle of lumbar lordosis (42). It has also been reported that lower limb amputations and defects can significantly affect human biomechanics in para-athletes with lower limb impairments (43, 44). Moreover, the ER/IR strength ratio was not significantly different between D and ND ($p = 0.333$, partial $\eta^2 = 0.019$, small effect) in both groups. However, there was a significant difference between the two groups ($p = 0.003$, partial $\eta^2 = 0.170$, large effect). Also, SV players demonstrated greater values than the general recommendations range (0.60-0.75) proposed by the literature on both the D and ND sides (15, 45). Thus, intra-limb asymmetrical findings were established in the shoulders' rotational strength of the SV para-athletes. Research indicates an abnormal ER/IR ratio could be associated with a greater risk of shoulder injuries in overhead athletes (45). A study found that athletes with an intra-limb imbalance in their IR and ER muscles are 2.5 times more likely to experience shoulder injury (14). This finding is particularly noteworthy for wheelchair-user players, as their shoulder function is essential to their movement and living independently. An injury could lead to loss of independence, career setbacks, limitations on para-athletes' activities, and social isolation. However, additional research is required to analyze the isokinetic strength of glenohumeral muscles in overhead athletes, which can aid in improving injury prevention strategies in these two para-sports. Also, in this study, SV players had a significantly greater ER/IR ratio than the WB players ($p = 0.016$) and a significant dominant side × group interaction effect ($p = 0.049$), which shows playing SV at the elite level can increase intra-limb asymmetry. These findings can be explained by the adaptive consequence of participating in SV practice for a long time and the technical nature of SV sport, which needs explosive unilateral shoulder IR movements to perform some repetitive techniques such as serving and spiking by the dominant side.

Limitations

The study had a limited sample size due to restrictive inclusion criteria, making it difficult to generalize the research results to sub-elite athletes in these two para-sports. Therefore, it is suggested that other researchers explore the same variables with an extended number of participants.

CONCLUSIONS

The results of the current study emphasize the bilateral asymmetries in elite WB and SV players. Although this muscle imbalance has been considered a shoulder injury risk factor among overhead athletes, it may not apply to WB and SV players. It seems to be a functional adaptation requirement for daily activities and sports-specific performance among para-athletes, particularly in those who primarily use a wheelchair. Moreover, there is no consensus about the adverse effects of bilateral and unilateral asymmetries on injury in current evidence. Although the results of this study highlight the imbalanced profile of glenohumeral IR and ER movement in elite WB and SV players, the correlation between inter-limb and intra-limb asymmetries and muscle injuries shows equivocal results (46-48) and a particular

threshold size of asymmetry that may cause injury has not been identified in previous studies (37). Therefore, further studies should investigate specific thresholds of asymmetry that may lead to shoulder injuries in elite WB and SV players and evaluate their effects on shoulder injuries.
The results of this study can be utilized for various training objectives, particularly to improve performance and prevent injuries. Thus, the authors recommend that pre-season assessments in SV and WB players include evaluations of the bilateral and unilateral strength profiles of IR and ER muscles, and prescribing ER strengthening exercises be considered as a strategy to modify these imbalances among elite WB and SV players.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

MM: writing – original draft. All authors: conceptualization, writing – review & editing, project administration, data curation.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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