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ORIGINAL ARTICLE

Isokinetic torque imbalances of shoulder of the french women's national water polo team

Évaluations isocinétiques de la coiffe des rotateurs de l'épaule des joueuses de l'équipe de France de water-polo

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Summary

Objective. – Evaluate the shoulder isokinetic strength of high-level female water polo players.
Methods. – Two groups were compared: a control group of noncompetitive females ($n=10$), and members of the French women's national water polo ($n=18$). Isokinetic measurements focused on the shoulder internal rotators (IR) and external rotators (ER), the evaluations were realized at $60^\circ \cdot s^{-1}$ and $240^\circ \cdot s^{-1}$ in the concentric mode and at $60^\circ \cdot s^{-1}$ in the eccentric mode. Agonist–antagonist ratios (ER/IR) were calculated using the same speed and contraction mode for the agonist and antagonist muscle groups and the mixed ratio, combining peak torque (PT; N·m) of the ER in the eccentric mode at $60^\circ \cdot s^{-1}$ and PT of the IR in the concentric mode at $240^\circ \cdot s^{-1}$, was calculated.

Results. – In concentric contraction, the PT of IR of the polo players was stronger than controls ($P < 0.05$). In eccentric contraction the PT of ER were greater in water polo players ($P < 0.05$). For the water polo players, a difference between both sides was observed when comparing the PT at $60^\circ \cdot s^{-1}$ ($P < 0.05$). No significant difference was found through the agonist–antagonist ratios between the dominant and the nondominant shoulders in both groups. Some players exhibit an altered mixed ratio.

Conclusion. – Intensive engagement in playing water polo will lead to an asymmetry in terms of force, with a dominance of the internal rotators of the dominant shoulder.

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MOTS CLÉS

Isocinétisme ;
Muscle ;
Sport ;
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Water-polo

Résumé

Objectif. – Évaluer les performances musculaires de la coiffe des rotateurs de l'épaule chez des joueuses de water-polo de haut niveau.

Méthode. – Deux groupes ont été comparés : un groupe contrôle composé de jeunes filles sédentaires ($n=10$) et le second comprenant les joueuses de l'équipe de France de water-polo ($n=18$). Des mesures isocinétiques des rotateurs internes et externes des deux épaules ont été effectuées. L'évaluation été réalisée à $60^\circ \cdot s^{-1}$ et $240^\circ \cdot s^{-1}$ en mode concentrique suivi d'une mesure en excentrique à $60^\circ \cdot s^{-1}$. Les ratios fonctionnels ont été calculés à partir d'un même mode de contraction avec des vitesses identiques, l'analyse du ratio mixte (rotateurs externes en excentrique à $60^\circ \cdot s^{-1}$ /rotateurs internes en concentrique à $240^\circ \cdot s^{-1}$) a été aussi prise en considération.

Résultats. – En mode concentrique, le moment de force maximal des rotateurs internes est significativement supérieur pour les joueuses ($p < 0,05$), ces sportives présentent aussi des données plus élevées au niveau des rotateurs externes en excentrique ($p < 0,05$). Concernant les joueuses de water-polo, une différence de performance est enregistrée entre les deux épaules à $60^\circ \cdot s^{-1}$ au niveau du moment de force maximal ($p < 0,05$). Aucune différence n'a été trouvée au niveau des ratios fonctionnels entre le coté dominant et non dominant quel que soit le groupe. Cependant plusieurs joueuses présentent un ratio mixte altéré.

Conclusion. – La pratique intensive du water-polo va entraîner une asymétrie en termes de force avec la supériorité des rotateurs internes de l'épaule dominante.

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1. Introduction

Water polo is an intermittent and high-intensity team sport that requires a combination of technical, high physical fitness and tactical skills [1]. This activity presents asymmetric aspects, particularly during the passing and throwing motions [1]. Repetition of these dynamic motions and swimming result in a cumulative micro-trauma leading to shoulder soreness [2]. Shoulder soreness is the most common musculoskeletal complaint for water polo players [3]. The relative increase in dominant shoulder external rotation observed in water polo players suggests that levels of shoulder soreness would be a result of throwing actions rather than swimming which did not require high level of force of external rotators [4]. Therefore, evaluation of shoulder muscle strength is of interest to identify shoulder muscles imbalance.

Measurement of isokinetic torque production remains the method of choice to assess peak muscle performance [5–9]. Quantitative establishment of the balance between the forces in rotator cuff muscles requires investigation of agonist/antagonist ratios [10]. Previous studies reported that men water polo players have greater internal than external rotation strength [11]. To our knowledge, isokinetics shoulder performance has not been investigated in high-level female players. It should be of interest to determine if similar muscle imbalance will be observed in women players.

In sports where over arm throwing plays an important role, isokinetic evaluations revealed an imbalance in muscle strength of the shoulder [8,12,13]. During throwing, there is a complementary action of concentric and eccentric contractions. The concentric action of internal rotators determines mainly the throwing velocity. The eccentric

contraction of external rotators plays a key role and act as a brake during the final deceleration of the upper limb, thereby limiting the pronounced increase in distraction force [14]. The use of a mixed ratio (eccentric peak torque of external rotators divided by concentric peak torque of internal rotators) is therefore advocated [15]. Upon comparing various high-level sporting populations and control subjects, Forthomme et al. [16] observed a decreased mixed ratio (ER ecc/IR conc) for the individuals engaged in the throwing activities (volley: 1.07 ± 0.23 , javelot: 1.04 ± 0.21 , badminton: 1.05 ± 0.16 , tennis: 1.10 ± 0.17) relative to control group (1.30 ± 0.27). This decreased ratio is the result of an increase in the peak torque performances of the IR in concentric mode without an increase of the ER in eccentric mode [17–19]. These data suggest that the shoulder imbalance is a consequence of sport practice.

The aim of this study was to determine if there is an imbalance in muscle strength of the shoulder in high-level female water polo players.

2. Materials and methods

2.1. Study design

Two groups were evaluated: a control group of noncompetitive females ($n=10$), and members of the French women's national water polo team ($n=18$). Control subjects did not practice throwing activities and were matched for age (± 4 years), height (± 5 cm) and weight (± 4 kg). The evaluations were always carried out in the morning, under identical conditions. The evaluation consisted in isokinetic shoulder strength assessments. All the subjects provided signed

Table 1 Mean physical characteristics of control and water polo players.

	Control (n = 10)	Water polo players (n = 18)
Age (years)	22 ± 2	22 ± 3
Height (cm)	167 ± 10	172 ± 8
Weight (kg)	62 ± 5	67 ± 10
Dominant hand		
Right	10	18
Left	0	0

Values are presented as mean ± SD. No difference was observed between the groups.

informed consent prior to their participation. The protocol was conducted according to the Declaration of Helsinki.

2.2. Population

Subjects characteristics were presented in Table 1. All water polo players were considered to be elite and highly trained at the time of testing (training duration > 15 h per week). Control subjects trained less than four hours of physical activity per week. All were right-hand dominant. None had a history of upper extremity injury, nor were they involved in regular upper arm activities.

2.3. Isokinetic assessment

Isokinetic evaluations were performed using a CON-TREX dynamometer (CMV AG, Regensdorf, swiss). After a warm-up with an elastic band and arm cranking, subjects were familiarized with the test using 10 submaximal concentric repetitions at 120°·s⁻¹ and three submaximal preliminary repetitions before each test speed data collection. Shoulders on both sides (dominant [D] and nondominant [ND]) of the subjects were assessed. The test was standardized to evaluate the right shoulder first. Measurements focused on the shoulder internal rotators (IR) and external rotators (ER). Subjects were placed in a supine position, with the arm abducted at 90° in the frontal plane and the elbow flexed at 90° [20]. To maximize the stability, the thorax and the elbow of the subject were strapped. The range of motion was standardized at between 50° of internal rotation and 70° of external rotation, neutral position was fixed with the forearm in 90° horizontal abduction. For all torque measurements, appropriate corrections were made for the gravitational effect of the leg. The isokinetic speeds selected were 60°·s⁻¹ (three repetitions of testing) and 240°·s⁻¹ (twenty repetitions of testing) in the concentric mode and 60°·s⁻¹ (four repetitions of testing) in the eccentric mode. Successive testing velocities were separated by 90 seconds of rest. The isokinetic testing procedure enabled the measurement of absolute peak torque (PT; N·m) and total work (joules).

Agonist–antagonist ratios (ER/IR) were calculated using the same speed and contraction mode for the agonist and antagonist muscle groups. A mixed ratio (combining ER PT in the eccentric mode at 60°·s⁻¹ and IR PT in the concentric mode at 240°·s⁻¹) was also calculated [18]. The subjects

were instructed and encouraged to reach the highest possible force level during these tasks but they did not receive any visual feedback.

2.4. Statistical Analysis

All data are presented as means ± SD. The Shapiro–Wilk normality test was used to check the normal distribution of the data. A Student unpaired *t* test was used to identify differences between the control group and the water polo players. The paired Student *t* was used to identify the significant differences between D and ND shoulders for the water polo players group. All statistical analyses were carried out with the SPSS statistical package (version 10, Chicago, IL) and *P* < 0.05 was used as the accepted level of significance.

3. Results

3.1. Isokinetic assessment

The comparison of isokinetic parameters of both groups are presented in Table 2. In concentric contraction, the IR peak torque was stronger in water polo players at velocities of 60°·s⁻¹ and 240°·s⁻¹ compared to control group (respectively +50% and +39% for D side and +46% and +30% for ND side). The control group displayed a lower total work over the exercises realized at 240°·s⁻¹ than the water polo players (*P* < 0.05). For the water polo players, there was a difference between D and ND sides when comparing the PT developed by the IR at 60°·s⁻¹ (*P* < 0.05). No difference between both groups and sides was observed for concentric contraction of ER at 60°·s⁻¹ and 240°·s⁻¹.

In eccentric contraction, no difference was observed between both groups and sides for IR. The peak torque of ER was greater in water polo players by 44% for D side and 38% for ND side (*P* < 0.05).

No difference was found through the agonist–antagonist ratios between the D and the ND shoulders and the two groups (Table 3). However, 2 water polo players presented a mixed ratio below 1.11 (range: 0.93–1.07) whereas no subject have ratio below 1.11 in the control group.

4. Discussion

The results showed that intensive engagement in playing water polo will lead to an asymmetry in terms of force, with a dominance of the internal rotators of the dominant shoulder. The isokinetic performances of the water polo players were stronger than controls. No difference was found through the agonist–antagonist ratios between the D and the ND shoulders and the two groups.

4.1. Peak torque measurements

Measurement of isokinetic torque production remains the preferred technique to assess peak muscle strength and to calculate the balance between agonist and antagonist groups [8]. Of all the positions described for shoulder muscle assessment of athletes in the cocking phase of throwing, the dorsal decubitus position with a shoulder adduction of

Table 2 Isokinetic performance of D and ND shoulders corresponding to the whole population of the study.

Motion	Control (n = 10)		Water polo players (n = 18)	
	D Side	ND Side	D Side	ND Side
Peak torque				
IR CON 60 (N·m)	24.9 ± 4.7*	23.5 ± 4.6*	37.3 ± 9.6	34.4 ± 8.5**
ER CON 60 (N·m)	18.1 ± 2.7	18.7 ± 2.1	23.6 ± 9.5	24.4 ± 5.1
IR CON 240	22.9 ± 2.1*	23.2 ± 1.9*	31.9 ± 5.9	30.2 ± 6.1
ER CON 240	17.8 ± 1.6	18.8 ± 1.4	20.9 ± 3.4	21.3 ± 4.1
IR ECC 60	27.4 ± 2.4	26.8 ± 2.1	29.9 ± 7.2	29.5 ± 7.2
ER ECC 60	28.1 ± 1.9*	29.1 ± 1.2*	40.6 ± 10.3	40.1 ± 9.4
Total work (J)	D Side	ND Side	D Side	ND Side
IR CON 240	572.2 ± 57.7*	545.4 ± 63.5*	1033.9 ± 200.4	981.4 ± 210.1
ER CON 240	463.8 ± 35.9*	428.6 ± 46.5*	636.9 ± 124.4	645.1 ± 141.1

Values are presented as mean ± SD. ER: External Rotators, IR: Internal Rotators; Con 60 = 60°·s⁻¹, concentric mode; Con 240 = 240°·s⁻¹, concentric mode; Ecc 60 = 60°·s⁻¹, eccentric mode.

* P < 0.05 between the control and water polo players.

** P < 0.05 between the D and ND shoulders.

Table 3 Isokinetic ratios of water polo players and control group for the both shoulders.

Motion	Control (n = 10)		Water polo players (n = 18)	
	D Side	ND Side	D Side	ND Side
ER/IR concentric ratios				
Angular velocity of 60°·s ⁻¹	0.73 ± 0.16	0.79 ± 0.14	0.63 ± 0.11	0.70 ± 0.12
Angular velocity of 240°·s ⁻¹	0.77 ± 0.07	0.81 ± 0.08	0.66 ± 0.09	0.71 ± 0.12
Mixed ratio				
ER ecc 60·s ⁻¹ /IR con 240·s ⁻¹	1.23 ± 0.06	1.26 ± 0.09	1.27 ± 0.21	1.32 ± 0.23
Mixed ratio < 1.11 (%)	0	0	16 (n = 2)	0

Values are presented as mean ± SD. Con: concentric mode; Ecc: eccentric mode; ER: External Rotators; IR: Internal Rotators. Conc 60·s⁻¹ = 60°·s⁻¹, concentric mode; Conc 240·s⁻¹ = 240°·s⁻¹, concentric mode; Ecc 60 = 60°·s⁻¹, eccentric mode. No difference was observed between the groups.

90° is considered to be the most suitable, while a seated position with 45° of shoulder adduction in the plane of the scapula (known as the modified Davies position) is thought to be the most relevant when it comes to pathologies [20]. Moreover, the position used in our study was associated with higher reproducibility and reliability for internal and external rotators [20].

Although isokinetic protocols are increasingly standardized (posture, saved settings, repetitions), the question concerning the speed of execution does not seem to have reached consensus yet. However, we believe that in the context of expertise, it is essential to take this element into account. An unsuited speed to the physical abilities of the subjects could lead to wrong conclusions. In our study, 3 subjects from the control group did not reach the faster speed (i.e. 240°·s⁻¹) and were excluded from the protocol. Faster is the velocity, smaller is the isokinetic phase. According to Osternig [21], for speeds of 300°·s⁻¹, the working phase at a constant speed does not exceed 55% of the range of motion (leg extension motion). This makes the interpretation of the results obtained during high-speed tests very random. We believe that beyond 240°·s⁻¹ with sedentary subjects, the part of the curve that is truly isokinetic is not large enough for the test carried out to be significant. Speeds close to

180°·s⁻¹ are probably best suited for the evaluation of the shoulder joint.

The water polo players exhibit higher total work both in concentric and eccentric condition. These results highlight higher muscle endurance performances in water polo players. However, the main difference between water polo players and control subjects is that the dominant shoulder of water polo players is stronger than the non-dominant shoulder. This imbalance had already been observed in previous studies [22]. This imbalance has been observed in men swimmers but not in women suggesting that the swimming practice per se does not benefit the imbalance of shoulder strength. The muscular performance of our female players is close to those recorded in women who participate in throwing sports [19]. Therefore, it seems that imbalance observed in our study is the result of the practice of high-level swimming and is probably accentuated by the throwing of repetitions.

4.2. Agonist/antagonist ratios

Quantitative establishment of the balance of the force between muscles with opposing actions requires investigation of the agonist/antagonist ratios [5]. Our results

revealed a significant difference in the muscle performances between the two shoulders of our players whereas no difference was observed for the different ratios. Investigation of agonist/antagonist ratios is typically of the concentric contraction alone. However, use of the shoulder during swimming or throwing involved concentric as well as eccentric movements. Moreover, we recently observed that shoulder isokinetic evaluations (IR in concentric mode and ER in eccentric mode) correlate significantly with swimming performance and throwing velocity of female water polo players [23]. The mixed ratio observed in this study were in accordance with previous studies [8,19]. A mixed ratio imbalance, reflecting weakness of the ER, would constitute the main risk factor for shoulder tendon pain [24]. Change in the agonist/antagonist balance with athletes is manifested particularly in the mixed ratio, with values that are consistently lower than the limit defined for healthy subjects [18]. The increase in the concentric force of the IR therefore does not appear to be proportionately compensated for by the braking action of the ER. Regarding the mixed ratios, two players exhibit lower ratio (ratio lower than 1.11) compared to the other players. Such a profile could prove to be detrimental in terms of tendon lesions of this joint. There is a higher variability in water polo players as demonstrated by higher SD suggesting a specific effect of training program on muscle peak torque enhancement. Indeed, players from our study come from different clubs that have their own training strategy. Specific muscle training performed each week with gym equipment could be a reason for this. Most of the exercises used during gym session aim to develop IR peak torque and eccentric contraction exercises of ER was never used. Moreover, the exercises are performed at high intensity levels that promote peak force production by the internal rotators, the performance speeds are slow and close to those used for the isokinetic evaluation (60 s^{-1}). An imbalance of force between antagonist muscles triggers an abnormal excursion of the humeral head in the glenoid cavity, which can lead to impingement or instability [25]. More typical for purely concentric ratios, most studies have confirmed the relative weakness of the ER relative to the IR [7,9,10,26]. This has proven to be detrimental to functioning of the shoulder area: the external rotators play an essential role at the end of the cocking phase since, by keeping the humeral head in the glenoid cavity, they limit tensioning of the anterior glenohumeral ligament [25]. At the biomechanical level, the integration of eccentric contraction of the ER in the establishment of the agonist/antagonist relationship seems obvious. Eccentric engagement of the posterior muscle girdle ensures a protective role upon throwing: the braking action limits the anterior translation of the humeral head upon powerful concentric contraction of the IR.

4.3. Practical applications

Wilk et al., 2002 [27] and Kibler 2003 [25] suggest to use concentric and eccentric ER strengthening exercises at the conclusion of a preventative and curative athlete's shoulder treatment to compensate for the weakness of the posterior girdle. They emphasize that an adequate compensatory strengthening of the antagonists (ER) does not seem to be detrimental to on-field performance [9]. We believe that

preventive strengthening of the ER for concentric and eccentric contraction modes, while keeping the IR in shape, would avoid an agonist/antagonist imbalance, without harming the overall competitive performance. We suggest using analytic movements to strengthen ER. A specific work outside of the water should be used because the water did not offer solid support to better control the movement. Studies pertaining to rebalancing of the ratios, the development of performance and the extent of shoulder injury should be considered.

5. Conclusion

Intensive engagement in playing water polo will lead to an asymmetry in terms of force, with a dominance of the internal rotators of the dominant shoulder. The players also present greater peak torque force of external rotor compared to control subjects when assessed during eccentric contraction.

Disclosure of interest

The authors declare that they have no competing interest.

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