Journal of Bodywork & Movement Therapies 40 (2024) 942–947

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

journal homepage: www.elsevier.com/jbmt

Differences in shoulder function among badminton players broken down by age and sex

Xiao Zhou [a,b], Kazuhiro Imai [b,*], Zhuo Chen [b], Xiao-Xuan Liu [b,c], Eiji Watanabe [d]

[a] School of Physical Education of Huazhong University of Science and Technology, China
[b] Department of Life Sciences, Graduate School of Arts and Sciences, The University of Tokyo, Komaba, Meguro-ku, Tokyo, Japan
[c] Faculty of Medicine, Dalhousie University, Halifax, Nova Scotia, Canada
[d] Institute of Sport, Senshu University, Kawasaki, Kanagawa, Japan

ARTICLE INFO

Handling editor: Jerrilyn Cambron

Keywords:
Racquet sports
Range of motion
Shoulder joint
Reference values

ABSTRACT

Background: Improving the understanding of shoulder function for badminton players would develop injury preventive programs. However, no studies on shoulder function reference parameters of badminton players when controlling for age and sex have been found.
Objectives: To examine the differences in shoulder function between elementary school-age badminton players and university badminton players using shoulder range of motion.
Design: Cross-sectional study.
Setting: Testing at elementary school and university.
Participants: 67 players (7-12 year-old players and 18-22 year-old players) without shoulder injury experience.
Main outcome measures: Shoulder range of motion (ROM) included internal rotation (IR), external rotation (ER), and total ROM (TROM).
Results: Significant differences in shoulder IR of both sides (dominant: 97.67° *vs* 77.78°, $p < 0.001$; nondominant:104.70° *vs* 88.89°, $p < 0.001$), dominant ER (126.30° *vs* 115.98°, $p = 0.013$), TROM of both sides (dominant: 222.97° *vs* 193.76°, $p < 0.001$; nondominant: 222.90° *vs* 200.10°, $p = 0.001$), and TROM loss (-0.06° *vs* 6.34°, $p = 0.047$) existed between elementary school-age and university players. Significant differences in IR of both sides existed between male elementary school-age and university players (dominant: 98.38° *vs* 72.50°, $p < 0.001$; nondominant: 106.72° *vs* 83.99°, $p < 0.001$) as well as in female players (dominant: 95.25° *vs* 82.84°, $p = 0.007$; nondominant: 103.01° *vs* 93.57°, $p = 0.035$). Additionally, significant differences in IR of both sides (dominant: 72.50° *vs* 82.84°, $p = 0.016$; nondominant: 83.99° *vs* 93.57°, $p = 0.012$) and TROM of both sides (dominant: 188.24° vs 199.05°, $p = 0.025$; nondominant: 192.43° *vs* 207.44°, $p = 0.002$) existed between male and female university players.
Conclusions: Compared with university badminton players, elementary school-age badminton players showed significantly greater shoulder IR and TROM of both sides and dominant ER while significantly smaller TROM loss. However, regardless of sex, no significant differences of bilateral deficit for glenohumeral rotation existed between elementary school-age and university badminton players.

1. Introduction

Badminton is an early initiation sport which leads child badminton players to sustain shoulder injury and pain (Zhou et al., 2021). Shoulder function is taken into consideration as a good integrated measure of the shoulder's capacity involved in the performance of overhead motion, and it is an important indicator of good shoulder health as well (Ortega et al., 2008). In overhead motion sports including badminton, deficits in shoulder function, such as shoulder range of motion (ROM), could lead to injury and pain (Reeser et al., 2010; Aragon et al., 2012; Wilk et al., 2015; Sekiguchi et al., 2020; Zhou et al., 2022). Overuse injuries of shoulder, including rotator cuff impingement (Fahlström and Soderman, 2007, 2006), rotator cuff tendinopathy (Jørgensen and Winge, 1987; Shariff et al., 2009), biceps tendinopathy (Shariff et al., 2009), scapulothoracic dyskinesis (Arora et al., 2015), and acromioclavicular subluxation (Yung et al., 2007) are diagnosed in amateur and elite

* Corresponding author.
E-mail address: imai@idaten.c.u-tokyo.ac.jp (K. Imai).

https://doi.org/10.1016/j.jbmt.2024.05.020
Received 9 July 2023; Received in revised form 6 April 2024; Accepted 25 May 2024
Available online 31 May 2024

badminton players. To ensure better long-term participation and injury-free across the lifespan for badminton players, it is crucial to study shoulder function, especially in elementary school-age badminton players. In badminton, shoulder internal rotation (IR), shoulder external rotation (ER), shoulder abduction and adduction are required for players to perform repetitive overhead motions (Brahms, 2014; Kuntze et al., 2009; Lo and Stark, 1991; Shariff et al., 2009). The repetitive overhead motions produce tremendous demands on the shoulder joint due to excessively high angular velocities, resulting in loss of shoulder IR (caused by increased posterior capsular thickness) and gain of shoulder ER (caused by decreasing tension on the anterior-inferior capsuloligamentous structures) on dominant shoulder joint (Ishigaki et al., 2015; Astolfi et al., 2015), thereby contributing to development of shoulder injury and pain (Shanley et al., 2011; Wilk et al., 2015).

Shoulder IR and ER with the arm abduction of 90° are commonly measured to study shoulder function among overhead motion players. Several studies of badminton have shown that shoulder IR on the dominant side was significantly weaker than that on the nondominant side among players over 15 years old (Fahlström et al., 2006; Couppé et al., 2014). A recent study has revealed that youth badminton players with shoulder IR less than 55° were more likely to sustain shoulder pain (Cejudo, 2022). In terms of other overhead motion players and healthy people controlling for age, several studies have studied shoulder ROM among children, adolescents, and adults. Literature reported that 7-11 year-old child baseball players had greater shoulder ROM (Shanley et al., 2015; Picha et al., 2016) compared with those of 12–18 year-old youth baseball players. Another study reported that youth softball players expressed greater shoulder ROM than college softball players (Friesen et al., 2020). Additionally, a past study of healthy people revealed that 3-9 year-old children showed greater shoulder ROM than those of people aged 10+ years (McKay et al., 2017).

Improving the understanding of shoulder function of varying ages of badminton players may facilitate badminton injury screening, preventive programs, and rehabilitation protocols to this population. Nonetheless, studies on differences in shoulder function between elementary school-age and university badminton players are lacking. Thus, the purpose was to study the differences in shoulder range of motion between elementary school-age and university badminton players broken down by sex.

2. Materials and methods

In this study, collaborated with the head coaches of Japan Schoolchildren Badminton Federation, Senshu University, and Waseda University, we recruited 22 elementary school-age badminton players aged 7–12 years at the national tournament level and 52 university top level badminton players aged 18–22 years. The ethical committee of the Graduate school of Arts and Sciences, the University of Tokyo approved the protocol (Notification Number 602–2) in accordance with the Declaration of Helsinki.

2.1. Questionnaire and shoulder ROM test

A questionnaire survey and shoulder ROM tests were performed before badminton training. To measure passive shoulder ROM, a digital goniometer (SA-5468, Suncosmo, Tokyo, Japan: 0–360 degree of measuring range with a 0.1° sensitivity with resolution of 0.05°) was used.

2.2. Questionnaire

Firstly, the questionnaire was used to collect demographic characteristics (sex, age, dominant side, weight, and height) (Brener et al., 2003; Connor et al., 2007), badminton training experience, training hours per day, training days per week, and history of injury related to badminton. Training hours was defined as hours of physical condition training or badminton motor skills under coaching supervision. Warm-up time and cool-down time were not considered as training exposure time.

2.3. Shoulder ROM test

Then, Shoulder ROM tests comprising of angles of shoulder IR and ER (Shanley et al., 2011; Wilk et al., 2015) were performed. Participants were positioned supine on a standard examination table, their shoulders positioned in 90° of abduction and their elbows positioned in 90° of flexion. The examiner stabilized the participants' scapula and placed their forearms in the neutral position. For generating maximum passive ER and IR, the examiner then pushed the forearms with the humerus rotation posteriorly (Fig. 1) and anteriorly (Fig. 2) respectively until the point where no more humerus rotation movement would occur without the movement of the scapula or the participant reported pain in the shoulder joint. The second examiner measured the start-stop angles of ER and IR on both shoulder joints of the participants. The loss of shoulder IR angle of the dominant side comparing with the nondominant side was defined as glenohumeral internal rotation deficit (GIRD) while increased shoulder ER angle was defined as ER gain. The sum of shoulder ER and IR angles of each side individually was defined as total ROM (TROM) of the side. TROM is proposed as a more complete evaluation of the overhead sports players' shoulder motion (Aaron Hellem et al., 2019). The loss of TROM angle of the dominant shoulder comparing with the nondominant shoulder was defined as TROM loss (Rose and Noonan, 2018; Achenbach et al., 2020). A surgeon with more than 20 years of experience and a doctoral candidate in sports medicine performed the tests.

Inclusion criteria of participants were as follows: (1) participants and their guardian that had completed an informed consent form; (2) playing badminton at a national level competition; (3) training per week regularly. Exclusion criteria of participants were as follows: (1) reported present shoulder/elbow injury, any shoulder/elbow injury within the last year, or shoulder/elbow surgery; (2) have not completed the questionnaire and/or shoulder ROM tests.

2.4. Statistical methods

The normality of the collected data was examined by Shapiro-Wilk test. Independent samples t-tests (height, weight, BMI, shoulder IR, shoulder ER, nondominant shoulder TROM, and shoulder ER gain) and Mann-Whitney *U* test (age, training hours per day, training days per week, years of badminton experience, dominant TROM, and GIRD) were conducted to identify intergroup differences between the elementary school-age players group and the university players group. Mann-Whitney *U* test was used for further analysis as the two groups were

Fig. 1. Shoulder ER measurement, scapula stabilized.

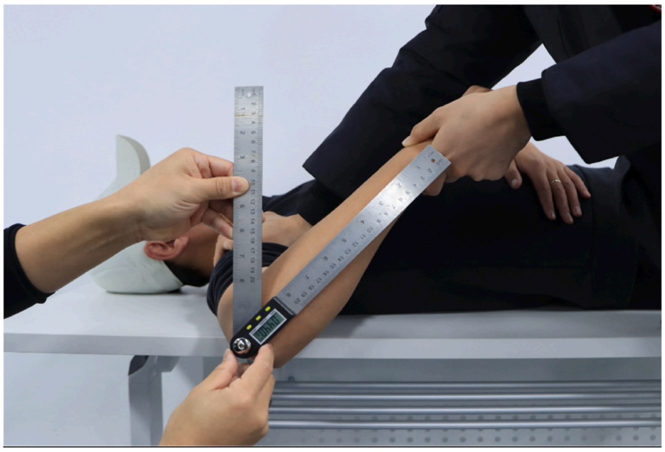

Fig. 2. Shoulder IR measurement, scapula stabilized.

broken down by sex. *Cohen's d* effect sizes were calculated and were interpreted using descriptors for magnitudes of *d* as 0.2–0.5 = small, 0.5–0.8 = moderate, and >0.8 = large, respectively (Cohen, 1988). Pearson correlation coefficient was used to examine the association between the shoulder ROM characteristics and basic parameters. A priori power analysis was conducted to calculate the sample size by G*power. A minimum sample size of 21 participants per age group was necessary to detect the significant differences in the means with large effect size (effect size = 0.9; power = 80%; two-tail α of 0.05).

3. Results

Seven university badminton players with upper limbs injuries were excluded. Therefore, 22 healthy elementary school-age badminton players were assigned as the elementary school-age players group and 45 healthy university badminton players were assigned as the university players group. Table 1 shows baseline data of the two groups. Significant differences in age, height, weight, BMI, badminton experiences, training days per week, training hours per day, and training hours per week were detected between the elementary school-age and university players groups.

Table 2 shows means, standard deviations (SD), 95% confident interval (CI) and inferential statistics for shoulder IR, ER, TROM, TROM loss, GIRD, and ER gain for the intergroup comparison between the elementary school-age and university players groups. Significant differences and large effects were detected for IR of both sides and TROM of both sides between the two groups. The university players group presented significantly greater mean values of IR of both sides and TROM of both sides than the elementary school-age players group. Significant differences and moderate effects between the two groups were detected for dominant ER and TROM loss. The elementary school-age players group presented significantly greater mean angle values of dominant shoulder ER, and TROM loss than the university players group.

Table 3 shows the profiles of shoulder ROM in the two groups broken down by sex. In the elementary school-age players group, no significant differences in all the variables of shoulder ROM were detected between the males and the females. In the university players group, there were significant differences of IR and TROM of both sides between the males and the females. Regarding the male badminton players, significant differences of shoulder IR of both sides (dominant, $p < 0.001$, *Cohen's d* = 2.03/large effects; nondominant, $p < 0.001$, *Cohen's d* = 2.03/large effects), ER of dominant side ($p = 0.033$, *Cohen's d* = 0.82/large effects), and TROM of both sides (dominant, $p < 0.001$, *Cohen's d* = 1.78/large effects; nondominant, $p = 0.001$, *Cohen's d* = 1.38/large effects) existed between the elementary school-age and university players. Regarding the female badminton players, significant differences of shoulder IR of both sides ($p = 0.007$, *Cohen's d* = 1.03/large effects; $p = 0.035$, *Cohen's d* = 0.75/moderate effects) and TROM of dominant side ($p = 0.034$, *Cohen's d* = 0.77/moderate effects) existed between the elementary school-age and university players.

4. Discussion

In this study, we set out to study the differences in shoulder function between elementary school-age and university badminton players to provide reference values for coaches, physicians, and physiotherapists to facilitate development of child badminton players and to ensure badminton players injury-free badminton participation. As far as we know, this study might be the first to compare shoulder ROM between shoulder injury-free elementary school-age and university badminton players. The new unique and vital findings are as follows: (1) significant differences of shoulder IR of both sides, dominant ER, TROM of both sides, and TROM loss existed between the elementary school-age and university badminton players, (2) regardless of sex, significant differences of shoulder IR and dominant TROM existed between the elementary school-age and university badminton players, (3) no significant differences in GIRD, ER gain, and TROM loss existed among the male elementary school-age and university badminton players as well as among the female elementary school-age and university badminton players.

Only one past study of shoulder rotational profiles in healthy badminton players showed that youth elite female badminton players (mean age: 16.6 years) presented significantly greater shoulder IR than male badminton players (mean age 17.1 years) (Couppé et al., 2014). In terms of other overhead motion sports, past studies revealed that 7-11 year-old child baseball players aged presented significantly greater shoulder ER (Shanley et al., 2015; Picha et al., 2016) and TROM (Picha et al., 2016) compared with 12–18 year-old youth baseball players. A previous study on humeral retroversion accounts for shoulder IR showed that when excluding the contributions of humeral retroversion to shoulder IR, 6-10 year-old youth baseball players showed greater shoulder IR than 11-13 year-old junior high school players, 14-15 year-old junior baseball players, and 16-18 year-old varsity baseball players (Hibberd et al., 2014). Another previous study on softball players showed that youth softball players presented greater shoulder IR

Table 1
Baseline characteristics of the elementary school-age players and the university players.

Variables	Elementary school-age players (n = 22)		University players (n = 45)		Between groups	
	Mean (SD)	95% CI	Mean (SD)	95% CI	*p*	F
Age, yr	9.23 (1.66)	8.49–9.97	19.64 (1.21)	19.28–20.00	<0.001	–
Height, cm	143.46 (10.83)	138.66–148.26	164.91 (7.37)	162.70–167.12	<0.001	2.44
Weight, kg	32.41 (7.58)	29.05–35.77	59.83 (7.46)	57.59–62.07	<0.001	0.05
BMI	15.54 (1.85)	14.72–16.36	21.94 (1.58)	21.47–22.41	<0.001	0.46
Badminton experiences, yr	1.09 (1.22)	0.55–1.63	11.02 (2.70)	10.21–11.83	<0.001	–
Days/per week	1.16 (0.32)	1.02–1.30	5.20 (0.62)	5.01–5.39	<0.001	–
Hours/per day	1.96 (0.24)	1.85–2.07	3.31 (0.50)	3.16–3.46	<0.001	–
Hours/per week	2.26 (0.62)	1.99–2.53	17.14 (2.84)	16.29–17.99	<0.001	–

Abbreviations: BMI, body mass index; SD, standard deviation; CI, confidence interval.

Table 2
Differences in shoulder range of motion variables between the elementary school-age players and the university players.

Variables	Elementary school-age players (n = 22)		University players (n = 45)		Between groups		
	Mean (SD)	95% CI	Mean (SD)	95% CI	F	*p*	Cohen's *d*
IR,°(D)	97.67 (9.78)	93.33–102.01	77.78 (14.70)	73.36–82.20	1.04	<0.001	1.59
IR,°(ND)	104.70 (10.54)	100.03–109.37	88.89 (12.98)	84.99–92.79	0.65	<0.00	1.34
ER,°(D)	126.30 (16.85)	118.83–133.77	115.98 (9.74)	113.05–118.91	14.30	0.013	0.75
ER,°(ND)	118.21 (15.12)	111.51–124.91	111.22 (10.03)	108.21–114.23	7.15	0.058	0.54
TROM,°(D)	222.97 (23.94)	212.36–233.58	193.76 (19.07)	188.03–199.49	–	<0.001	1.35
TROM,°(ND)	222.90 (22.40)	213.04–232.76	200.10 (16.73)	195.07–205.13	6.21	0.001	1.15
TROM loss,°	−0.06 (10.43)	−4.68–4.56	6.34 (12.90)	2.46–10.22	0.75	0.047	0.55
GIRD,°	8.02 (6.72)	5.04–11.00	11.10 (11.36)	7.69–14.51	–	0.25	0.33
ER gain,°	8.09 (7.20)	4.90–11.28	4.76 (8.68)	2.15–7.37	0.31	0.13	0.42

Abbreviations: SD, standard deviation; CI, confidence interval; IR, internal rotation; ER, external rotation; TROM, total range of motion; GIRD, glenohumeral internal rotation deficit; D, dominant; ND, nondominant.

Table 3
Comparisons of shoulder range of motion variables by age and sex.

Variables	Elementary school-age players (n = 22)				University players (n = 45)			
	Males (n = 10)	Females (n = 12)	Between sex		Males (n = 22)	Females (n = 23)	Between sex	
	Mean (SD)	Mean (SD)	*p*	Cohen's *d*	Mean (SD)	Mean (SD)	*p*	Cohen's *d*
IR,°(D)	98.38 (8.63)[††]	95.25 (10.81)[††]	0.468	0.32	72.50 (16.19)*	82.84 (11.28)	0.016	0.75
IR,°(ND)	106.72 (9.21)[††]	103.01 (11.65)[a]	0.424	0.35	83.99 (13.05)*	93.57 (11.31)	0.012	0.71
ER,°(D)	129.15 (16.23)[a]	123.92 (17.69)	0.482	0.31	115.75 (9.60)	116.20 (10.09)	0.877	0.05
ER,°(ND)	118.19 (16.63)	118.23 (14.49)	0.996	0.003	108.44 (10.30)	113.87 (9.21)	0.069	0.56
TROM,°(D)	227.53 (23.02)[††]	219.17 (25.02)[a]	0.391	0.37	188.24 (20.33)*	199.05 (16.54)	0.025	0.71
TROM,°(ND)	224.91 (23.50)[††]	221.23 (22.35)	0.711	0.16	192.43 (16.14)**	207.44 (14.00)	0.002	0.96
TROM loss,°	−2.62 (10.76)	2.07 (10.09)	0.309	0.45	4.19 (11.20)	8.40 (14.28)	0.279	0.33
GIRD,°	8.34 (7.23)	7.76 (6.58)	0.817	0.01	11.50 (10.81)	10.73 (12.09)	0.547	0.18
ER gain,°	10.96 (6.11)	5.69 (7.39)	0.087	0.77	7.31 (6.03)	2.33 (10.17)	0.053	0.59

Abbreviations: SD, standard deviation; IR, internal rotation; ER, external rotation; TROM, total range of motion; GIRD, glenohumeral internal rotation deficit; D, dominant; ND, nondominant.
[a] *p*-value <0.05 between the two groups; ††*p*-value <0.01 between the two groups; **p*-value <0.05 between the male and female; ***p*-value <0.01 between the male and female.

and ER than college softball players (Friesen et al., 2020). In addition, literature of healthy people showed that 3-9 year-old children presented greater shoulder IR and ER compared with 10–19 year-old adolescents, 20-59 year-old adults, and older adults over 60 years (McKay et al., 2017). In agreement with the findings of the previous studies, the elementary school-age badminton players presented significantly greater shoulder ROM (IR, ER, and TROM) compared with the university badminton players in this study which can be explained by the different musculoskeletal maturation levels. Additionally, as well as previous studies (Achenbach et al., 2020; Couppé et al., 2014), controlling for age, significant differences in shoulder IR and TROM of both sides existed between the male and female university badminton players. These findings of this study are important when explaining clinical examinations of shoulder ROM, IR, and ER examinations should be assessed based on age- and sex-related norms (Hibberd et al., 2014) rather than comparing all badminton players to the same criteria.

Regarding bilateral differences in shoulder ROM, past studies of baseball revealed that there were no significant differences in TROM loss and GIRD between youth players, junior players, and varsity players (Hibberd et al., 2014; Shanley et al., 2015). A past study of handball showed no significant difference of GIRD between handball players under-13 years and those under-15 years (Fernandez-Fernandez et al., 2022). Another study of tennis revealed that no significant differences in GIRD and ER gain existed between male and female tennis players; no significant differences in GIRD, ER gain, and TROM loss existed between tennis players under-16 years, 16–18 years, and over-18 years (Kibler et al., 1996). In agreement with the previous studies, our studies found that no significant differences in GIRD, ER gain, and TROM loss existed in badminton players broken down by sex and age. On the contrary, a tennis study revealed that male tennis players under-15 years showed greater significant GIRD compared to those under-13 years while no such significant differences in female tennis players (Fernandez-Fernandez et al., 2019). Several male tennis players under-15 years of the study presented GIRD more than 20° which means they were at the risk window of shoulder injury (Burkhart et al., 2003) that might cause the findings of the study to differ from our studies.

Healthy overhead sports athletes regularly present with soft-tissue and musculoskeletal adaptations of the dominant upper limb due to the repeated load of overhead motion. These changes, including humeral retroversion, musculoskeletal and soft-tissue tightness or laxity, are represented as changers in shoulder ROM, leading to asymmetry of shoulder ROM (including GIRD, ER gain, and TROM loss) as a consequence (Hibberd et al., 2014; Reuther et al., 2018). GIRD, ER gain, and TROM loss are commonly used to predict risk for shoulder injury as overhead motion athletes who show GIRD > 20° or 25°, ER gain < 5°, or TROM loss > 5° (Wilk et al., 2015; Camp et al., 2017), are more susceptible to shoulder injury. According to these judgements, although the participants of our studies have not experienced a history of shoulder injury, some female adult badminton players (mean TROM loss: 8.40°, mean ER gain: 2.33°) were at the risk of shoulder injury. In addition, GIRD and ER gain occurred in both elementary school-age and university badminton players. However, no significant differences in GIRD and ER gain between the elementary school-age and university badminton players were found even the university badminton players expensed significantly more hours on badminton training. Based on the results, we speculated that GIRD and ER gain may develop at a young age and persist through adolescence to adulthood in overhead athletes. Hence, coaches and physiotherapists should examine symmetry of shoulder ROM among badminton players regardless of age regularly, and could eliminate shoulder ROM asymmetries using neuromuscular training such as stretching and balance training (Sakata et al., 2019).

4.1. Limitations

Some limitations should be acknowledged. A large number of elementary school-age and university badminton players is needed to verify the findings of this study, and to detect the cut-off value of shoulder function indexes for badminton shoulder injury screening. In addition, this study is a cross-sectional study that a prospective study is needed to verify the findings of this study. Dynamic postural stability and shoulder rotation strength have been revealed to be associated with shoulder injury among handball and swimming players (Aguado--Henche et al., 2018; Achenbach et al., 2020; Barbosa et al., 2023). Likewise, poor posterior shoulder muscle strength increases the risk of throwing related pain in baseball players (Trakis et al., 2008). However, in our studies, we did not perform muscular functional tests among the badminton players. In addition, shoulder structure limiting the ROM, such as muscle cross-sectional area and humeral retroversion was not evaluated. In future, the comparisons of shoulder function between badminton players who have shoulder injury experiences and those without should be studied. Moreover, shoulder function of large number badminton players should be compared with the normative values of the same aged and sex population. In addition, we attempted to examine the association of the shoulder ROM with the basic characteristics using Pearson correlation coefficient. As well as age, a negative association between years of badminton experience and shoulder IR of both sides, ER of both sides, and TROM of both sides was found. A positive association ($p = 0.04$) between age and TROM loss was found while no association was found between years of badminton experience and TROM loss. In future, studies should be performed the associations among large number of badminton players.

5. Conclusion

This study is the first to provide reference values for shoulder function in badminton players and investigate the differences on shoulder ROM in badminton players by maturation (6–12 years and 18–22 years) and sex (males and females). Compared with university badminton players, elementary school-age badminton players showed significantly greater shoulder IR and TROM of both sides and dominant ER while significantly smaller TROM loss. While there was a decline in IR and ER from child to adult badminton players, GIRD and ER gain remained constant across age, indicating that keeping symmetry of shoulder ROM may contribute to prevent shoulder injury.

6. Clinical relevance

1. Shoulder ROM changed along with age in badminton players, especially in males.
2. Shoulder IR and TROM reduced significantly from child to adult badminton players.
3. GIRD and ER gain were similar in child and university badminton players.
4. The findings of this study will assist coaches and clinicians to find the deficits of shoulder ROM which may lead to shoulder injuries, to improve injury prevention programs and to implement the injury prevention program appropriately.

Funding

This research was partially financial supported by "Badminton World Federation (BWF)" and "Humanities and Social Science Foundation of Ministry of Education (Grant NO. 20YJC890009)".

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

CRediT authorship contribution statement

Xiao Zhou: Writing – original draft, Software, Methodology, Investigation, Funding acquisition, Formal analysis. **Kazuhiro Imai:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Zhuo Chen:** Software, Formal analysis. **Xiao-Xuan Liu:** Writing – review & editing, Investigation. **Eiji Watanabe:** Supervision, Resources, Project administration, Conceptualization.

Declaration of competing interest

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this manuscript. The manuscript has been submitted solely to this journal and is not published, in press, or submitted elsewhere of any part of the work including details of any presentation of the study as an abstract at a professional meeting. As Corresponding Author, I confirm that the manuscript has been read and approved for submission by all the named authors.

Acknowledgements

"Badminton World Federation (BWF)" and "Humanities and Social Science Foundation of Ministry of Education (Grant NO. 20YJC890009)" are acknowledged for the partial financial support provided. We really appreciate BWF in conducting sports science research. We gratefully acknowledgement the Japan Schoolchildren Badminton Federation, Senshu University and Waseda University for that collaborated with us on data collection.

References

Achenbach, L., Laver, L., Walter, S., Zeman, F., Kuhr, M., Krutsch, W., 2020. Decreased external rotation strength is a risk factor for overuse shoulder injury in youth elite handball athletes. Knee Surg. Sports Traumatol. Arthrosc. 28, 1202–1211. https://doi.org/10.1007/s00167-019-05493-4.

Aguado-Henche, S., Slocker de Arce, A., Carrascosa-Sánchez, J., Bosch-Martín, A., Cristóbal-Aguado, S., 2018. Isokinetic assessment of shoulder complex strength in adolescent elite synchronized swimmers. J. Bodyw. Mov. Ther. 22, 968–971. https://doi.org/10.1016/j.jbmt.2018.01.018.

Aragon, V.J., Oyama, S., Oliaro, S.M., Padua, D.A., Myers, J.B., 2012. Trunk-rotation flexibility in collegiate softball players with or without a history of shoulder or elbow injury. J. Athl. Train. 47, 507–515. https://doi.org/10.4085/1062-6050-47.3.11.

Arora, M., Shetty, S.H., Khedekar, R.G., Kale, S., 2015. Over half of badminton players suffer from shoulder pain: is impingement to blame? J. Orthop. Surg. Res. 2, 33–36. https://doi.org/10.1016/j.jajs.2014.12.006.

Astolfi, M.M., Struminger, A.H., Royer, T.D., Kaminski, T.W., Swanik, C.B., 2015. Adaptations of the shoulder to overhead throwing in youth athletes. J. Athl. Train. 50, 726–732. https://doi.org/10.4085/1062-6040-50.1.14.

Barbosa, G.M., Saccol, M.F., Pinheiro, S.M., Costa, Í.D.S., Camargo, P.R., Scattone, Silva, R., 2023. Stability, performance and upper and lower extremities range of motion in elite beach handball athletes: a cross sectional study. J. Bodyw. Mov. Ther. 36, 178–184. https://doi.org/10.1016/j.jbmt.2023.04.023.

Brahms, B.V., 2014. In: Badminton Handbook: Training, Tactics, Competition. Meyer Verlag; P. 41–3, pp. 101–2. (ISBN NO978-1782550426 .).

Burkhart, S.S., Morgan, C.D., Kibler, W.B., 2003. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. Arthroscopy 19, 404–420. https://doi.org/10.1053/jars.2003.50128.

Brener, N.D., Mcmanus, T., Galuska, D.A., Lowry, R., Wechsler, H., 2003. Reliability and validity of self-reported height and weight among high school students. J. Adolesc. Health 32, 281–287. https://doi.org/10.1016/s1054-139x(02)00708-5.

Camp, C.L., Tubbs, T.G., Fleisig, G.S., Dines, J.S., Dines, D.M., Altchek, D.W., et al., 2017. The relationship of throwing arm mechanics and elbow varus torque: within-subject variation for professional baseball pitchers across 82,000 throws. Am. J. Sports Med. 45, 3030–3035. https://doi.org/10.1177/0363546517719047.

Cejudo, A., 2022. Risk factors for, and prediction of, shoulder pain in young badminton players: a prospective cohort study. Int. J. Environ. Res. Publ. Health 19, 13095. https://doi.org/10.3390/ijerph192013095.

Cohen, J., 1988. The t test for means. Statistical Power Analysis for the Behavioral Sciences, second ed. Lawrence Erlbaum Associates, Hillsdale, NJ, p. 20. e27 (ISBN NO. 9780805802832).

Connor, G.S., Tremblay, M., Moher, D., Gorber, B., 2007. A comparison of direct vs. self-report measures for assessing height, weight and body mass index: a systematic review. Obes. Rev. 8 (4), 307–326. https://doi.org/10.1111/j.1467-789X.2007.00347.x.

Couppé, C., Thorborg, K., Hansen, M., Fahlström, M., Bjordal, J.M., Nielsen, D., Baun, M., Storgaard, M., Magnusson, S.P., 2014. Shoulder rotational profiles in young healthy elite female and male badminton players. Scand. J. Med. Sci. Sports 24, 122–128. https://doi.org/10.1111/j.1600-0838.2012.01480.x.

Fahlström, M., Söderman, K., 2007. Decreased shoulder function and pain common in recreational badminton players. Scand. J. Med. Sci. Sports 17, 246–251. https://doi.org/10.1111/j.1600-0838.2006.00562.x.

Fahlstrom, M., YeapJ, S., AlfredsonH, SodermanK, 2006. Shoulder pain–a common problem in world-class badminton players. Scand. J. Med. Sci. Sports 16, 168–173. https://doi.org/10.1111/j.1600-0838.2004.00427.x.

Fernandez-Fernandez, J., Nakamura, F.Y., Moreno-Perez, V., Lopez-Valenciano, A., Del-Coso, J., Gallo-Salazar, C., Barbado, D., Ruiz-Perez, I., Sanz-Rivas, D., 2019. In: Age and sex-related upper body performance differences in competitive young tennis players. PLoS One. 14: e0221761. https://doi.org/10.1371/journal.pone.0221761.

Fernandez-Fernandez, J., Granacher, U., Martinez-Martin, I., Garcia-Tormo, V., Herrero-Molleda, A., Barbado, D., Garcia-Lopez, J., 2022. Physical fitness and throwing speed in U13 versus U15 male handball players. BMC Sports Sci Med Rehabil 14, 113. https://doi.org/10.1186/s13102-022-00507-0.

Friesen, K., Downs, J., Wasserberger, K., Shannon, D., Oliver, G.D., 2020. Glenohumeral and hip range of motion in youth softball athletes. Int. J. Sports Med. 41, 59–64. https://doi.org/10.1055/a-1019-7742.

Hellem, A., Shirley, M., Schilaty, N., Dahm, D., 2019. Review of shoulder range of motion in the throwing athlete: Distinguishing normal adaptations from Pathologic deficits. Curr Rev Musculoskelet Med 12, 346–355. https://doi.org/10.1007/s12178-019-09563-5.

Hibberd, E.E., Oyama, S., Myers, J.B., 2014. Increase in humeral retrotorsion accounts for age-related increase in glenohumeral internal rotation deficit in youth and adolescent baseball players. Am. J. Sports Med. 42, 851–858. https://doi.org/10.1177/0363546513519325.

Ishigaki, T., Ishida, T., Samukawa, M., Saito, H., Ezawa, Y., Hirokawa, M., et al., 2015. Does restriction of glenohumeral horizontal adduction reflect posterior capsule thickening of the throwing shoulder? J. Phys. Ther. Sci. 27, 1299–1302. https://doi.org/10.1589/jpts.27.1299.

Jørgensen, U., Winge, S., 1987. Epidemiology of badminton injuries. Int. J. Sports Med. 8, 379–382. https://doi.org/10.1055/s-2008-1025689.

Kibler, W.B., Chandler, T.J., Livingston, B.P., Roetert, E.P., 1996. Shoulder range of motion in elite tennis players. Effect of age and years of tournament play. Am. J. Sports Med. 24, 279–285. https://doi.org/10.1177/036354659602400306.

Kuntze, G., Sellers, W.I., Mansfield, N., 2009. Bilateral ground reaction forces and joint moments for lateral sidestepping and crossover stepping tasks. J. Sports Sci. Med. 8, 1–8.

Lo, D., Stark, K., 1991. Sports performance series: the badminton overhead shot. Strength Cond J 13, 6–15. https://bit.ly/30Q2btO.

McKay, M.J., Baldwin, J.N., Ferreira, P., Simic, M., Vanicek, N., Burns, J., 2017. Normative reference values for strength and flexibility of 1,000 children and adults. Neurology 88, 36–43. https://doi.org/10.1212/WNL.0000000000003466.

Ortega, F.B., Ruiz, J.R., Castillo, M.J., Sjöström, M., 2008. Physical fitness in childhood and adolescence: a powerful marker of health. Int. J. Obes. 32, 1–11. https://doi.org/10.1038/sj.ijo.0803774.

Picha, K.J., Harding, J.L., Bliven, K.C., 2016. Glenohumeral and hip range-of-motion and strength measures in youth baseball athletes. J. Athl. Train. 51, 466–473. https://doi.org/10.4085/1062-6050-51.7.09.

Reeser, J.C., Joy, E.A., Porucznik, C.A., Berg, R.L., Colliver, E.B., Willick, S.E., 2010. Risk factors for volleyball-related shoulder pain and dysfunction. Pm&r 2, 27–36. https://doi.org/10.1016/j.pmrj.2009.11.010.

Reuther, K.E., Sheridan, S., Thomas, S.J., 2018. Differentiation of bony and soft-tissue adaptations of the shoulder in professional baseball pitchers. J Shoulder Elbow Sur 27, 1491–1496. https://doi.org/10.1016/j.jse.2018.02.053.

Rose, M.B., Noonan, T., 2018. Glenohumeral internal rotation deficit in throwing athletes: current perspectives 9, 69–78. https://doi.org/10.2147/OAJSM.S138975. J Sports Med.

Sakata, J., Nakamura, E., Suzuki, T., Suzukawa, M., Akeda, M., Yamazaki, T., et al., 2019. Throwing injuries in youth baseball players: can a prevention program Help? A Randomized controlled Trial. Am. J. Sports Med. 47, 2709–2716.

Sekiguchi, T., Hagiwara, Y., Yabe, Y., Tsuchiya, M., Itaya, N., Yoshida, S., Yano, T., Sogi, Y., Suzuki, K., Itoi, E., 2020. Restriction in the hip internal rotation of the stride leg is associated with elbow and shoulder pain in elite young baseball players. J. Shoulder Elbow Surg. 29, 139–145. https://doi.org/10.1016/j.jse.2019.07.004.

Shanley, E., Kissenberth, M.J., Thigpen, C.A., Bailey, L.B., Hawkins, R.J., Michener, L.A., Tokish, J.M., Rauh, M.J., 2015. Preseason shoulder range of motion screening as a predictor of injury among youth and adolescent baseball pitchers. J Shoulder Elbow Sur 24, 1005–1013. https://doi.org/10.1016/j.jse.2015.03.012.

Shanley, E., Rauh, M.J., Michener, L.A., Ellenbecker, T.S., Garrison, J.C., Thigpen, C.A., 2011. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. Am. J. Sports Med. 39 (9), 1997–2006. https://doi.org/10.1177/0363546511408876.

Shariff, A.H., George, J., Ramlan, A.A., 2009. Musculoskeletal injuries among Malaysian badminton players. Singapore Med J 50, 1095–1097.

Trakis, J.E., McHugh, M.P., Caracciolo, P.A., Busciacco, L., Mullaney, M., Nicholas, S.J., 2008. Muscle strength and range of motion in adolescent pitchers with throwing-related pain: implications for injury prevention. Am. J. Sports Med. 36, 2173–2178.

Wilk, K.E., Macrina, L.C., Fleisig, G.S., Aune, K.T., Porterfield, R.A., Harker, P., Evans, T. J., Andrews, J.R., 2015. Deficits in glenohumeral passive range of motion increase risk of shoulder injury in professional baseball pitchers: a prospective study. Am. J. Sports Med. 43, 2379–2385. https://doi.org/10.1177/0363546515594380.

Yung, P.S., Chan, R.H., Wong, F.C., Cheuk, P.W., Fong, D.T., 2007. Epidemiology of injuries in Hong Kong elite badminton athletes. Res. Sports Med. 15, 133–146. https://doi.org/10.1080/15438620701405263.

Zhou, X., Imai, K., Chen, Z., Liu, X.X., Watanabe, E., 2022. Mechanism for shoulder pain and injury in elite badminton players. Int J Sports Med Rehabil 5, 25. https://doi.org/10.28933/ijsmr-2022-06-150.

Zhou, X., Imai, K., Liu, X.X., Watanabe, E., 2021. Epidemiology and pain in elementary school-aged players: a survey of Japanese badminton players participating in the national tournament. Sci. Rep. 11, 6459. https://doi.org/10.1038/s41598-021-85937-5.