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Mechanism for shoulder pain and injury in elite badminton players

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ABSTRACT

Purpose: to detect the mechanisms for shoulder pain and injury during forehand overhead stroke using the questionnaire and 2D video analysis. **Methods and Materials:** Participants were 48 university badminton players (aged 18-22) with national tournament level who had no current shoulder injuries. A questionnaire investigation and a forehand overhead clear test were performed. The angle of arm slot at the moment of hit was calculated from 2D videos analysis using Image J software. Data were compared between badminton players with shoulder problems and those without. **Results:** There were 6 badminton players reported a history of shoulder injury that all of them were offensive players. 11 badminton players (8 offensive players and 3 defensive players) reported present shoulder pain that offensive players showed 7.33 times more likely to sustain present shoulder pain than defensive players (OR = 7.33, 95%CI: 1.55-34.70, p = 0.007; Fisher's Exact test: p = 0.012). Moreover, offensive players with present shoulder pain had significantly greater score of VAS (visual analog scale) than defensive players (74.0 mm ± 14.2 mm vs 44.6 mm ± 24.4 mm, p = 0.04). Significant differences of arm slot angle were found among badminton players with shoulder pain free, history of shoulder injury and present shoulder pain (35.74o ± 4.85° vs 42.90° ± 11.89 o vs 37.81° ± 6.40°, F = 3.27, p = 0.047). **Conclusion:** Offensive badminton players are more likely to suffer from shoulder injury and strong intensity of shoulder pain. Greater arm slot angle of hit phase might be the mechanism leading to shoulder problems in badminton players. For improving shoulder re-injury prevention and rehabilitation protocols, our findings should be taken into consideration by physiotherapists, physicians and coaches.

Keywords: national level badminton players, forehand overhead stroke, 2D analysis, arm slot angle, VAS

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Shoulder pain and injury are common in badminton players mostly caused by forehand overhead stroke. Badminton forehand overhead stroke is recognized as the fundamental and the most typical skill requiring joint coordination and balance ability to perform body core mass shifting, trunk rotation and upper limb rotation simultaneously [1,2]. Improper (poor or inexperienced) forehand overhead motions producing abnormal biomechanics that not only negatively affect overhead motion performance, but also lead to injuries [3,4]. Conventionally, forehand overhead stroke is divided into four phases, that is, preparation, acceleration, hit, and follow-through (Fig. 1A).

The phase of the preparation takes approximately three quarters of one second to perform the motions as following: (1) moving the center of gravity followed by the dominant side leg step in a posterior and slightly lateral direction, (2) the shoulder is extended and adducted and the wrist is extended leading to the racket-head to point upward, (3) pointing the nondominant hand toward the shuttlecock to sustain the balance posture. Acceleration is a highly dynamic phase consisting of a backswing and a forward swing. Two factors of the acceleration phase dominate the effects of hit: (1) adequate performance of the backswing forward swing which need players perform weight shift, trunk rotation, racket-head backswing, shoulder adduction and forearm rotation smoothly and simultaneously, (2) the length of the kinematic chain at the moment of hitting the shuttlecock. From preparation to hit, upper limb muscles, such as biceps brachii, triceps brachii, extensor carpi radialis and flexor carpi ulnaris, were activated. At a constant time before the phase of hit, the peak electromyographic amplitude appears in the triceps brachii, extensor carpi radialis, flexor carpi ulnaris and trapezius [5]. After the hit, players perform the follow-through phase to dissipate excess momentum by crossing the racket to the contralateral side while swing the rear foot to the front foot [2,6,7].

Poor overhead motion techniques are regarded as mechanisms to increase injury risk in overhead motion sports. A study of tennis revealed that compared with tennis players without shoulder injury history, tennis players with shoulder injury history had significantly less humeral abduction angle at the end of acceleration during serve [8]. Studies of baseball showed that baseball pitchers with greater arm slot angle at the instant of ball release, or improper trunk rotation sequence might be vulnerable to shoulder injuries [9,10].

As for badminton players, our previous studies showed that training hours of per day, decreased trunk rotation and weak balance ability were risk factors for shoulder pain [11,12]. Although previous badminton studies adopted biomechanics to examine forehand overhead stroke motion [5,13,14], no studies on the association of forehand overhead stroke motion phases and shoulder pain and injury were found. Additionally, video analysis has high reliability to evaluate sports motor skills, including phases of overhead motion [15,16], however, such studies of badminton were scarce.

Proper forehand overhead stroke techniques and coaching approaches are important for coaches and badminton players to decrease the joint loading and possibly prevent and rehabilitate upper limb injuries and pain. The purpose of this study was to detect the mechanisms for shoulder pain and injury during forehand overhead stroke using the questionnaire asking the characteristics and the type of player (offensive/defensive) and 2D video analysis.

Methods

Participants

52 university badminton players (26 males and 26 females) belonging to Kanto University Badminton Association were recruited from August 2018 to March 2019. This study was approved by Ethical Committee of the Graduate School of Arts and Sciences, the University of Tokyo, Japan (Notification Number 602-2 July 26, 2018). All the design complied with the declaration of Helsinki. Informed consent forms written by all the participants have been obtained.

Questionnaire and badminton test

A self-reported questionnaire asked for baseline consisting of gender, age, height, weight, dominant hand, years of badminton experienced playing, training hours of per day, training days of per week, warm-up, injury/pain histories related to badminton, types of players (offensive players or defensive players), and playing categories (single, double or both).

A forehand overhead clear test was performed after warm-up to examine the arm slot angle (angle of the arm relative to the ground at the instant of hit a shuttlecock) (Fig. 1B) and was recorded using a high speed digital video camera with 240 frame per second slow motion model (FDR-AX700, Sony, Japan). 2D video analysis of overhead motion has been demonstrated high reliability using Image J software for two-dimensional joint and segment angles analysis [16]. The arm slot angle was digitized using Image J software. The instant of hit was identified as the first frame in which the shuttlecock contacted the racket. The arm slot angle was calculated by a research assistant who did not have playing/coaching badminton experience, but was trained to measure the angle. The high speed digital video camera was placed in the middle area of the court to enable the forehand overhead stroke to be recorded. The bubble level of tripod and the grid on the camera video display were used to ensure that the camera was level. A badminton racket with a higher tension of 28 lb was used. The shuttlecocks with an international speed metric of 3/77 were selected. Due to the requirement of the reproducible serve for forehand overhead clear test, the serve was performed by the same badminton players. Three trials for forehand overhead clear were performed by the participants using maximal power. Mean arm slot angle of three trials of forehand overhead stroke was used to analyze. After forehand overhead clear test, all the participants were asked immediately “Do you have any shoulder pain during the forehand overhead stroke?”. If “yes”, the participants were also asked “Please record the location of shoulder pain (anterior, outside or posterior), and mark pain intensity in the visual analog scale (VAS)” and “Which phases of forehand overhead stroke motor skill (preparation, acceleration, hit and follow-through) caused your shoulder pain?”

Definition of injury and pain

For keeping consistency in the definitions and enabling data across studies to be compared, the definitions of sports injury published by IOC (International Olympic Committee) [17] were used to make the judgement criteria in this study. An injury was defined as any physical complaint sustained during badminton match or training causing one or more of the three judgement criteria as follows: (1) have to stop the current badminton match or training immediately, (2) cannot presence in subsequent badminton match or training, and (3) require medical attention irrespective of the potential absence from match or training. Pain was defined as any physical painful complaint or discomfort with sustained badminton capacity. Participants with lacking data were excluded.

Statistical methods

SPSS and R software were adopted for statistical analysis. Shapiro-Wilk test was used to examine normality of baseline data. One-way analysis of variance (ANOVA) followed by Bonferroni test was used for statistical analysis on groups (pain free group, injury group and present pain group). Comparisons of the prevalence of shoulder pain between categorial variables were analyzed using χ^2 test and Fisher's exact test. Mann-Whitney U-test was used to detect present shoulder pain intensities between different player types. Comparisons of the differences between offensive and defensive players without shoulder problems were analyzed using independent samples t-tests and Mann-Whitney U-test. For statistical analysis, the level of significance was set as below 0.05.

Results

After excluding lacking data (n = 4), 48 participants of 24 males and 24 females were included in this study. All the participants' dominant sides were right sides. Among all the participants, 22 participants were offensive players while the rest of the 26 participants were defensive players. 31 participants without any shoulder pain were divided into pain free group, while 6 participants with shoulder injury experience were divided into injury group and 11 participants with present shoulder pain were divided into present pain group. The results of baseline parameters are shown in Table 1 and 2. Table 1 shows that 6 injured players were all offensive players. Using χ^2 test and Fisher's exact test for categorical variables analysis, we found that the participants with history of shoulder pain showed 13.846 times more likely to sustain present shoulder pain (OR = 13.846, 95%CI: 1.572-121.985, $p = 0.005$, Fisher's Exact test: $p = 0.006$) than those without. Moreover, compared with defensive players, offensive players showed 7.3 times more likely to sustain present shoulder pain (OR = 7.333, 95%CI: 1.550-34.695, $p = 0.007$; Fisher's Exact test: $p = 0.012$). VAS score of present shoulder pain analyzed by Mann-Whitney U-test in offensive players was stronger than defensive players (74.0 mm ± 14.2 mm *vs* 44.6 mm ± 24.4 mm, $p = 0.04$). Additionally, among the 11 players with present shoulder pain, 3 players reported the phase of acceleration causing pain, 7 players reported hit and 1 player reported hit and follow-through. 5 cases located in outside shoulder, 2 cases in posterior shoulder and 4 cases in anterior shoulder.

For the three groups analyzed by one-way ANOVA, there were no significant differences of age, height, weight, BMI, years of badminton experience, training hours of per day, days of per week and total training hours of per week among pain free, injury and present pain groups (Table 2). For arm slot angle analyzed by one-way ANOVA, significant differences were found among the three groups (pain free *vs* injury *vs* present pain: 35.74° ± 4.85° *vs* 42.90° ± 11.89° *vs* 37.81° ± 6.40°, F = 3.27, $p = 0.047$). With Post-hoc analysis using Bonferroni test, significant differences were found in arm slot angle between pain free group and injury group ($p = 0.046$). Additionally, data of badminton players without shoulder problems broken down by type of player (9 offensive players and 22 defensive players) were also analyzed (Table 3). There were significant differences of age, weight and BMI between offensive and defensive players while no other significant differences were found. Offensive players showed a tendency to significantly greater arm slot angle compared with defensive players (offensive players vs defensive players: 38.19° ± 4.18° vs

34.74° ± 4.83°, p = 0.07).

Discussion

To the best of our knowledge, this is the first study to identify the mechanisms of forehand overhead motion with shoulder pain and injury in badminton players. In this study, some vital and special findings were found: (1) type of offensive badminton players was a risk factor of shoulder pain and injury, (2) offensive badminton players showed significantly stronger shoulder pain than defensive badminton players, and (3) greater arm slot angle of the phase of the hit might be the mechanism of shoulder pain and injury in elite university badminton players with national tournament level.

Table 1. Characteristics of all the badminton players.

	Pain free (n = 31)	Injury (n = 6)	Present pain (n = 11)
Gender			
Male	16	3	5
Female	15	3	6
Type of player			
Offensive players	9	6	8
Defensive players	22	-	3
Playing categories			
Single	14	1	5
Double	14	5	5
Both	3	-	1
History of shoulder pain			
Yes	13	-	10
No	18	-	1
VAS score (mm)			
Offensive players	-	-	74.0 ± 14.2*
Defensive players	-	-	44.6 ± 24.4

*p-value < 0.05, between offensive players and defensive players with present pain.

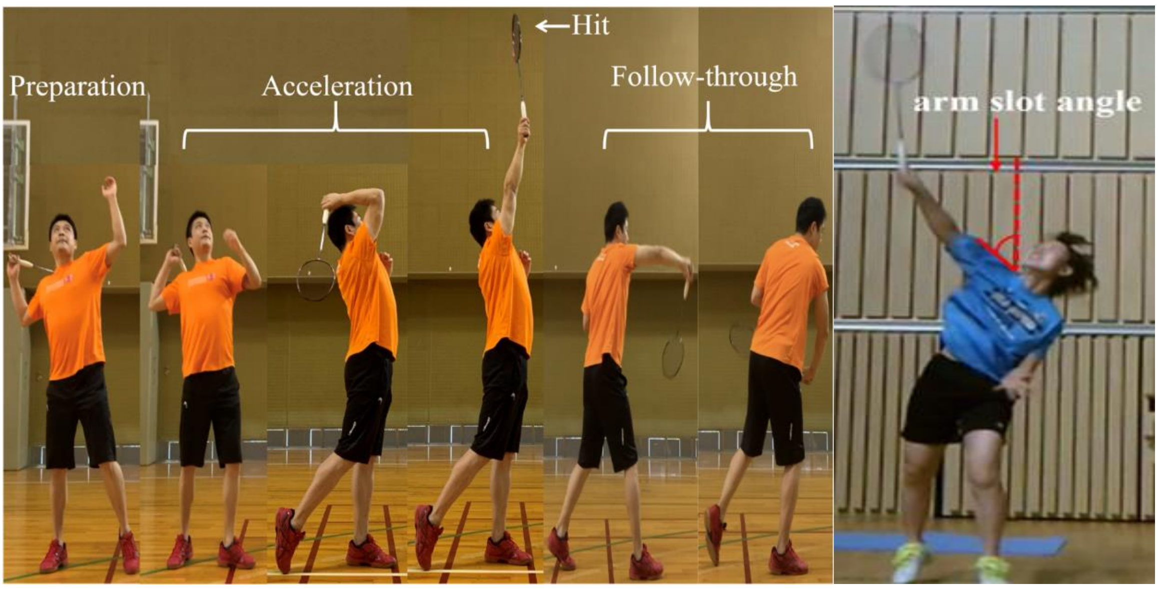

Figure 1-A: phases of forehand overhead stroke, B: arm slot angle.

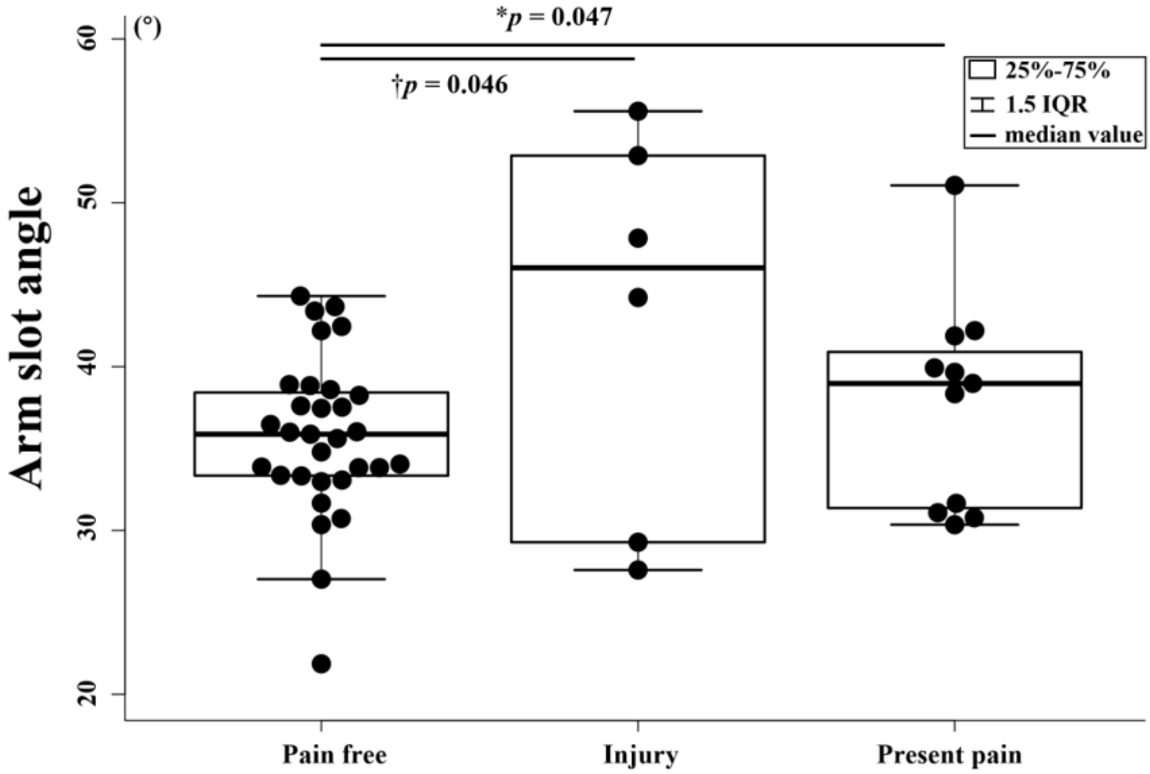

Figure 2-Box plot shows median value, 1.5 IQR (interquartile range) and the distribution for the arm slot angles of all the participants. Black spots represent the distribution of arm slot angles. *p (ANOVA), between pain free, injury and present pain groups †p (Bonferroni test), between pain free and injury groups.

Table 2. Baseline parameters of all the badminton players broken down by shoulder pain and injury.

	Pain free (n = 31)	Injury (n = 6)	Present pain (n = 11)	F	*p*-value
Age, yr	19.58 ± 1.15	20.67 ± 0.52	19.82 ± 1.54	2.08	0.137
Height, cm	165.56 ± 7.29	168.50 ± 7.87	164.35 ± 8.28	0.59	0.559
Weight, kg	60.32 ± 7.10	62.50 ± 5.24	59.95 ± 8.80	0.26	0.770
BMI	21.97 ± 1.64	22.05 ± 1.75	22.08 ± 1.57	0.22	0.978
Years	10.90 ± 2.55	12.17 ± 0.75	11.09 ± 3.48	0.57	0.571
Days, weekly	5.23 ± 0.56	5.33 ± 0.52	5.09 ± 0.80	0.33	0.718
Hours, daily	3.33 ± 0.50	3.33 ± 0.52	3.23 ± 0.52	0.19	0.829
Total hours, weekly	17.36 ± 2.76	17.67 ± 2.25	16.36 ± 3.23	0.61	0.546

BMI: body mass index (calculated by height and weight).

Table 3. Baseline parameters of two types of badminton players without shoulder problems.

	Offensive players (n = 9)	Defensive players (n = 22)	*p*-value
Age, yr	18.89 ± 1.27	19.86 ± 0.99	0.017**
Height, cm	167.78 ± 5.89	164.65 ± 7.73	0.286
Weight, kg	64.67 ± 7.48	58.55 ± 6.26	0.027**
BMI	22.92 ± 1.79	21.58 ± 1.44	0.035**
Years	10.00 ± 3.28	11.27 ± 2.16	0.263
Days, weekly	5.44 ± 0.73	5.14 ± 0.47	0.121
Hours, daily	3.30 ± 0.59	3.35 ± 0.47	0.712
Total hours, weekly	17.87 ± 3.57	17.15 ± 2.43	0.559
Arm slot angle, °	38.19±4.18	34.74±4.83	0.07

BMI: body mass index (calculated by height and weight). ***p*-value < 0.05, between offensive players and defensive players.

Shoulder pain not only affects overhead motion performance negatively, but disturbs activity of daily living in overhead motion sports athletes [9,18-20]. Previous studies have studied shoulder pain in recreational and world-class badminton players, however, no risk factors were found [18,19]. Although type of player has been studied in the previous studies, no significant differences of incidence of shoulder pain were found between offensive badminton players and defensive badminton players. In this study, offensive badminton players showed significantly higher incidence of shoulder pain compared with defensive badminton players which is inconsistent with the previous studies. Badminton players required medical attention were categorized as shoulder injury group in this study whereas the previous studies categorized 50% badminton players with shoulder pain required medical attention as shoulder pain group. The differences of the definition of injuries and pain between our studies and the previous studies which might interpret the differences. In addition, a previous study of shoulder pain in Japanese badminton players demonstrated a history of shoulder pain to be a risk factor for recurrent shoulder pain [21]. In this study, we found that badminton players with a history of shoulder pain showed significantly higher risk of recurrent shoulder pain that consistent with the previous study.

Improper overhead motion producing abnormal kinetic chain has been demonstrated to be the mechanism of shoulder pain and injury in previous overhead motion sports studies. A previous studies of baseball revealed that pitchers with arm slot angle ≥ 70° at the instant of ball release showed greater shoulder external rotation that may increase the risk of shoulder labral injury [10]. A review study of overhead motion sports revealed that insufficient coordination in shoulder elevation tasks were mechanisms of shoulder injuries in baseball pitchers, cricket bowlers, handball players, volleyball players, football quarterbacks and other overhead motion sports players [22]. Another previous study of tennis demonstrated that tennis players with a history of shoulder problems showed less humeral abduction which means greater arm slot angle, than those without at the end of the acceleration phase during serve [8]. In this study, our results were similar to the previous studies that the participants with shoulder problem showed significantly greater arm slot angle.

Similar to throwing motion, badminton forehand overhead motion, referred to as a kinetic chain, requires multi-limb coordination to perform body core mass shift, trunk rotation and upper limb rotation simultaneously. The complex mechanics of the overhead motion could generate tensile stress on the shoulder [23-25]. Undeniably, in badminton playing, numerous repetitions of overhead motion performing, such as clear and smash, increase the risk of shoulder problems. Health skilled badminton players showed a more constant time from peak electromyographic amplitude to hit. Immediately after hit, the electromyographic activity of flexor carpi radialis and triceps brachii decreased in health skillful badminton players while badminton players with immature motions showed continued electromyographic activity after hit [5]. Deficits in kinetic chain of overhead motion causing abnormal electromyographic activity could alter stress in shoulder joint, ultimately result in shoulder pain and injury as a consequence. Moreover, the more arm slot angle near the instant of ball release the pitchers perform, the more elbow flexion torque occurs that the torque places on shoulder joint, which can lead to superior labrum anterior to posterior (SLAP) lesions [10]. In addition, the offensive badminton players without shoulder problems in this study tended towards significantly greater arm slot angle than the defensive badminton players (p = 0.07). We speculate that badminton players in our studies changed the phase of hit with greater arm slot angle, compensating for deficits in energy translation, to perform overhead stroke, which resulted in abnormal electromyographic activity in altering the tensile stress on shoulder joint. These findings support our results that type of offensive badminton players and badminton players with greater arm slot angle showed more risk of shoulder pain and injury, and interpret why badminton players with a history of shoulder pain which may be caused by improper overhead motion, showed greater risk of recurrent shoulder pain.

It is not an easy task to correct overhead motion in high level badminton players who are accustomed to their greater arm slot angle and the timing at the instant of performing forehand overhead stroke. A promising badminton motor skills acquirement method, named "task analysis teaching method" [26], is recommended to be implement for improper phases correction. Additionally, balance control is fundamental to the execution of smooth and coordinated neuromuscular action that involves displacement of body segments or the entire body [27,28]. The execution of smooth and coordinated neuromuscular action is vital for badminton overhead motion performance which could be improved by balance training. Plus, weaker balance ability is a risk factor for shoulder pain [11]. The advanced exercise program and plyometric trainings on balance improved balance ability [29,30], which might be implemented in badminton.

Some limitations should be considered in this study. Firstly, this study is a cross-sectional study. Although greater arm slot angle was speculated to be the mechanism of shoulder pain and injury, a prospective study is supposed to verify the cause-and-effect. Secondly, 2D video analysis has high reliability of overhead motion, however, the kinematic during forehand overhead stroke in badminton players with shoulder problems could not be studied for identifying deficits in energy transfer. In future, a motion capture technology, named “Video Motion Capture System from the Part Confidence Maps of Multi-

Camera Images by Spatiotemporal Filtering Using the Human Skeletal Model (VMocap)" which could be used in large measurement field [31], is supposed to be used to detect the mechanisms of badminton injuries and pain in badminton training and matches.

Conclusions

Offensive badminton players are more likely to suffer from shoulder injury and strong intensity of shoulder pain. Greater arm slot angle of hit phase might be the mechanism leading to shoulder problems in badminton players.

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Conflict of Interest

The authors declare no conflict of interest.

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