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Differences in strength and fatigue resistance of scapular protractors and retractors between symptomatic and asymptomatic dyskinesis

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Abstract

Context: Scapular dyskinesis is a shoulder dysfunction that can be asymptomatic or associated with pain or weakness. Reduced strength and fatigue resistance of the scapular protractor and retractors muscles that stabilize the scapula might contribute to dyskinesis.

Objective: To determine the strength and fatigue resistance profiles of subjects with symptomatic and asymptomatic scapular dyskinesis, and to compare them to healthy controls using isokinetic assessment.

Design: Cross-sectional study.

Setting: University Hospital

Participants: Twenty healthy controls and 21 overhead athletes with symptomatic (n=10) and asymptomatic (n=11) scapular dyskinesis.

Main Outcome Measures: Strength (peak torque, maximum work), fatigue resistance (total work) and protraction/retraction ratios measured during a closed-chain isokinetic protocol (40 repetitions in concentric mode at 24.4 cm/s).

Results: The scapular protractors' strength and fatigue resistance were significantly higher ($p<0.01$) in healthy controls (peak torque: 5.0±0.9 N/Kg; maximum work: 2.4±0.5 J/Kg; total work: 72.4±0.6 J/Kg) than in asymptomatic (peak torque: 3.4±0.7 N/Kg; maximum work: 1.7±0.4 J/Kg; total work: 50.0±13.7 J/Kg) and symptomatic (peak torque: 3.8±0.6 N/Kg; maximum work: 1.8±0.3 J/Kg; total work: 58.1±12.9 J/Kg) dyskinetic participants. The dyskinetic symptomatic group presented the highest retractors' strength and fatigue resistance ($p<0.01$) values (peak torque: 5.2±0.6 N/Kg; maximum work: 2.9±0.8 J/Kg; total work:

87.7±22.7 J/Kg) followed by the healthy controls (peak torque: 4.7±1.0 N/Kg; maximum work: 2.1±0.5 J/Kg; total work: 65.3±17.9 J/Kg) and the asymptomatic dyskinetic participants (peak torque: 3.9±1.0 N/Kg; maximum work: 1.9±0.6 J/Kg; total work: 58.6±18.5 J/Kg). The protraction / retraction ratios showed a gradual decrease ($p<0.001$) from healthy controls (1.1) to asymptomatic (0.9) and symptomatic (0.7) dyskinetic subjects.

Conclusions: Scapular dyskinesis is characterized by weaker scapular protractors and reduced agonist/antagonist ratios, especially when symptomatic. Targeting the scapular protractors for a better balance of scapular musculature in rehabilitation and strengthening programs may improve shoulder symptoms and function, but more interventional studies are required.

Keywords: shoulder injuries; scapular dyskinesis; isokinetic; fatigue; closed-chain; protraction; retraction; strength

Key Points:

- Scapular dyskinesis affects shoulder motion in overhead athletes and can be symptomatic (i.e., painful) or not.
- Scapular muscle strength and fatigue resistance significantly differ between symptomatic patients, asymptomatic patients, and healthy controls, as assessed by a specific isokinetic protocol.
- Weaker shoulder protractors and reduced agonist-antagonist ratio characterize symptomatic dyskinesis and should be taken into consideration in strengthening and rehabilitation strategies

Introduction

Overhead athletes place specific constraints on their shoulder joint, given the demanding nature of movements such as throwing, hitting or swimming. The important ranges and amplitudes of these scapulohumeral movements require precise positioning and smooth motion of the scapula. When these motion patterns are altered, it results in a condition known as scapular dyskinesis. This phenomenon, initially defined by Kibler as "an alteration in the normal position or motion of the scapula during coupled scapulohumeral movements" [1,2], is particularly prevalent among overhead athletes, with a reported rate of 61% compared to 33% in non-overhead athletes [3]. Past research indicates that scapular dyskinesis increases the risk of shoulder pain and injuries [4,5].

Biomechanically, the upper, middle and lower trapezius along with the serratus anterior play key roles in scapular positioning [6]. The serratus anterior facilitates protraction, while the middle trapezius enables retraction, ensuring scapular stability both during movement and at rest [6]. For overhead athletes, who continually stress their shoulders, these stabilizing muscles are pivotal. Strength deficits in these muscles may contribute to the physiopathology of dyskinesis [7,8]. For instance, decreased strength in the lower trapezius and the serratus anterior are associated with reduced scapular upward rotation during maximal contraction [9]. Consequently, athletic performance can be impaired due to the insufficient mobility and the risk of injury is increased given the disturbed biomechanics [10].

Fatigue resistance of the scapular protractors and retractors also plays a specific role in the context of scapular dyskinesis. Scapular muscles lose their stabilizing capacity when fatigued with an intense training session, or a specific exhausting fatigue protocol, which is deleterious for scapular kinematics [11–14]. For example, a decreased posterior tilting and an increased internal rotation of the scapula were observed following a fatigue protocol (i.e., modified push-up plus task) for the serratus anterior [14].

Quantitatively measuring strength and fatigue deficits of scapular protractors and retractors can be achieved using isokinetic testing, considered as the gold standard for scapular strength measurements [15,16]. A specific closed-chain isokinetic protocol for protraction and retraction movements developed by Cools et al. has demonstrated excellent test-retest reliability (intra-class correlation coefficient 0.82 – 0.96) [17]. The original protocol consisted of ten repetitions focusing on maximal strength assessment [17–19]. Later iterations included 40 repetitions to evaluate muscle endurance [20–22]. This protocol focuses on the assessment of fatigue by increasing the number of repetitions. The prolonged muscle effort will indeed solicit the anaerobic lactic pathway [23]. This pathway accurately reflects scapular muscle demands on the field, where overhead athletes sustain multiple prolonged efforts that can induce scapular fatigue.

To date, the isokinetic assessment of scapular protractors and retractors focuses on either providing sport-specific normative values [20–22] or on the relationship between muscle dysfunction (i.e., reduced strength and imbalanced protraction/retraction ratios) and subacromial impingement symptoms in athletes [18,19]. The strength and fatigue resistance profiles of scapular protractors and retractors in the context of scapular dyskinesis remain largely unexplored. This assessment could enhance the early detection and diagnosis of scapular dyskinesis, currently reliant on clinical evaluation. Even though debated, scapular dyskinesis appears to be a risk factor for shoulder injury in overhead athletes [24,25]. Allowing early detection and refining the diagnosis with quantitative measures would allow for a proactive management of this risk. Additionally, scapular dyskinesis can be asymptomatic, with individuals not experiencing pain or discomfort even when their scapular kinematics are altered [26]. It remains unclear whether these asymptomatic cases exhibit similar muscle profiles to symptomatic ones or should be treated differently.

The aim of this study was therefore to compare the isokinetic strength and fatigue resistance profiles of scapular protractors and retractors among overhead athletes with symptomatic and asymptomatic scapular dyskinesis, along with healthy controls, unaffected by their sports practice. A second aim was to determine whether asymptomatic cases are more similar to the healthy controls or the symptomatic profiles. We hypothesize observing significant differences between the three groups, with symptomatic cases demonstrating lower strength and fatigue resistance compared to asymptomatic cases and healthy controls. We further hypothesize that asymptomatic cases present similar profiles to symptomatic ones.

Material and methods

Study design, ethics and participants' selection

This was a cross-sectional study complying with the ethical standards of the Declaration of Helsinki, and the protocol was reviewed by the institutional Ethics Committee. The participants were recruited through the Faculty and University Hospital databases. Using convenience sampling, participants potentially meeting inclusion criteria were invited to participate. Each included participant gave their signed informed consent. Inclusion criteria for the dyskinetic subjects were as follows: male subjects between 18 and 35 years old, practicing overhead sports (e.g., handball, tennis, rugby) for minimum of 3 hours and maximum of 5 hours a week, currently able to practice, with no history of musculoskeletal lesion of the upper limbs, without spine scoliosis, thoracic kyphosis beyond the norms or cervical hyperlordosis, and without lower limb length differences which could affect the assessment and the homogeneity of the study group. They were also required to have no other pathology in their dyskinetic shoulder and their contralateral shoulder had to be free of pathology (i.e., unilateral dyskinesis only). For the healthy controls, the same criteria were applied with the exception that they did not practice overhead sports, or practiced them for less than 2 hours a week. Participants were allocated to one of three different groups (i.e., healthy control, asymptomatic dyskinesis and symptomatic dyskinesis) depending on their clinical assessment (see below and Figure 1). Participants were required to not perform any upper limb training on the day prior to, and the day of the assessments.

Clinical assessment

Based on clinical evaluation by a physical therapist who specialized in shoulder pathology, subjects were classified into three groups: symptomatic unilateral dyskinesis (DS-S); asymptomatic unilateral dyskinesis (DS-A) and healthy controls (HC). The evaluations were all done by the same physical therapist. The clinical assessment consisted of two parts: the first part focused on identifying the presence or absence of dyskinesis and the second part focused on determining whether the shoulder was symptomatic (i.e., painful and/or weak) or not. These evaluations including a series of evaluations described hereafter and were chosen based on both the existing literature and clinical practice. Their reliability data and illustrative examples can be found in Supplementary Material.

For the first part, the examiner assessed dyskinesis using four steps:

1) Visual observation at rest and during arm elevation to assess the presence (i.e., abnormal floating of the scapula and/or abnormal scapular movement) or absence of dyskinesis.
2) Kibler Lateral Scapular Slide Test (LSST); which consists of measuring the distance between the lower angle of the scapula and the corresponding vertebra spinal process. This measurement is performed in 3 positions: arm alongside the body; hands on hips and arm at 90° abduction in maximal internal rotation. This test is considered positive for an asymmetry superior or equal to 1.5cm in two out of the three positions [27].
3) Stiffness of the pectoralis minor [28]; while the participant lies supine, arms relaxed alongside their body and palms facing downward, the distance (cm) between the posterior edge of the acromion and the table is measured. The test is considered positive above the 4-cm cut-off [29].
4) Stiffness of the posterior shoulder structures [28,30]; while the subject is in the sleeper stretch position (lateral decubitus, shoulder and elbow flexed to 90°), the investigator applies maximum internal rotation and measures the distance between the radial styloid and the table [31]. The test is considered positive above the 19-cm cut-off [32].

To be considered dyskinetic, the subject had to meet the following criteria: Criterion 1 (observation) positive; *and* criterion 2 (LSST) positive; *and* criteria 3 (pectoralis minor stiffness) *and/or* 4 (posterior structures stiffness) positive.

Once identified as dyskinetic, participants were included in the symptomatic group if they reported pain or weakness on at least three of the following five isometric tests (reliability data and illustrations in Supplementary Material):

1) Jobe test (supraspinatus) [33,34]: shoulder elevation and internal rotation with arm extended at 90° abduction in the scapular plane
2) Patte test 0° (infraspinatus) [35,36]: shoulder external rotation at 0° abduction with elbow flexed
3) Patte test 90° (teres minor) [35,36]: shoulder external rotation at 90° abduction with elbow flexed
4) Lift off test (subscapularis) [36,37]: shoulder internal rotation starting with hand behind the back
5) Palm up test (long head biceps) [36,38]: shoulder elevation with arm extended at 90° and external rotation

If the subject was previously considered as dyskinetic but not positive for any of these isometric tests, they were considered asymptomatic. The healthy controls all had negative dyskinesis and isometric tests. This categorization is presented in Figure 1.

Isokinetic assessment

The isokinetic assessment protocol was adapted from the one described and used by Cools et al. in several studies on the scapular assessment of overhead athletes [17–22]. In the present context of dyskinesis, where the fatigue component is important, we opted for the 40-repetition protocol. Arm dominance was recorded for each participant. The dominant arm corresponds to the one the subject used in their sporting gesture. The dyskinetic participants (DS groups) were assessed on their dyskinetic side while the healthy controls (HC groups) were assessed on their dominant side. The isokinetic assessment of scapular protractors and retractors was performed in the concentric mode using a Biodex System 4 (Biodex Medical Systems, USA). An initial warm-up consisting of performing 2*20 push-ups and 2*20 rowing exercises using elastics bands in a standing position was performed. The isokinetic assessment was then performed in a closed chain setting as follows: the chair was rotated to 15° from the sagittal plane while the engine base was rotated to 45°. The shoulder was elevated to 90° in the scapular plane. The subject had to keep their elbow actively extended throughout the tests in a neutral position. Compensation was limited by a belt as shown in Figure 2. The height of the seat was adjusted so that their arm was horizontal, and the subject was instructed to perform a maximal protraction and retraction movement (see Figure 2). The total range of motion was set at 8 cm. The assessment protocol consisted in: (1) familiarization at 18.3 cm/s (10 trials) followed by 1-minute rest; (2) 3 sub-maximal trials followed by 10-second rest and 40 maximal trials at 24.4 cm/s in concentric mode. The Biodex software was used to calculate:

- Peak torque (Newton): maximum force developed by the subject over the 40 trials.
- Maximum work (Joule): maximum amount of work performed on one trial
- Total work (Joule): total amount of work performed over the 40 trials

These parameters were calculated for the protractors and retractors in the concentric mode at 24.4 cm/s. For each variable, agonist/antagonist (i.e., protractor/retractor) ratios were calculated as well. These variables were normalized by body weight (Kg). Strength measurements included peak force and maximum work. Fatigue resistance was measured by the total work.

Statistical analysis

Regarding sample size, this was a convenience sample and no a priori statistical estimation was made. Statistical analyses were performed using R 3.6.2 (R Core Team 2008). The nature of the data distribution (normality) was assessed using Shapiro-Wilk tests. Comparisons of the demographic and isokinetic variables between the three groups (i.e., dyskinetic asymptomatic, dyskinetic symptomatic and controls) were performed using one-way ANOVAs after the homogeneity of variances was verified using Levene's tests. The effect sizes for each variable were calculated with the partial eta squared (η^2) and its 95% confidence interval. The interpretation of the magnitude of effect was small > 0.01; medium > 0.06; large > 0.14. Post-hoc pairwise comparisons were performed using Tukey's HSD test. Results were considered significant at the $p<0.05$ level.

Results

Population

Forty-one male subjects (age: 22 ± 2 years old; height: 181 ± 10 cm; mass: 80 ± 13 kg) were prospectively included in the study based on a convenience sampling. Following the first part of the clinical assessment described above (Figure 1), 21 subjects presented dyskinesis and 20 were healthy controls (HC) with no clinical feature of dyskinesis (i.e., scapular dyskinesis evaluation negative for dyskinesis). Following the second part of the clinical assessment, 11 subjects presented with asymptomatic (DS-A) and 10 with symptomatic dyskinesis (DS-S). The DS-A group had no positive isometric test on the second symptomatology evaluation. The DS-S group had at least 3 positive isometric tests and the HC had none. Five participants among the DS-A and the DS-S groups presented with dyskinesis on their non-dominant side. Demographic and clinical characteristics of the sample are presented in Table 1. There were no significant differences between the three subgroups regarding age ($p=0.26$), weight ($p=0.18$), and height ($p=0.18$). Isokinetic testing was performed according to the protocol for all the subjects and there was no report of discomfort and/or pain during and right after the testing. Isokinetic data was normally distributed as assessed by Shapiro-Wilk tests (all p's>0.05) and the group variances were assumed equal as assessed by Levene tests (all p's>0.05).

Strength assessment

Peak torque and maximum work values for the protraction / retraction 24.4 cm/s concentric movement are presented in Table 2. The peak torques of the protractors were significantly different ($p<0.001$) between the DS-S, DS-A and HC groups, with a large effect size ($\eta^2=0.49$). The HC showed the highest values (5.0 ±0.9 N/Kg) followed by the DS-S (3.8 ±0.6

N/Kg) and the DS-A (3.4 ±0.7 N/Kg). Post-hoc pairwise comparisons showed significant differences between the HC and DS-A and the HC and DS-S groups. Regarding maximum work for the protractors, the three groups showed significantly different values ($p<0.001$) with a large effect size ($\eta^2=0.34$). Again, the HC showed the highest values (2.4 ±0.5 J/Kg) followed by the DS-S (1.8 ±0.3 J/Kg) and the DS-A (1.7 ±0.4 J/Kg). Post-hoc pairwise comparisons showed significant differences between the HC and DS-A and the HC and DS-S groups.

The retractors showed a different profile. The peak torques were significantly different ($p=0.004$) between the three groups, with a large effect size ($\eta^2=0.25$). However, the DS-S group had the highest values (5.2 ±0.6 N/Kg) followed by the HC (4.7 ±1.0 N/Kg) and the DS-A (3.9 ±1.0 N/Kg). Post-hoc pairwise comparisons showed significant differences between the DS-A and HC and the DS-A and DS-S groups. Likewise, for the maximum work, the DS-S had the highest values (2.9 ±0.8 J/Kg) followed by the HC (2.1 ±0.5 J/Kg) and the DS-A (1.9 ±0.6 J/Kg), with a significant difference between the three groups ($p=0.002$) and a large effect size ($\eta^2=0.28$). Post-hoc pairwise comparisons showed significant differences between the DS-S and HC and the DS-S and DS-A groups.

This is reflected by the protractor/retractor ratios. They were significantly different between the three groups ($p<0.001$) with a large effect size ($\eta^2=0.44$). The highest ratio was for the HC (1.1 ±0.2) followed by the DS-A (0.9 ±0.1) and the DS-S (0.7 ±0.1). Post-hoc pairwise comparisons showed significant differences between the DS-S and HC and the DS-S and DS-A groups. Likewise, for the maximum work, the HC had the highest ratios (1.1 ±0.2) followed by the DS-A (0.9 ±0.2) and the DS-S (0.7 ±0.2), with a significant difference between the three groups ($p<0.001$) and a large effect size ($\eta^2=0.49$). Post-hoc pairwise comparisons showed significant differences between all the pairs. This is presented in Figure 3.

Fatigue resistance assessment

Total work values for the protraction / retraction 24.4 cm/s concentric movement are presented in Table 2. The total work of the protractors was significantly different ($p=0.003$) between the DS-S, DS-A and HC groups, with a large effect size ($\eta^2=0.26$). The HC showed the highest values (72.4 ±19.7 J/Kg) followed by the DS-S (58.1 ±12.9 J/Kg) and the DS-A (50.0 ±13.7 J/Kg). Post-hoc pairwise comparisons showed significant differences between the HC and DS-A and the HC and DS-S groups. As for the strength values, the retractors presented a different profile. The total work was significantly different ($p=0.003$) between the three groups, with a large effect size ($\eta^2=0.26$). However, the DS-S group was the one with the highest values (87.7 ±22.7 J/Kg) followed by the HC (65.3 ±17.9 J/Kg) and the DS-A (58.6 ±18.5 J/Kg). Post-hoc pairwise comparisons showed significant differences between the DS-S and HC and the DS-S and DS-A groups.

The protractors/retractors ratios were significantly different ($p<0.001$) between the three groups with a large effect size ($\eta^2=0.36$). The HC presented the highest ratio (1.1 ±0.2) followed by the DS-A (0.9 ±0.2) and the DS-S (0.7 ±0.3). Post-hoc pairwise comparisons showed significant differences between the HC and DS-A and the HC and DS-S groups. This is presented in Figure 4.

In summary, the protractors of the dyskinetic (symptomatic and asymptomatic) participants were weaker and had less fatigue resistance than the healthy controls. On the other hand, the retractors of the dyskinetic symptomatic participants were stronger and had better fatigue resistance than the healthy controls and the dyskinetic asymptomatic participants. The protractors/retractors ratios showed a gradual decrease from healthy controls, to dyskinetic asymptomatic, to dyskinetic symptomatic participants.

Discussion

Main findings

This study investigated the isokinetic strength (peak torque, maximum work) and fatigue resistance (total work) of scapular protractors and retractors using a 40-repetition 24.4 cm/s protocol for symptomatic and asymptomatic scapular dyskinesis, with a healthy group for comparison. This extended protocol aimed to engage the anaerobic lactic pathway while maintaining optimal movement speed [23]. The study aimed to identify strength and fatigue resistance imbalances associated with symptomatic scapular dyskinesis and assess whether asymptomatic cases align more with healthy controls or symptomatic profiles.

While prior studies often centered on shoulder rotators, research on the assessment of scapular protractors and retractors is limited. Nonetheless, it is crucial to include this assessment to detect muscle imbalances specific to these groups. For instance, certain athletes (e.g., elite field hockey players) may exhibit a symmetric rotational strength profile but an asymmetric strength protraction-retraction profile [22]. Such patterns can lead to injuries if unaddressed.

Our results show that both symptomatic and asymptomatic dyskinetic individuals present abnormal strength and fatigue resistance compared to healthy controls, with the discrepancy being more pronounced in symptomatic cases. This is evident in the gradual decrease of scapular protractors/retractors ratios, from around 1.1 in healthy controls to 0.9 in dyskinetic asymptomatic participants and 0.7 in dyskinetic symptomatic participants. Although normative values are lacking, previous reports suggest values ranging from 1 to 1.18 in a healthy non-athletic population [16,17]. For overhead athletes with impingement symptoms, this ratio was lower for injured shoulders (0.97) compared to healthy shoulders (1.05) [19], indicating weaker scapular protractors relative to retractors. Thus, there appears to be a continuous decrease in ratios along with symptomatology.

Surprisingly, symptomatic subjects exhibited significantly stronger scapular retractors than asymptomatic participants when considering protraction and retraction separately. Several explanations could account for this unexpected finding. Firstly, this imbalance in favor of the retractors could result from kinematic adaptation to dyskinesis, where retractor muscles adapt to misaligned scapula positioning, potentially exacerbating the issue. Conversely, starting with strong retractors that lack balance with the protractors might contribute to symptomatic dyskinesis by pulling the scapula away from the rib cage [7]. This hypothesis of altered kinematics due to muscle imbalances requires confirmation through larger prospective studies. Secondly, conventional training and rehabilitation programs often emphasize retractor strengthening, potentially neglecting scapular protractors like the serratus anterior, which tends to be weaker [7]. Prioritizing retractor strengthening over protractors, or not addressing protractors sufficiently, could result in an imbalanced ratio as observed in this study. Thirdly, the composition of the symptomatic dyskinetic sample, primarily consisting of handball players (six out of ten), could explain their stronger retractors. Handball players often exhibit pain complaints and dyskinesis [24,39] due to the sport's unique kinematic demands, characterized by high-velocity and large amplitude overhead movements that heavily engage the shoulder retractors, unlike other sports in the study (e.g., tennis, swimming). This study does not explore these hypotheses in-depth and they require further investigation. Other studies reporting normative values in elite field hockey and gymnastics indicate significantly stronger retractors in the dominant shoulder compared to the non-dominant and/or control non-athletes [21,22]. However, the present study is the first to observe stronger retractors in symptomatic subjects relative to non-symptomatic participants and controls.

Clinical implications

Scapular dyskinesis is prevalent among overhead athletes (61% according to a systematic review [3]) and may be underestimated due to its potential asymptomatic nature [26]. There is an ongoing debate whether dyskinesis represents an adaptation to sports practice or even a performance-enhancing adaptation [40]. Our results tend to challenge this premise, as both symptomatic and asymptomatic dyskinetic groups show altered protractors/retractors ratios, suggesting compromised scapular function. Despite having stronger retractors, the symptomatic group reported pain, dispelling the notion of positive adaptation.

The dyskinetic asymptomatic group might represent an intermediate stage before transitioning into the symptomatic category, though this requires further investigation. It could pave the way for primary prevention programs to counterbalance low protraction/retraction ratios. Such strengthening programs should aim at achieving a proportionate protractors/retractors ratio (about 1.1 in our healthy controls sample). Clinicians and staff should adapt rehabilitation and conditioning to focus on both retractors and protractors, specifically the weaker serratus anterior, using tailored exercises (e.g., exercises laying down using dumbbells). Both the strength and fatigue resistance modalities should be targeted. This involves short exercises with heavy loads (e.g., 3 x 4-5 repetitions at 85-90% of the one-repetition maximum; strength) and long exercises with medium loads (e.g., 3 x 15-20 high-intensity repetitions at 50-60% of the one-repetition maximum; fatigue resistance). This dual approach has been effective in rebalancing the supraspinatus and the infraspinatus strength in the context of a dyskinesis [41].

Benefits and limitations of a quantitative assessment

Traditional assessment of scapular dyskinesis relies on subjective visual observation. A quantitative evaluation of muscle strength and fatigue through isokinetic testing offers personalized rehabilitation goals and customized strengthening programs, moving beyond the "one-size-fits-all" approach. Additionally, follow-up assessments can gauge intervention effectiveness. However, this assessment approach has its limitations. Apart from cost and expertise requirements, the closed-chain isokinetic protocol is highly analytical and does not capture the complete function of the shoulder, only some specific parameters. To tackle this issue, it might be interesting to complement the evaluation with field tests that are more accessible and versatile.

To fully capture fatigue resistance performance, we considered total work over 40 repetitions, instead of solely the first and last trials, to avoid over-reliance on the first trials' performance. While it was assumed participants maintained maximal effort throughout, mental fatigue could lead to suboptimal performance towards the end. Therefore, investigators must offer proper encouragement and visually inspect strength curves to ensure maximal effort throughout the evaluation.

Methodological strength and limitations

Several limitations in this study should be considered before generalizing the results. First, strict inclusion criteria for sports practice compromised the study's external validity for other sports participation levels (e.g., leisure or professional). The control group consisted of participants not heavily engaged in overhead sports to be able to isolate the impact of sports practice on scapular dynamics. Second, this was a prospective convenience sample without a priori sample size estimation. However, significant differences were observed between the three groups of interest, which refine the understanding of scapular dyskinesis and underscore the value of a combined clinical and isokinetic approach.

Future directions

Future research could explore the multimodal assessment of scapular dyskinesis by integrating the data from other assessments like electromyography to distinguish activation patterns during fatigue resistance tests or sport-specific movements. Prospective studies could also evaluate the impact of interventions aimed at rebalancing low protraction/retraction ratios on symptomatology. Additionally, comparing dyskinesis classification accuracy between clinical experts and machines, such as isokinetic devices or others, could further refine diagnostic approaches.

Conclusions

This study presents an innovative approach to assessing symptomatic and asymptomatic scapular dyskinesis by combining qualitative (clinical) and quantitative (isokinetic) assessment of scapular protractors and retractors. This comprehensive evaluation of muscle function appears capable of distinguishing symptomatic and asymptomatic dyskinesis based on the muscle imbalance in favor of the retractors. Addressing such imbalances, even in asymptomatic cases, is crucial to prevent the development of symptomatic dyskinesis. Consequently, tailored training regimens that restore the balance between protractors and retractors, focusing on both strength and fatigue resistance, should be considered, particularly since asymptomatic subjects already display altered profiles compared to healthy controls.

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Figure and Table Legends

Figure 1: Categorization of the study participants based on the clinical assessment of dys-kinesis and on the symptomatology. LSST = lateral scapular slide test

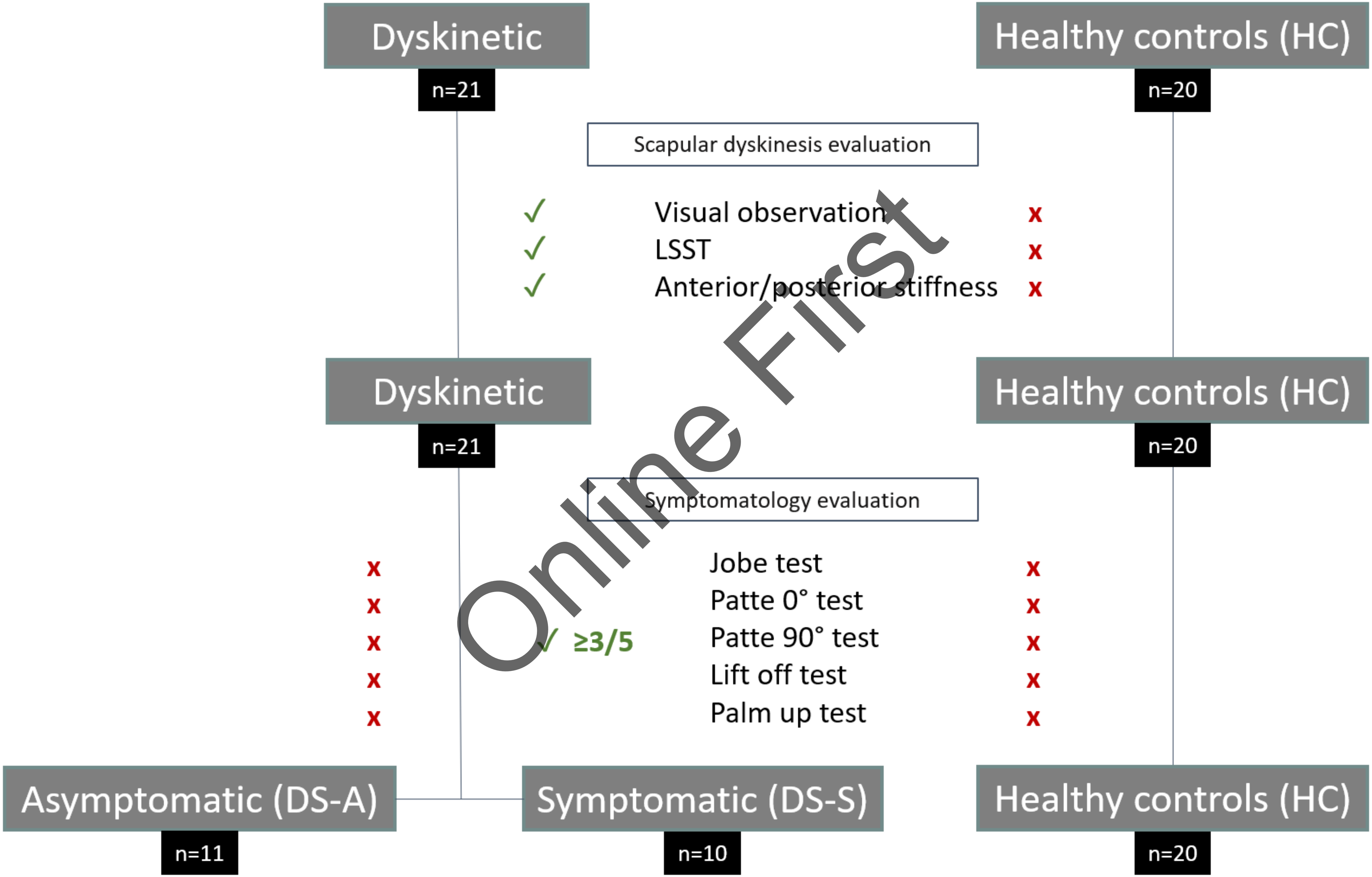
Figure 2: Subject's positioning on the isokinetic dynamometer (Biodex System 4)

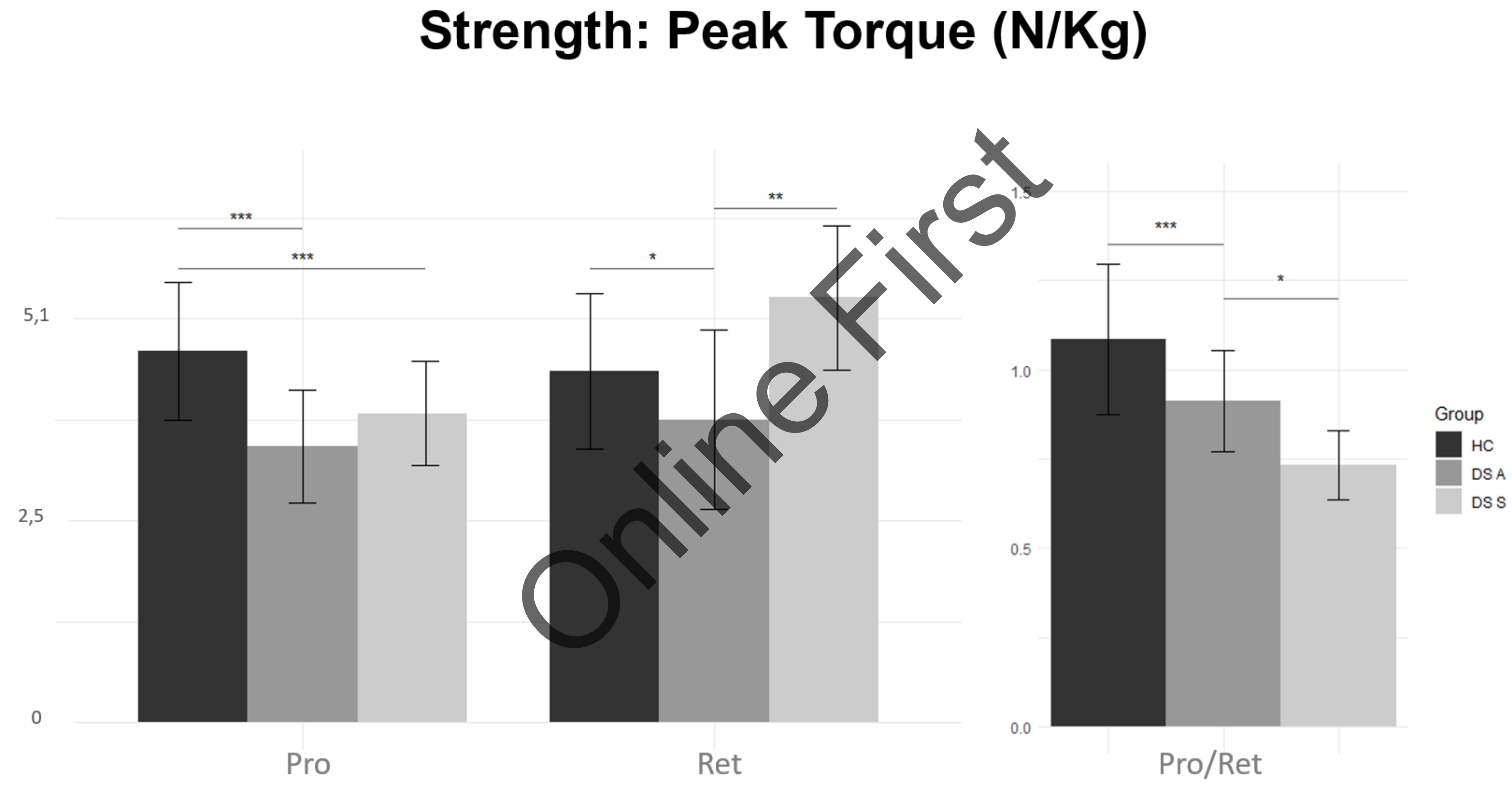
Figure 3: Barplot of the mean total work (body weight normalized) during the fatigue re-sistance protocol (40 repetitions) for the scapular protractors (Pro) and retractors (Ret) and for the ratio Pro/Ret. HC = healthy control (n=20); DS A= dyskinetic asymptomatic (n=11); DS S= dyskinetic symptomatic (n=10). Pro/Ret = agonist/antagonist ratio. Error bars represent the standard deviation from the mean. * $p<0.05$; ** $p<0.01$; *** $p<0.001$

Figure 4: Barplot of the mean peak torque values during the fatigue resistance protocol (40 repetitions) for the scapular protractors (Pro) and retractors (Ret) and for the ratio Pro/Ret. DS A= dyskinetic asymptomatic (n=11); DS S= dyskinetic symptomatic (n=10); HC = healthy control (n=20). Error bars represent the standard deviation from the mean. * $p<0.05$; ** $p<0.01$; *** $p<0.001$

Table 1: Demographic and anthropometric characteristics of the dyskinetic - symptomatic (DS-S; n=10), dyskinetic - asymptomatic (DS-A; n=11) and control (HC; n=20) subjects. [a] = one-way ANOVA test

Table 2: Isokinetic variables for the fatigue resistance protocol (40 repetitions) of healthy controls (HC), sub-jects with asymptomatic dyskinesis (DS-A) and with symptomatic dys-kinesis (DS-S); mean ± stand-ard deviation; body weight normalized. PRO = protractors; RET = retractors;) a = one-way ANOVA test, F value, p value, η^2 effect size and [95% confi-dence interval]; b = Tukey HSD test pairwise comparisons.


Dyskinetic
n=21
Healthy controls (HC)
n=20
Scapular dyskinesis evaluation
Visual observation
LSST
Anterior/posterior stiffness
Dyskinetic
n=21
Healthy controls (HC)
n=20
Symptomatology evaluation
Jobe test
Patte 0° test
Patte 90° test
Lift off test
Palm up test
≥3/5
Asymptomatic (DS-A)
n=11
Symptomatic (DS-S)
n=10
Healthy controls (HC)
n=20
Online First


Strength: Peak Torque (N/Kg)
***
***
*
**
5,1
2,5
0
Pro
Ret
***
*
1.5
1.0
0.5
0.0
Pro/Ret
Group
HC
DS A
DS S

Fatigue Resistance: Total Work (J/Kg)

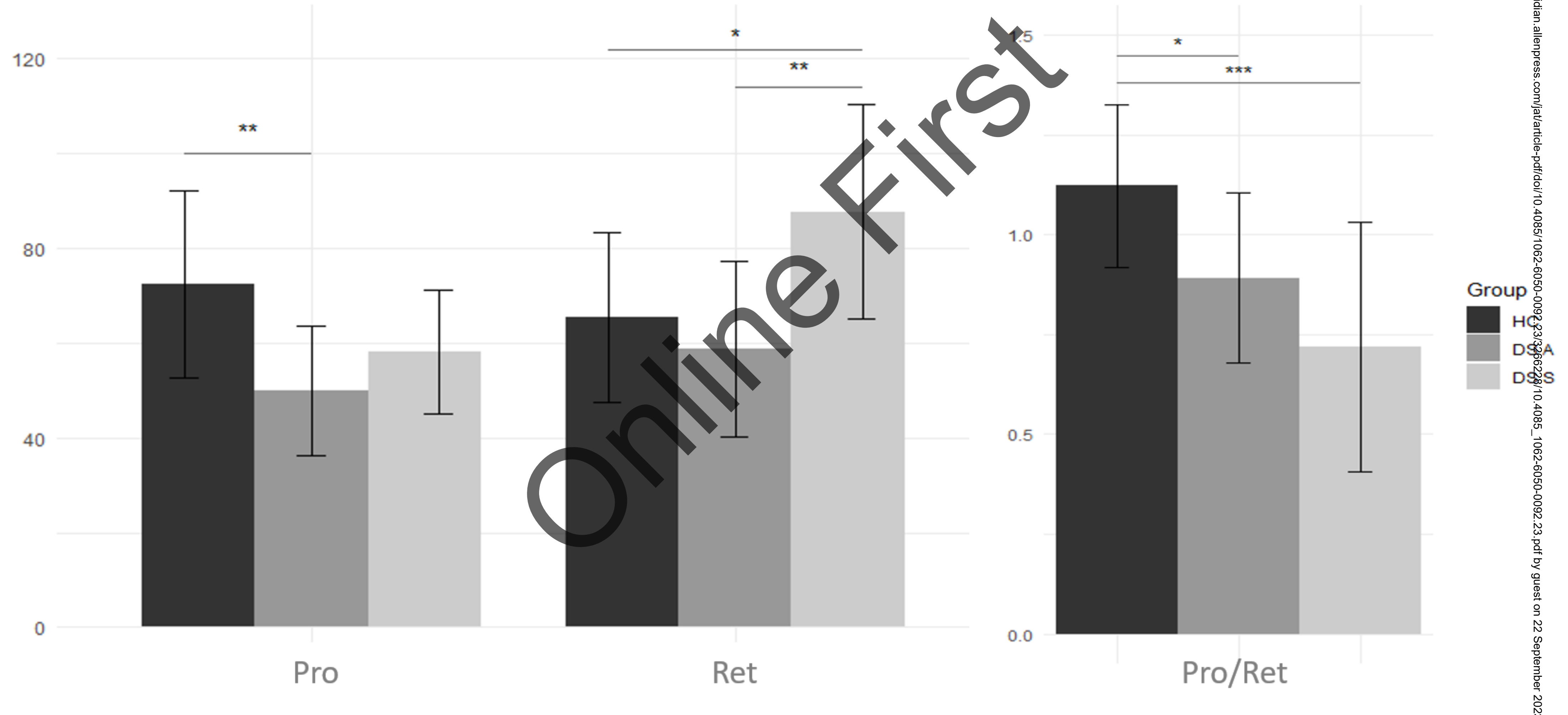


Table 1: Demographic and anthropometric characteristics of the dyskinetic - symptomatic (DS-S), dyskinetic - asymptomatic (DS-A) and control (HC) groups. [a] = one-way ANOVA test

	Dyskinetic – Asymptomatic (n=11)			**Dyskinetic – Symptomatic** (n=10)			**Controls** (n=20)			**p-value [a]**
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	
Age (years)	22.4	2.4	19 - 26	24.6	4.7	18 - 33	23.0	2.6	20 – 30	0.26
Height (cm)	180.5	9.6	168 - 203	182.4	4.9	176 - 190	177.6	6	163 – 190	0.18
Mass (kg)	80.2	13.3	60 - 105	81.2	12.4	68 - 108	73.8	10.5	60 – 102	0.18
Dominance	Right : n=10 Left : n=1			Right : n=10			Right : n=15 Left : n=5			
Dyskinetic side	Dominant : n=9 Non-dominant : n=2			Dominant : n=7 Non-dominant : n=3						
Sport practice (h)	4.2	0.9	3 - 5	4.0	0.8	3 - 5				
Practised sport	Tennis: n=4 Swimming: n=2 Rugby: n=2 Climbing: n=1 Decathlon: n=1 Volley-ball: n=1			Handball: n =6 Swimming: n=1 Rugby: n=1 Tennis: n=1 Weightlifting: n=1						

Table 2: Isokinetic strength (peak torque, maximum work) and fatigue resistance (total work) values over a 40-repetitions protraction-retraction protocol for healthy controls (HC), subjects with asymptomatic dyskinesis (DS-A) and with symptomatic dyskinesis (DS-S); mean ± standard deviation; body weight normalized. PRO = protractors; RET = retractors; [a] = one-way ANOVA test, F value, p value, η^2 effect size and [95% confidence interval]; [b] = Tukey HSD post-hoc test pairwise comparisons. Significant p values are depicted in bold.

Movement	Variable	Groups			ANOVA [a]			pwc p values [b]		
		HC (n=20)	**DS-A** (n=21)	**DS-S** (n=20)	F	p	η^2	HC/DS-A	HC/DS-S	DS-A/DS-S
PRO Conc 24.4 cm/s	Peak torque (N/Kg)	5.0 ± 0.9	3.4 ± 0.7	3.8 ± 0.6	18.19	**<0.001**	0.49 [0.28, 1.0]	**<0.001**	**<0.001**	0.53
	Maximum work (J/Kg)	2.4 ± 0.5	1.7 ± 0.4	1.8 ± 0.3	9.77	**<0.001**	0.34 [0.13, 1.0]	**<0.001**	**0.01**	0.69
	Total work (J/Kg)	72.4 ± 19.7	50.0 ± 13.7	58.1 ± 12.9	6.83	**0.003**	0.26 [0.07, 1.0]	**0.003**	**0.09**	0.52
RET Conc 24.4 cm/s	Peak torque (N/Kg)	4.7 ± 1.0	3.9 ± 1.0	5.2 ± 0.6	6.50	**0.004**	0.25 [0.06, 1.0]	**0.02**	0.48	**0.004**
	Maximum work (J/Kg)	2.1 ± 0.5	1.9 ± 0.6	2.9 ± 0.8	7.54	**0.002**	0.28 [0.08, 1.0]	0.62	**0.007**	**0.002**
	Total work (J/Kg)	65.3 ± 17.9	58.6 ± 18.5	87.7 ± 22.7	6.65	**0.003**	0.26 [0.07, 1.0]	0.63	**0.01**	**0.004**
PRO/RET Conc 24.4 cm/s	Peak torque (ratio)	1.1 ± 0.2	0.9 ± 0.1	0.7 ± 0.1	15.13	**<0.001**	0.44 [0.23, 1.0]	0.10	**<0.001**	**0.01**
	Maximum work (ratio)	1.1 ± 0.2	0.9 ± 0.2	0.7 ± 0.2	18.50	**<0.001**	0.49 [0.29, 1.0]	**0.01**	**<0.001**	**0.03**
	Total work (ratio)	1.1 ± 0.2	0.9 ± 0.2	0.7 ± 0.3	10.49	**<0.001**	0.36 [0.15, 1.0]	**0.03**	**<0.001**	0.22

Differences in strength and fatigue resistance of scapular protractors and retractors between symptomatic and asymptomatic dyskinesis

Supplementary material

1. Psychometric properties of the clinical tests used

Test	Validity	Reliability [a]		Refs.
		Intra-rater	Inter-rater	
Lateral Scapular Slide Test (LSST)	0.91 correlation with radiographic measurement	0.84 – 0.88	0.77 – 0.85	[1]
Stiffness pectoralis minor	100% sensitivity with gold standard recommendation of 2.6 cm threshold	0.76 – 0.97	0.47 – 0.72	[2,3]
Stiffness posterior shoulder structures	0.16 correlation with instrumented assessment of humeral rotation range of motion	0.92 – 0.95	0.80	[4,5]
Jobe test	89% sensitivity with radiographic evaluation of rotator cuff tear	1.00	0.44	[6,7]
Patte test	93% sensitivity with radiographic evaluation of rotator cuff tear	1.00	1.00	[8]
Lift off test	12% sensitivity with arthroscopic evaluation of subscapularis tear	0.29	0.38	[9,10]
Palm up test	69% sensitivity with biceps pathologies on ultrasonography	NA	0.44	[11]

[a] ICC classification[12]: <0.50 poor; ≥50 moderate < 0.75; ≥ 0.75 good < 0.90; ≥0.90 excellent

2. Illustrative examples of the clinical tests used

Stiffness of the posterior shoulder structures

Stiffness of the pectoralis minor

Lateral Scapular Slide Test 1

Lateral Scapular Slide Test 2

Lateral Scapular Slide Test 3

Jobe test

Lift off test

Patte test 90°

Patte test 0°

Palm up test

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