Shoulder Rotators Electro-Mechanical Properties Change with Intensive Volleyball Practice: A Pilot Study

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Key words
- volleyball
- isokinetic
- shoulder rotations
- surface electromyography
- muscle torque
- isometric

Abstract

This pilot study was designed to assess the incidence of high-level volleyball practice on muscle strength production and muscle activation during internal and external shoulder rotations. Seven professional and seven French amateur league volleyball players performed maximal isometric at three forearm angles, concentric and eccentric isokinetic internal and external shoulder rotations. The torque production and muscle activation levels of *pectoralis major and infraspinatus* were determined. Few significant differences were found for muscle activation and co-activation between amateur and professional volleyball players during both internal and external rotations. No significant difference in torque production was observed for shoulder internal rotation between professional and amateur volleyball players. Torque production was significantly higher during shoulder external rotation for amateur (46.58 ± 2.62 N.m) compared to professional (35.35 ± 1.17 N.m) volleyball players relative to isometric contractions, but it was not different during isokinetic efforts. The torque ratios for external/internal rotations were always significantly lower for professional (0.42 ± 0.03 pooling isometric and concentric conditions) compared to amateur volleyball players (0.56 ± 0.03 pooling isometric and concentric conditions). Those results emphasize that a high level of volleyball practice induces a strong external rotators deficit compared to sports such as swimming, baseball or tennis.

Introduction

The shoulder stabilizing muscles determine a high level of performance in athletes who request this joint preferentially [26]. Furthermore, some studies have shown the prevalence of shoulder pain [8,18,28] and shoulder external/internal rotation imbalances with [30] or without [1,31] injuries among volleyball players. Rokito et al. [25] described the electromyographic pattern of shoulder muscle activations during the volleyball serve and spike in professional and collegiate-level athletes. They found that the *infraspinatus* and *teres minor* muscles were used to rotate the *humerus* externally during cocking. Then, during the acceleration, *infraspinatus* activity declined. Furthermore, the anterior wall muscles worked to decelerate movement during cocking. Moreover, the important level of activity of the *infraspinatus* and *teres minor* muscles has been emphasized during common shoulder external rotation [24] whereas the *subscapularis* and *pectoralis major* muscles were found to be highly involved with internal rotation force production [5].

The isometric [13] and isokinetic protocols in both eccentric [9] and concentric [19] conditions were found to be reliable considering torque measurements of the external and internal shoulder rotators. The isometric and isokinetic studies were then used widely to assess torque imbalance in shoulder rotations in sports such as badminton [22], waterpolo [20], tennis [7,21], handball [3] and volleyball [1,30,31,33]. Nevertheless, few studies have focused on assessing both torque production and muscle electromyographic activities in the shoulder rotators of volleyball players [33]. Thus, the aim of this pilot study was then to characterize muscle mechanical properties associated with surface electromyographic activations during external and internal shoulder rotation in amateur (Amat VB) and professional volleyball (Pro VB) players. The examination was conducted to identify the possible deficit induced by this intensive practice

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Table 1 Main mean physical characteristics of the subjects.

		Height (cm)	Weight (kg)	Age (years)
Pro VB, **n=7**	mean	196.6	90.8	24.2
	SD	5.0	7.8	4.5
Amat VB, **n=7**	mean	183.4***	71.8***	22.1 ns
	SD	4.4	7.5	1.7

***: significant difference between Pro VB and Amat VB ($p<0.001$), ns: non significant difference between Pro VB and Amat VB ($p>0.05$)

and determine whether it originates from muscle or activation dysfunction.

Methods

Subjects

Seven French professional (elite) volleyball players (Pro VB) and seven French amateur league volleyball players (Amat VB) volunteered to participate in this study. Some of the subjects' physical characteristics are shown in **Table 1**. All players were informed of the nature and the aim of this study and signed an informed consent form. This study was conducted according to the Helsinki Statement (1964) and was approved by the local ethics committee.

Procedure

A Biodex System 3 Pro® Isokinetic Dynamometer (Biodex Medical, Shirley, N.Y., USA) was used to perform shoulder isometric and isokinetic tests. This apparatus was calibrated according to the procedure recommended by the manufacturer (sensitivity level and gravitational correction feature for shoulder joint analysis). A ME 3000 apparatus (Biometrics Ltd) was used to collect surface electromyographic (SEMG) signals. In order to reduce cross-talk and as suggested by Winter et al. [32], bipolar SEMG signals were recorded using miniature Ag/AgCl surface electrodes (4 mm diameter, 11 mm inter-electrode distance). Each SEMG channel was connected to a preamplifier (band pass filter: 6–400 Hz) and was amplified (bandwidth: 10–1 000 Hz) through an isolated amplifier (Gould 6600®).

The experiment was designed as follows. Firstly, surface electrodes were placed on the *pectoralis major* muscle (internal shoulder rotator) and on the *infraspinatus* muscle (external shoulder rotator) according to the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations [10]. The electrode positions were checked by real-time visual inspections of the SEMG signals during standardized contractions. In the literature, the SEMG activity of *infraspinatus* and *teres* minor for external rotation whereas *subscapularis* and *pectoralis major* are assessed during internal rotation [5,24,25]. A preliminary study has shown that SEMG signals of *infraspinatus* and *pectoralis* muscles were easier to obtain (i.e. cleaner) so that these two muscles were chosen for further analysis. Electrode-skin impedance was then reduced below 55 kΩ [11] using standard skin preparation procedures. The subject was then placed on the a seat and was held by special restraint systems in order to keep his body and head respectively against the seat back and headrest. The seat was adjusted by means of a moving system near the motor column to ensure that the subject's forearm rested on the forearm support. The motor rotation axis was aligned with the longitudinal axis of the *humerus*. The subject's general posture during the experiment was set with the arm at

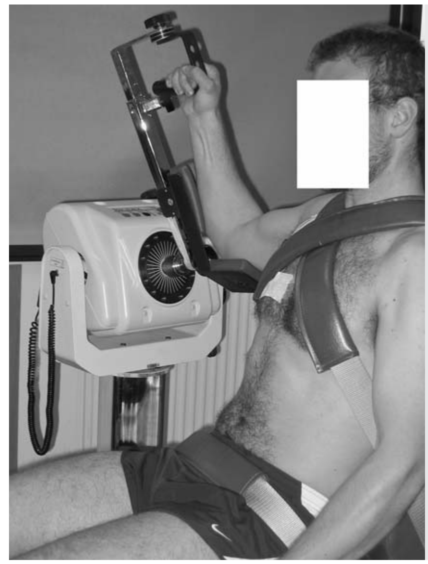

Fig. 1 Illustration of the general posture of the subject during the test.

80° of abduction associated with about 20° of shoulder horizontal flexion while the elbow joint angle was set at 90 degrees (**Fig. 1**). This posture was checked using goniometers. This position, already found in some study dealing with shoulder strength assessment [2], remains unusual but was chosen in order to increase the participants' comfort during the testing procedure [23] and to reduce risk of shoulder instability [16,27].

The test session began with a warm-up consisting of isokinetic sets of 6 repetitions of internal and external shoulder rotations at 180, 120 and 90°.s^{-1}. Then, for the actual tests, 3 trials of isometric contractions were performed for external and internal shoulder rotations at 3 different angles of internal rotation of the shoulder: the forearm was then placed at 10°, 35° and 65° (0° and 90° corresponding to the forearm in the vertical and the horizontal planes respectively). Each isometric contraction lasted 3 s, and 1 min of rest was given between each trial. Finally, the subjects were asked to perform isokinetic trials of three internal/external shoulder rotations in a concentric mode at 30, 60, 90, 120 and 240°.s^{-1} and then, in an eccentric mode at 30, 60 and 90°.s^{-1}. For those isokinetic tests, a range of motion of 90° (between 0° and 90°) was defined for full shoulder internal-external rotation movements. A three-minute rest period was given between each trial. Furthermore, the order of the isokinetic tests was randomized but the tests never began by the velocity of 30°.s^{-1} in either isokinetic modes in order to prevent the risk of injury. During all tests, the subjects received oral and visual feedbacks and were instructed to perform an effort as hard as possible.

Data processing

Mechanical (position, torque and velocity) and SEMG data were collected during all the tests. Data processing was accomplished

Table 2 Mean external rotation/internal rotation torques ratios.

a- Isometric Mode

	Angle = 10°		Angle = 35°		Angle = 65°	
	Pro VB	Amat VB	Pro VB	Amat VB	Pro VB	Amat VB
mean	0.39	0.51*	0.37	0.51**	0.44	0.60**
SD	0.08	0.10	0.09	0.08	0.10	0.04

b- Isokinetic Mode

	$30°.s^{-1}$		$60°.s^{-1}$		$90°.s^{-1}$		$120°.s^{-1}$		$240°.s^{-1}$		$-30°.s^{-1}$		$-60°.s^{-1}$		$-90°.s^{-1}$	
	Pro VB	Amat VB	Pro VB	Amat VB	Pro VB	Amat VB	Pro VB	Amat VB	Pro VB	Amat VB	Pro VB	Amat VB	Pro VB	Amat VB	Pro VB	Amat VB
mean	0.45	0.59**	0.45	0.58***	0.46	0.59**	0.44	0.57**	0.37	0.57**	0.46	0.55*	0.55	0.59 ns	0.53	0.60 ns
SD	0.08	0.04	0.05	0.04	0.05	0.07	0.09	0.06	0.07	0.11	0.07	0.05	0.33	0.07	0.23	0.10

ns, *, **, *** difference between Pro VB and Amat VB with $p>0.05$ (non significant), $p<0.05$, $p<0.01$, $p<0.001$ respectively

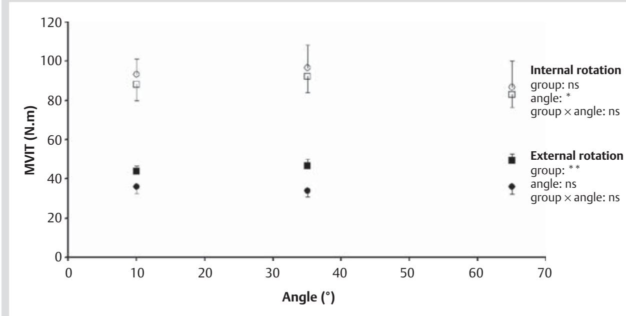

Fig. 2 Mean maximal voluntary isometric torque (MVIT). □ shoulder internal rotation for Amat VB; ○ shoulder internal rotation for Pro VB; ■ shoulder external rotation for Amat VB; ● shoulder external rotation for Pro VB. Differences between the two populations, **: p<0.01, *: p<0.05, ns: non significant.

using the Biodex® software for mechanical data and a custom program (Matlab®, The MathWorks, Natick, Inc., MAUSA) for SEMG signals.

Considering isometric tests, the maximal voluntary isometric torque (MVIT) of a subject for each articular angle and effort (i.e. external and internal shoulder rotations) was assessed as the highest torque value produced during the three trials. For the isokinetic tests, the highest peak torque (PT) was retained from the best of the three repetitions of movement considering each effort and velocity. Then external vs. internal shoulder rotations torque ratios (ER/IR) were calculated for all conditions tested.

Surface electromyographic signals (SEMG) were filtered using a Butterworth second order band pass filter (6–400 Hz). During both isometric and isokinetic efforts, SEMG signals were used to calculate the root mean square (SEMG-RMS) amplitude, thus reflecting the level of muscle activity. The isometric SEMG-RMS value (SEMG-RMSmax) was averaged over a 0.02 s period during which the maximal torque was approximately constant. For the isokinetic tests, SEMG signals were only analyzed during the steady velocity state. In this phase, the SEMG-RMS was calculated every 0.1 s in consecutive windows. For all tests, an antagonist SEMG-RMS was calculated under the same conditions as the agonist in terms of data processing and calculation windows. The antagonist SEMG-RMS was then considered as a level of co-activation. Further, SEMG-RMS data were normalized regardless of isometric or isokinetic test conditions relative to the maximal SEMG-RMSmax of the considered muscle.

Statistical analysis

Considering the isometric condition, seven separate 2×3 (group×angle) analyses of variance (ANOVAs) with repeated measures on angle were used to analyze MVIT in shoulder internal rotation and external rotation conditions, muscle activation and co-activation levels in shoulder internal rotation and external rotation conditions, and isometric ER/IR ratios. Furthermore, considering the isokinetic condition, seven separate 2×8 (group×velocity) analyses of variance (ANOVAs) with repeated measures on velocity were used to analyze PT in shoulder internal rotation and external rotation conditions, muscle activation and co-activation levels in shoulder internal rotation and external rotation conditions and isokinetic ER/IR ratios. LSD *post hoc* analyses were used as appropriate. Statistica® software (Statsoft, Inc, Tulsa, USA) was used for all statistical analyses. The significant level was fixed at $p<0.05$ for all analyses. In addition the

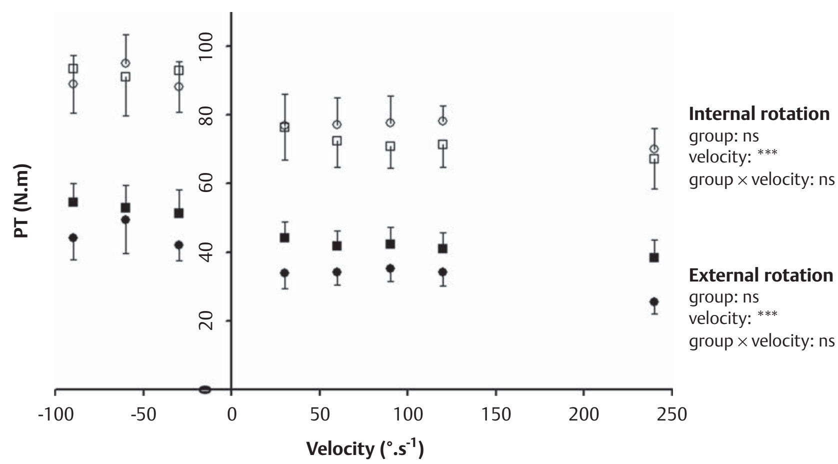

Fig. 3 Mean peak torque (PT) during isokinetic condition. □ shoulder internal rotation for Amat VB; ○ shoulder internal rotation for Pro VB; ■ shoulder external rotation for Amat VB; ● shoulder external rotation for Pro VB. Differences between the two populations, ***: p<0.01, ns: non significant.

effect size (ES) was assessed, using the d number proposed by Cohen [6] to assess the magnitude of a treatment effect independent of sample size. According to Cohen [6], the ES is considered as small for d = 0.2, medium for d = 0.5, and large for d = 0.8.

Results

Maximal voluntary isometric torque (MVIT)

As expected, shoulder internal rotation MVIT was higher than shoulder external rotation MVIT regardless of the angle or the subject. Furthermore, no significant difference was observed in terms of mean shoulder internal rotation between Pro VB and Amat VB ($p > 0.05$, d = 0.245) whereas mean MVIT during shoulder external rotation was significantly higher for Amat VB than for Pro VB ($p < 0.01$; F = 11.9, d = 1.682) for all tested angles (**Fig. 1**). An angle effect was found to be significant only when considering the internal rotation.
Moreover, isometric ER/IR ratios were significantly higher for Amat VB than for Pro VB (**Table 2a**) regardless of the angle considered ($p < 0.01$; F = 17.4, d = 1.604).

Isokinetic peak torque (PT)

No significant difference in PT was found between Pro VB and Amat VB either in terms shoulder internal rotation PT (IRPT, d = 0.091) or external rotation PT (ERPT, $p = 0.083$, F = 3.58, d = 0.699) regardless of velocity or dynamic condition. Furthermore, a velocity effect ($p < 0.001$; F = 21.0) was found for both IRPT and ERPT (**Fig. 2**). Moreover, isokinetic ERPT/IRPT ratios were significantly higher ($p < 0.05$; F = 6.6, d = 1.003) for Amat VB than for Pro VB regardless of the velocity considered (**Table 2b**). Furthermore, isokinetic ERPT/IRPT ratio was found to be lower at the higher velocity (240°.s^{-1}) when compared to the others for the Pro VB while it remained constant regardless of velocity for Amat VB (**Table 2b**).

Muscles activation and co-activation

For the shoulder internal rotation, no significant differences were found in terms of *pectoralis major* muscle activation between Amat VB and Pro VB regardless of the condition tested in the isometric mode and isokinetic modes, except for −30 and −90°.s^{-1} where normalized SEMG-RMS were higher ($p < 0.01$, d = 1.298 and d = 0.0841 respectively) for Amat VB than for Pro VB (interaction group × velocity: $p < 0.05$; F = 2.25; **Fig. 3**). Furthermore, the *infraspinatus* muscle co-activation in the isometric condition was significantly higher for Pro VB than Amat VB at 10° angle whereas the contrary was the case at 65° (interaction group × angle: $p < 0.05$; F = 7.72). For the isokinetic mode, no significant difference was found in terms of *infraspinatus* muscle co-activation between Amat VB and Pro VB except at 240°.s^{-1} where normalized SEMG-RMS is higher ($p < 0.001$, d = 1.482) for Amat VB than for Pro VB (interaction group × velocity: $p < 0.05$; F = 2.67; **Fig. 3**).
Concerning the shoulder external rotation, no significant difference was found in terms of *infraspinatus* muscle activation and *pectoralis major* muscle co-activation between Amat VB and Pro VB in the isometric mode. The same holds true for the *infraspinatus* muscle activation and the *pectoralis major* muscle co-activation regardless of isokinetic condition (**Fig. 4**).

Discussion

The aim of this pilot study was to characterize the muscle mechanical properties associated with surface electromyographic activations during external and internal shoulder rotation in amateur (Amat VB) and professional volleyball (Pro VB) players. This was accomplished in order to identify the possible deficit induced by this intensive practice and whether it originates from muscle or activation dysfunction. The study must be considered as a first approach to this complex topic and its results should be examined carefully since the number of subjects is limited. In fact, a statistical power test shows that between 17 and 20 subjects would have been needed in this study with a beta error of 20%. Nevertheless, some of our results are consistent with those already observed in the literature.
In terms of muscles strength production, our results correspond with those in the literature that show a higher torque production in internal rotation rather than in external rotation leading to ER/IR < 1 regardless of the subject or the test condition. Furthermore, ER/IR ratios were significantly higher for Amat VB than for Pro VB in isometric and dynamic conditions. This emphasizes the fact that an imbalance in shoulder rotators can possibly be induced by a high level of volleyball practice although the sample size estimation indicated above should be kept in mind. In fact, volleyball movements during spikes and serves are

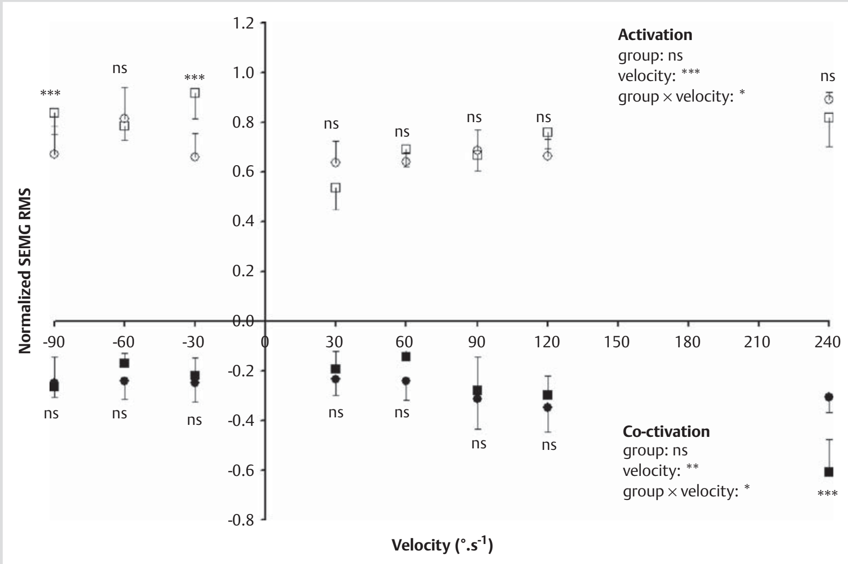

Fig. 4 Muscle activation and co-activation during isokinetic shoulder internal rotation. ⇐ activation for Amat VB; ○ activation for Pro VB; ■ co-activation for Amat VB; ● co-activation for Pro VB. Differences between the two populations, ***: p<0.001, **: p<0.01, *: p<0.05, ns: non significant.

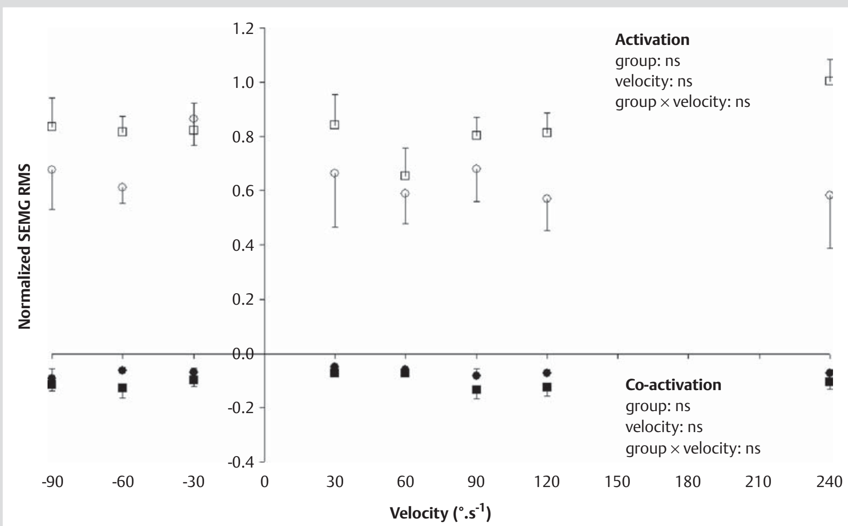

Fig. 5 Muscle activation and co-activation during isokinetic shoulder external rotation. ⇐ activation Amat VB; ○ activation for Pro VB; ■ co-activation for Amat VB; ● co-activation for Pro VB. Differences between the two populations, ns: non significant.

centered predominantly on concentric internal rotation and eccentric external rotation [33]. Assuming that *i*) concentric training is known to increase concentric and eccentric strength whereas eccentric training just increases eccentric strength production [21] and *ii*) eccentric training increases the muscle damage and degeneration [15], it could be surmised that volleyball specific training leads to stronger internal rotators and weaker external rotators [31]. As a matter of indicative comparison of the ER/IR ratios for the volleyball players in our study obtained in isokinetic 30°.s^{-1} and other physical activities, a progressive increase can be observed considering, respectively Pro VB (ratio = 0.45), swimmers (ratio≈0.5), Amat VB (ratio = 0.59), baseball pitchers (ratio range between 0.59–0.7), tennis players (ratio≈0.68) and sedentary subjects (ratio ≥ 0.7) [4, 12, 14, 20, 29]. This showed that volleyball activity induces a strong deficit in the external rotators (◉ **Fig. 5** ■ ■ ■).

More precisely, concerning internal shoulder rotation, and regardless of the experimental condition, no significant difference was observed regarding torque production and the muscle activation between Pro VB and Amat VB (except for muscle activation in the eccentric condition at 30 and 90°.s^{-1}: Amat VB > Pro VB). This means, considering the elite players participating in this study, that intensive volleyball practice does not lead to changes in the shoulder internal rotators, neither in terms of muscle activation nor in terms of muscle specific damage. Furthermore, it can be noticed that muscle co-activation is significantly higher for Amat VB only at the highest velocity which can be relevant with a more efficient pattern of movement for those high velocities of movement among elite volleyball players. This would induce a better resistance to fatigue considering the repetition of high movement velocity for the Pro VB. In contrast, during external rotation, the torque production deficit was found for Pro VB *vs.* Amat VB in isometric condition (and only a tendency is observed in isokinetic condition) without any level of activation difference. This would demonstrate that the shoulder external rotation deficit originates from muscle specific damage rather than activation deficit, which would correspond to the *infraspinatus* hypotrophy possibly involved in volleyball practice consecutive to *suprascapular* neuropathy [33]. Nevertheless, the normalization process of the SEMG-RMS data used in our study can be discussed, as in many others studies that deal with EMG investigations, since it does not take into account muscle inhibition that could be linked to pain [13]. Thus, it cannot be excluded that an activation deficit occurs during maximal isometric contraction, which leads to shoulder external rotation torque deficit, but that for normalized process reasons, this SEMG-RMS deficit cannot be pointed out. Whatever it may be, the muscle damage that is probably involved in the strength deficit observed in this study should be confirmed, e.g. using MRI investigations. This would be an interesting result since it might lead to recommendations for strengthening shoulder external rotators to prevent such a deficit.

These preliminary results emphasize that a high level of volleyball practice may induce a strong external rotators deficit compared to some others physical activities, possibly originating from muscle specific damage. Nevertheless, this study requires further investigations to determine precisely whether the mechanisms involved in the external rotation torque production deficit induced by volleyball practice as observed in this study originate only from muscle damage or from muscle and nerve deficit.

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