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Tight shoulders: a clinical, kinematic and strength comparison of symptomatic and asymptomatic male overhead athletes before and after stretching

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ABSTRACT

A tightness of the posterior structures of the throwing shoulder has been hypothesized to be associated with injuries and pain because of alterations of the scapular kinematics and muscular imbalances. The aims of this study were to identify the clinical and biomechanical profile of symptomatic and asymptomatic overhead athletes with a tight shoulder and to evaluate the efficiency of a self-applied stretching program.

Twenty male overhead athletes were recruited. Half of them reported a painful shoulder at the beginning of the study. For four weeks, the volunteers performed daily stretching exercises. Before and after the stretching program, gleno-humeral mobility, scapular kinematics, rotator muscles strength and pain were evaluated.

Before stretching, the main difference between the groups was more impingement syndrome and rotator cuff tendon lesion positive tests in the symptomatic group ($p<0.027$, effect size = 0.51). After the program, pain reported by the symptomatic volunteers was reduced by approximately 40% and the gleno-humeral internal rotation bilateral difference was significantly reduced by 77.6% ($p<0.009$, effect size = 0.84). In the symptomatic group, the scapula at rest was significantly more posteriorly tilted ($p=0.027$, effect size = 0.69) after the stretching; a position that has been shown to limit the risk of impingement.

The absence of significant differences of the profiles of the symptomatic and asymptomatic overhead athletes before stretching may indicate that the initiation of early prevention programs, including self-applied stretching, should not rely solely on biomechanical and clinical parameters and might be recommended to all players with a tight shoulder.

Keywords: scapula, gleno-humeral, rehabilitation, prevention

INTRODUCTION

Athletes involved in regular and intensive overhead activities are more at risk of suffering shoulder injuries and developing shoulder pain than sedentary people (1,2). Even in healthy athletes, the practice of overhead activities has been shown to lead to scapulo-thoracic (3) and gleno-humeral (4) kinematic adaptations. When micro-traumatic shoulder lesions are involved, those specific adaptations may appear progressively and, if they are detected in time, prevention programmes may be effective. There is therefore a real motivation to identify not only the characteristics of symptomatic athletes but also those of the asymptomatic athletes.

Physical therapy based on stretching has been shown to be an effective approach to reduce the pain of a symptomatic tight shoulder as well as to restore the mobility of the gleno-humeral joint (5). Asymptomatic subjects also seem to benefit from a stretching programme (6). Though actual rehabilitation programmes based on stretching seem to influence gleno-humeral mobility, there is little knowledge of their effects on other factors that have been shown to favour shoulder disorders, such as subacromial impingement syndrome (SAIS). These additional factors include muscle imbalances and altered scapular posture and kinematics (7–9). Having a better understanding of the effects of stretching programmes on multiple risk factors will help us to evaluate whether these programmes are sufficient or need to be augmented by additional exercises focusing on non-addressed risk factors.

The present study evaluated symptomatic and asymptomatic athletes with a dominant tight shoulder. The two main aims were: 1) to compare the profiles of asymptomatic and symptomatic athletes with a dominant tight shoulder in terms of gleno-humeral mobility, muscle strength, scapular kinematics and pain; and 2) to evaluate the effects of a self-applied stretching programme on these parameters. We hypothesize that the self-applied stretching program will have a similar effect than a program managed by a physiotherapist on pain reduction and on increasing gleno-humeral mobility and will not affect strength. Such knowledge could help to develop early and more efficient rehabilitation and prevention programmes.

METHODS

Participants

Twenty male overhead recreational athletes playing either handball or volleyball were recruited. To be eligible, participants had to be aged between 18 and 30 years old and to have practiced more than six hours per week during the five years preceding the study. None of the participants had a history of surgery on their dominant (throwing) shoulder. Furthermore, the participants needed to present, on their dominant side, a gleno-humeral internal rotation deficit (GIRD) and a horizontal adduction deficit. These variables were estimated using both the sleeper stretch (2) and the cross-body arm (9) tests (Figure 1) using the methodology described in reference papers (2,9). The sleeper stretch and cross-body arm evaluations were performed by the same examiner. A participant was considered as 'tight' when the results of these two tests were in the extreme 2.5% values of a healthy, sedentary population (i.e. practicing less than two hours of a sport involving the upper limbs) tested in our laboratory using the same protocol (personal unpublished data). The 2.5% value corresponds to the inferior (superior) tail of a normal distribution cuts off by a limit equal to the mean minus (plus) 1.96 times the standard deviation observed in the reference population. The thresholds for both tests are superior to 19 cm for the sleeper stretch (distance between the radial styloid and the table) and inferior to 28° for the cross-body arm (angle between the vertical position and the arm).

The volunteers were divided into two groups. The volunteers of the asymptomatic group did not suffer from any pain at their dominant shoulder whereas the volunteers from the symptomatic group reported, at the beginning of the study, a painful dominant shoulder during training and competition. A score of at least three on a Numerical Rating Scale ranging from zero to ten, NRS-11, was required, zero corresponding to no pain and 10 to the worst imaginable pain. This scale was reported to be valid and reliable (10). The score of three was shown to be the limit between mild and moderate pain with respect to a verbal numeric scale (11). The pain should not prevent them from practicing their sport. No significant differences were found between the characteristics of the two groups (Table 1).

The study was approved by the local ethics committee and each participant was informed of the details of the study and provided signed consent before participation.

Stretching programme

The participants self-performed, at home, two different stretching exercises on their dominant side daily for four weeks (five repetitions of 30 seconds with a 30 second pause between each repetition): the sleeper stretch (2) and the cross-body arm (9). The sleeper stretch was performed in a side lying position with the dominant arm and elbow flexed at 90°. The non-dominant arm was used to internally rotate the dominant arm by pushing the wrist down. The cross-body arm was performed in a standing position against a wall to stabilise the scapula. The arm was elevated at 90° and then maximally horizontally adducted. For both stretching exercises, the participants were instructed to stop the stretch before pain was reached (maximum five over ten on a NRS-11) (12).

Careful instructions and demonstrations were given by an experienced physiotherapist before the programme. Participants' comprehension of the instructions was verified in order to ensure that the programme was correctly applied. The participants had to fill out a form every day to ensure that the stretching programme was carried out correctly.

All the evaluations described in the following sections were performed twice by the same examiner: once before the stretching programme and once after.

Clinical evaluations before and after the stretching programme

Pain during physical activity (training and competition) was reported using a NRS-11 ranging from zero (no pain) to ten (worst imaginable pain).

The tightness of the shoulder was measured using the procedure already described in the 'Participants' section, using the sleeper stretch and the cross-body arm tests. The stiffness of the pectoralis minor muscle was evaluated by measuring the distance between the posterior angle of the acromion and the surface of the table while the subject lay in the supine position (2). Passive internal and external range of motion of the shoulder was assessed with the athletes in supine position and their shoulder at 90° of abduction in the frontal plane. The examiner mobilised the gleno-humeral joint up to a maximal rotation. The rotation was measured using a goniometer.

The reproducibility of the tests evaluating the tightness of the shoulder were previously evaluated (Intraclass correlation, ICC) in the literature (2,9). ICC values are superior to 0.89 except for cross body arm (0.75). Based on the ICC values and standard deviation described in these previous papers (2,9), Standard Error of Measurement (SEM) estimations for internal rotation, external rotation, sleeper stretch, cross body arm and pectoralis minor stiffness are equal to 4.8°, 3.2°, 1.2 cm, 1.8° and 0.6 cm respectively. Minimal Detectable Change (MDC_{95}) estimated from the SEM are equal to 13.3°, 8.9°, 3.3 cm, 5.0° and 1.7 cm.

The tightness tests were performed alongside a physical examination of the shoulder: checking for any impingement syndrome (Neer's, Hawkins', and Yocum's tests); and checking for rotator cuff lesions (Jobe's test, Patte's test, lift-off test, and palm-up test). The clinical examination was performed by a physiotherapist with 30 years of experience.

Isokinetic evaluation

Isokinetic evaluation of the shoulder internal (IR) and external (ER) rotator strength was performed using a Cybex Norm dynamometer (Henley Healthcare, Sugarland, TX, USA). The dominant shoulder was assessed in the supine position with the arm in the frontal plane at 90° of abduction with the elbow flexed at 90° (13). After a standardised warm up using an elastic band and a familiarisation on the dynamometer with submaximal contractions, the protocol consisted of maximal concentric exertions

at 60°/s (three repetitions) and 240°/s (five repetitions) and eccentric exertions at 60°/s (four repetitions). The peak torque relative to the body mass as well as the classic (ER concentric/IR concentric) and mixed (ER eccentric/IR concentric) ratios were calculated.

Evaluation of the scapula kinematics

The 3D motion of the scapula was recorded using four Codamotion CX1 units (Charnwood Dynamics, Rothley, UK) at a sampling rate of 100 Hz. This system has been shown to have good accuracy (14). Four markers were placed on the thorax with respect to the International Society of Biomechanics (ISB) recommendations (15). Six markers were placed on the upper posterior face of the dominant scapula (16). Finally, four markers were added to the side of the dominant arm.

The participants were asked to perform two active motions on their dominant side: arm elevation in the sagittal plane and in the frontal plane with the arm externally rotated. For each motion, the participants actively moved their arm up to their maximal range five times. The position at rest of the participants was measured in an upright position with the hands alongside the body.

The bone kinematics were expressed using the anatomical-based reference frames recommended by the ISB (15). Scapular and humerus orientations were expressed relative to the thorax using the YXZ Cardan angles decomposition (17,18). The position at rest was used to define an arbitrary zero for the humeral rotations. The kinematic data were averaged first for each subject over five repeated trials and then over the population for every 30 degrees increment of the humeral elevation. The scapular kinematics are shown up to 120° of humerus elevation.

Statistical analysis

Descriptive statistics of the measures are presented. As the samples were not found to follow a Gaussian distribution (Kolmogorov-Smirnov test), non-parametric paired tests (Wilcoxon signed rank test) were used to compare the parameters before and after the stretching programme (R, package *stats*, version 3.5.3) (19). Non-parametric non-paired tests (Wilcoxon rank sum test) were used to compare the parameters of the two groups. The level of significance was set at $p < 0.05$. Effect sizes were also computed when statistical differences were found between groups (R, package *rstatix*, version 0.4.0). The estimates for the effect size of the non-parametric tests rely on the formulas provided in Tomczak et al. (20). The classification for effect size was based on Cohen's d (21).

RESULTS

Clinical tests

Before stretching, the symptomatic group reported a higher level of pain than the asymptomatic group (0 versus 5 on a NRS-11) (Table 2). Both groups exhibited tightness compared to a reference group of healthy and sedentary volunteers of the same age tested in the laboratory (sleeper stretch: 15.8±2.6 cm, cross-body arm: 37.2±6.4°, internal rotation: 68.8±11.7°, external rotation: 83.7±16.0°, total range: 152.5±20.6°). In comparison with the non-dominant arm, the Total Arc of Mobility Difference (TAMDiff) was equal to 0.0° [-7.3 – 8.8°] in the asymptomatic group, against -4.0° [-5.8 – 1.0°] in favour of the non-dominant side in the symptomatic group. The bilateral gleno-humeral internal rotation differences (GIRDiff) were equal to -12.5° [-13.8 – -10.3°] and -6.5° [-11.3 – -3.5°] in the asymptomatic and symptomatic groups, respectively. The asymptomatic group presented a significant reduced mobility of the gleno-humeral joint in comparison with the symptomatic group (cross body arm: $p=0.039$; internal rotation: $p=0.048$) but the effect sizes are only small (values inferior to 0.47). The symptomatic group displayed a statistically significant higher level of positive test results for impingement syndrome and rotator cuff lesions ($p<0.027$, medium effect sizes > 0.51).

The stretching programme led to a significant decrease of pain (median decrease of 41.4%, $p=0.021$, large effect size = 0.81) in the symptomatic group, even if pain did not completely disappear. A significant decrease of tightness in both groups ($p=0.006$, large effect sizes = 0.89) and an increase of the internal passive mobility of the shoulder ($p<0.022$, large effect sizes > 0.80) was also observed (Table 3). Apart from pain levels, there were no longer any significant differences observed between the two groups at the end of the stretching programme ($p>0.078$). Moreover, the GIRDiff were significantly reduced by 68.8% (8.0° [4.5 – 7.8°], $p=0.006$, large effect size = 0.89) and 77.6% (5.0° [2.0 – 6.2°], $p=0.009$, large effect size = 0.84) after stretching in the asymptomatic and the symptomatic groups, respectively. At the end of the stretching programme, the positive tests for impingement syndrome and rotator cuff lesion in the two groups were no longer significantly different ($p > 0.078$).

The modifications observed in the clinical tests are close or superior to the MDC_{95} values and should therefore represent a noticeable change in ability of the volunteers.

Isokinetic tests

No significant changes to the concentric and eccentric maximal strength of the internal and external rotators of the shoulder were observed after stretching (Table 2) ($p>0.107$), either for the asymptomatic nor the symptomatic dominant shoulders. Nor was there any modification of the ratios ($p>0.106$).

Kinematic evaluations

No differences in kinematics were observed between the two groups before stretching ($p>0.063$). The stretching programme led to limited modifications to the posture and

the kinematics of the scapula. The stretching programme led to a significantly more posteriorly tilted scapula in the symptomatic group at rest (6.0°, p=0.027, medium effect size = 0.69) (Table 3).

DISCUSSION

The first aim of this study was to characterise the profiles of athletes with symptomatic and asymptomatic tight shoulders in terms of gleno-humeral mobility, muscle strength and scapular kinematics, which are recognised risk factors for shoulder disorders such as subacromial impingement syndrome (SAIS). The second aim was to report the consequences of a self-applied stretching programme on these risk factors. In order to increase internal validity only male participants were included in the study (22).

Characterisation of the asymptomatic and symptomatic tight shoulders before stretching

Most overhead throwing athletes develop a specific kinematic pattern for their dominant arm. While some of these modifications are normal adaptations to overhead throwing, some of them may contribute to shoulder injuries or pain (7–9). The posterior tightness of the shoulder in both groups reveals a modification of the normal mobility of the gleno-humeral joint. Limits for symptomatic GIRD usually range from 20° (23) to 25° (1). These values are nearly twice as the GIRDiff observed in the symptomatic group (6.5°) demonstrating the absence of deficit in our populations. The GIRDiff observed in the symptomatic group could be partially related to the humeral head retroversion bilateral difference of 17° observed previously in baseball players (24). No imaging of the humerus was however performed in this study to verify this hypothesis. In overhead athletes a decrease in internal rotation is usually associated with a significant increase in the maximum external rotation in comparison with the non-dominant side (7,8,24). Similar results were obtained in our study. Some authors (4) have found that the risk of injury is increased if the loss of internal rotation is not compensated for by an equivalent gain of external rotation. The amplitude of internal/external rotation should remain constant (constant Total Arc of Mobility). Wilk et al. (23) reported that athletes with a TAMD superior to 5° are twice as more likely to get injured than other athletes. As for the internal rotation, we observed in the present study that the symptomatic group presented a TAMDiff (4.0°) inferior to the limit used by Wilk. The overhead athletes engaged in our study practice however differ from the professional baseball players of the study of Wilk et al in terms of practiced sports and skill levels. Overall, our observations seem to demonstrate that athletes without GIRD or TAMD (with respect to the thresholds usually used in the literature) can already be symptomatic. These results advocate for the development of early prevention programmes that would not be based solely on these variables. However, this statement should be confirmed by prospective studies, which may reconsider the limits used to define at-risk levels for GIRD or TAMD.

The symptomatic group probably suffered a reduced subacromial space, indicated by the significantly higher number of positive impingement syndrome test results when compared to the asymptomatic group. Increased scapular upward rotation has been shown to limit the risk of impingement (25) by increasing the subacromial space. Several authors report that chronic adaptations of the scapular kinematics occur in overhead athletes, including a more upward rotation of the scapula (26,27). Inappropriate scapular kinematics could therefore lead to conflicts such as those reported in the symptomatic group. In comparison with a healthy and sedentary population (0.5° of upward rotation, 8° of anterior tilt) (28) tested with a similar

protocol, both the symptomatic and the asymptomatic groups of the current study had a less upwardly rotated and more anteriorly rotated scapula. These results could indicate that prevention programmes should not limit their objectives to the restoration of the gleno-humeral joint mobility but also to scapular kinematics relative to the thorax. Our study was, however, not able to identify postural or kinematic differences between the asymptomatic and symptomatic athletes. This once again suggests that the appearance of pain is multi-factorial and that the implementation of a prevention programme should not rely solely on the biomechanical variables evaluated in this study (such as GIRDiff, TAMDiff). Other variables that have been shown to relate with shoulder injuries should also be carefully monitored including the training load (29), scapula muscles' strength (30), shoulder laxity (30), proprioception (31), altered throwing kinematics (31) and injury history (32).

Several studies (2,33) have hypothesised that weakened posterior shoulder muscles increase the risk of injury and pain in overhead athletes. The eccentric force of the internal and external rotators has a protective influence on the shoulder (2). Conversely, an imbalance between the rotator muscles' strength and a weakness of the maximal eccentric strength developed by the external rotators have been previously associated with shoulder injuries (2,34). Indeed, a repetition of eccentric overloads of the external rotators during the follow-through stage of the throw would be prejudicial to the shoulder structures. Stickley et al. (35) observed a significant lower agonist-antagonist ratio for adolescent female volleyball athletes with a shoulder injury history than their counterparts without a shoulder injury history. The current study did not find differences in the maximal strength developed by rotator muscles (in neither eccentric nor concentric conditions) or of the agonist/antagonist balance between symptomatic and asymptomatic shoulders. In none of the populations did the reported ratios indicate a risk as defined by the values reported in the literature (2,13). Therefore, in the context of a tight shoulder, prevention programmes may not need to give priority to muscle strengthening unless a specific strength deficit has been detected.

Effects of the stretching programme

This study has evaluated the effects of a stretching programme on several risk factors of the SAIS. As described by Kibler (36), two stretching exercises of the posterior shoulder structures are predominantly described in the literature and used clinically: the cross-body arm and the sleeper stretch. The stretching lasts at least 30 seconds (5,6,37,38) and is repeated between three (5,6,37) and five times (38), three (5,37) to seven days a week (6). The duration of the programme is usually four weeks (38), but can be as short as three weeks (5) and as long as twelve (39). The stretching programme used in the present study combined these two main stretching exercises. Our programme was, in terms of protocol (duration, repetitions etc.) in the average of those present in the literature (5,6,37,38). Contrary to other studies (5), the stretching was self-applied and the physiotherapist only intervened at the beginning of the programme as an instructor. Developing self-applied protocols is of great interest if they are to be proposed to asymptomatic athletes who are not under the active care of a physician or a physiotherapist.

The symptomatic population reported a significant reduction of pain. The reduction of pain may be explained by the reduction of impingement symptoms (as shown by the significant decrease of positive impingement tests), thanks in turn to a reduction of the posterior tightness of the shoulder. Indeed, in both groups, the GIRD was reduced by more than 65%. These observations complement previous results (5,39), which show an increase in the range of motion after stretching. This hypothesis is also supported by Maenhout (6), who found (using ultrasound imaging) that stretching increases the subacromial space after a six-week programme. Our results regarding the effectiveness of the stretching protocol show that stretching can be effective without the presence of a physiotherapist at every stage of the programme and that simply providing detailed instructions/demonstrations at the beginning of the programme could be sufficient. This result opens interesting opportunities to implement such programmes in sports clubs.

At the end of the stretching programme, pain had, however, not completely disappeared in the symptomatic group. This result may be explained by the persistence of positive impingement tests even though the difference between the two groups was no longer significant. It is difficult to conclude the reason for these remaining positive impingement tests from the results of this study. One explanation could be that, even though there was a normalisation of the tightness parameters, the positioning of the scapula was still not optimal and not significantly influenced by the stretching programme. Indeed, after the stretching programme, the scapula in the symptomatic group was, at rest, significantly less upwardly rotated than in the asymptomatic group and no significant modifications of the kinematics were observed during flexion/abduction in the symptomatic group. An increased upward rotation of the scapula seems to be needed in throwing activities, as this particular kinematics has been reported to be an adaptation of non-symptomatic throwers (26,27). Based on these results, future studies may investigate the interest of prevention programmes including exercises dedicated to the scapular positioning in addition to the stretching exercises. Another explanation to the persistence of pain could be the history (length) of the symptoms as well as the individual processing of pain.

The stretching programme had no significant impact on the strength of the internal and external rotators. Indeed, the rotators' strength characteristics (peak torque and ratios) were not significantly altered. Fowles' study (40) on plantar flexors supports our results; their findings show that the duration of the effect of stretching on the muscle strength lasts only a short period of time (one hour).

Limitations

The clinical evaluation was based on clinical tests used frequently in clinical practice, which may not have the same specificity and/or specificity than other technics (such as medical imaging) for diagnosis purposes. Furthermore, the isokinetic muscles strength was evaluated in a supine position and only for the shoulder rotators. This modality has the advantage to be specific and reliable but did not allow us to evaluate the whole kinetic chain, which is known to be important in overhead sports. Finally, even if the choice of using a self-applied stretching program has the advantage to be

more easily used by sport practitioners, it has the drawbacks of lacking a control of the load applied during stretching and the adherence to the program. In this study, the participation was self-reported.

Concerning the scope of this study, readers should be cautious in extrapolating the results to other populations because only a relatively small number of male athletes were evaluated. The history of the symptoms was not taken into account in the present study even though it might have explained some differences observed in the symptomatic population with respect to the efficiency of the stretching program on pain.

CONCLUSION

Based on the results of this study, few differences were found in terms of gleno-humeral mobility, scapula kinematics and strength of the rotator muscles between a population of asymptomatic athletes and a population of symptomatic athletes, all of whom were still able to train and participate in competition. This study demonstrates, however, that symptomatic athletes may report pain even without GIRD and TAMD with respect to the threshold values usually reported in the literature. Prevention programmes might therefore be valuable as soon as tightness appear at the gleno-humeral joint. Future research may focus on protocols restoring the correct scapular posture and kinematics and their effects. The stretching programme used in this study was self-applied and was found to be as efficient as previously reported programmes. It could therefore be easily and efficiently included in the exercises proposed by fitness coaches, physiotherapists or certified athletic trainers to athletes.

CONFLICT OF INTEREST

The authors have no conflicts of interest.

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	Asymptomatic group		Symptomatic group		Statistics
	Median [Q25 – Q75]		*Median [Q25 – Q75]*		*p-value*
Age (years)	20.0	20.0 – 22.5	24.0	21.3 – 28.8	0.067
Height (m)	1.86	1.77 – 1.90	1.84	1.81 –1.85	0.622
Weight (kg)	74.0	72.0 – 78.75	78.0	75.3 –82.8	0.306
Laterality (R -- L)	9 -- 1		9 -- 1		-

Q: quartile, R: right, L: left

Table 1 – Groups' characteristics

			Asymptomatic group *Median [Q25 – Q75]*		**Symptomatic group** *Median [Q25 – Q75]*		*p-value effect size [95% CI]*
Clinical evaluation	Impingement syndrome tests (% of positive tests)		0.0	[0.0 – 13.3]	33.3	[33.3 – 66.7]	**0.027 0.51 [0.12 0.82]**
	Rotator cuff lesion tests (% of positive tests)		0.0	[0.0 – 0.0]	25.0	[0.0 – 43.8]	**0.020 0.53 [0.19 0.84]**
	Numerical Rating Scale (from 0 to 10)		0.0	[0.0 – 0.0]	5.0	[4.3 – 5.0]	-
	Sleeper Stretch (cm)		22.5	[20.9 – 24.4]	22.5	[21.6 – 24.0]	0.909
	Cross Body Arm (°)		10.0	[10.0 – 13.5]	15.0	[14.3 – 16.0]	**0.039 0.47 [0.07 0.83]**
	Pectoralis minor stiffness (cm)		7.5	[7.13 – 7.88]	7.0	[7.0 – 7.8]	0.485
	Internal rotation (°)		30.0	[26.3 – 30.0]	36.0	[32.5 – 42.5]	**0.048 0.45 [0.06 0.79]**
	External rotation (°)		101.0	[97.8 – 110.0]	100.0	[90.3 – 101.5]	0.111
	GIRDiff (°)		-12.5	[-13.8 – -10.3]	-6.5	[-11.3 – -3.5]	0.082
	TAMDiff (°)		0.0	[-7.3 – 8.8]	-4.0	[-5.8 – 1.0]	0.449
Isokinetic testing	Internal rotation (IR) (N.m/kg)	c60	0.60	[0.55 – 0.66]	0.64	[0.58 – 0.66]	0.631
		e60	0.67	[0.64 – 0.81]	0.73	[0.69 – 0.78]	0.436
	External rotation (ER) (N.m/kg)	c60	0.46	[0.41 – 0.46]	0.47	[0.43 – 0.5]	0.520
		e60	0.61	[0.53 – 0.63]	0.61	[0.60 – 0.64]	0.631
	Classic ratio	ER c60 / IR c60	0.69	[0.64 – 0.80]	0.74	[0.65 – 0.84]	0.684
	Mixed ratio	ER e60 / IR c240	1.20	[1.02 – 1.23]	1.23	[1.09 – 1.34]	0.650
Scapular kinematics	Internal rotation (°)	Humerus at rest	30.6	[24.3 – 36.6]	31.9	[27.9 – 32.7]	0.734
	Anterior tilt (°)	Humerus at rest	12.5	[10.9 – 15.1]	12.6	[9.8 – 13.9]	0.579
	Upward rotation (°)	Humerus at rest	-3.3	[-6.8 – -1.3]	-4.6	[-7.7 – -3.9]	0.218
	Upward rotation (°)	Humerus at 120° abd	29.3	[28.2 –30.9]	28.9	[25.5 – 29.6]	0.315
	Humeral amplitude (°)	Abduction	160.0	[150.8 – 163.0]	165.3	[159.9 – 171.9]	0.063

GIRDiff: gleno-humeral internal rotation bilateral difference, TAMDiff: total arc of mobility bilateral difference (for GIRDiff and TAMDiff, negative values indicate a deficit of the dominant arm), IR: internal rotation, ER: external rotation, c60: concentric mode at 60°/s, e60: eccentric mode at 60°/s, c240: concentric mode at 240°/s, abd: abduction Q: quartile, CI: confidence interval

Table 2 – Profiles of the asymptomatic and symptomatic groups before the stretching program

			Asymptomatic group *Median [Q25 – Q75]*		**Symptomatic group** *Median [Q25 – Q75]*		*p-value effect size [95% CI]*		
							*	†	‡
Clinical evaluation	Impingement syndrome tests (% of positive tests)		0.0	[0.0 – 0.0]	16.7	[0.0 – 33.3]	0.139	1.000	0.057
	Rotator cuff lesion tests (% of positive tests)		0.0	[0.0 – 0.0]	0.0	[0.0 – 18.8]	0.078	1.000	0.065
	Numerical Rating Scale (from 0 to 10)		0.0	[0.0 – 0.0]	2.5	[2.0 – 4.0]	-	-	**0.021 0.81 [0.63 0.90]**
	Sleeper Stretch (cm)		14.5	[12.4 – 15.9]	14.5	[12.3 – 16.3]	0.820	**0.006 0.89 [0.89 0.92]**	**0.006 0.89 [0.89 0.90]**
	Cross Body Arm (°)		24.5	[22.5 – 26.8]	20.5	[20.0 – 24.3]	0.139	**0.006 0.89 [0.89 0.91]**	**0.006 0.89 [0.89 0.91]**
	Pectoralis minor stiffness (cm)		6.0	[5.63 – 7.0]	6.8	[6.0 – 7.0]	0.440	**0.019 0.76 [0.40 0.90]**	0.142
	Internal rotation (°)		43.5	[39.0 – 45.8]	44.0	[39.8 – 46.5]	0.820	**0.006 0.89 [0.89 0.90]**	**0.022 0.80 [0.63 0.88]**
	External rotation (°)		102.0	[95.0 – 107.2]	99.0	[95.0 – 100.0]	0.305	0.241	0.483
	GIRDiff (°)		-4.5	[-5.8 – -1.3]	-2.0	[-5.5 – 1.5]	0.426	**0.006 0.89 [0.89 0.91]**	**0.009 0.84 [0.65 0.90]**
	TAMDiff (°)		5.5	[-1.5 – 13.3]	5.5	[1.5 – 7.0]	0.970	0.073	0.017
Isokinetic testing	Internal rotation (IR) (N.m/kg)	c60	0.57	[0.52 – 0.65]	0.57	[0.52 – 0.64]	0.971	0.107	0.352
		e60	0.65	[0.63 – 0.71]	0.72	[0.67 – 0.83]	0.166	0.554	0.275
	External rotation (ER) (N.m/kg)	c60	0.44	[0.41 – 0.47]	0.46	[0.39 – 0.50]	0.971	1.000	0.554
		e60	0.56	[0.53 – 0.57]	0.57	[0.52 – 0.60]	0.821	0.375	0.155
	Classic ratio	ER c60 / IR c60	0.73	[0.71 – 0.81]	0.75	[0.70 – 0.81]	1.000	0.322	0.236
	Mixed ratio	ER e60 / IR c240	1.10	[0.99 – 1.18]	1.10	[0.95 – 1.19]	0.940	0.106	0.322

Scapular kinematics	Internal rotation (°)	Humerus at rest	28.9	[27.4 – 35.1]	34.5	[28.9 – 41.3]	0.315	0.625	0.160
	Anterior tilt (°)	Humerus at rest	12.3	[9.5 – 14.6]	6.6	[5.7 – 8.3]	**0.002** **0.66 [0.34 0.83]**	0.557	**0.027** **0.69 [0.24 0.89]**
	Upward rotation (°)	Humerus at rest	-1.7	[-5.1 – 1.6]	-9.2	[-11.1 – -2.4]	**0.029** **0.49 [0.11 0.77]**	0.770	0.064
	Upward rotation (°)	Humerus at 120° abd	31.2	[29.5 – 31.8]	30.3	[28.6 – 31.7]	0.529	**0.049** **0.11 [0.02 0.70]**	0.232
	Humeral amplitude (°)	Abduction	162.6	[155.0 – 169.2]	165.1	[159.6 – 169.8]	0.631	**0.010** **0.79 [0.41 0.89]**	0.846

**: p-values between both groups at post test*

†: p-values between pre and post tests in the asymptomatic group

‡: p-values between pre and post tests in the symptomatic group

GIRDiff: gleno-humeral internal rotation bilateral difference, TAMDiff: total arc of mobility bilateral difference (for GIRDiff and TAMDiff, negative values indicate a deficit of the dominant arm, IR: internal rotation, ER: external rotation, c60: concentric mode at 60°/s, e60: eccentric mode at 60°/s, c240: concentric mode at 240°/s, abd: abduction, Q: quartile, CI: confidence interval

Table 3 – Profiles of the asymptomatic and the symptomatic groups after the stretching program

FIGURE LEGENDS

Figure 1: Tests used for the shoulder tightness evaluation: (i) cross body arm and (ii) sleeper stretch