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In vivo effects of two shoulder girdle motor control exercises on acromiohumeral and coracohumeral distances in healthy men

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ABSTRACT

Introduction: Altered motor control and proprioceptive deficits are associated with kinematics dysfunctions and may cause alterations in subacromial space (SAS) that could lead to shoulder pathologies. Dimensions of the subacromial space, as well as interventions aimed at its normal restitution, can be explored by ultrasound (US).
Objective: To describe the effect of two shoulder girdle motor control exercises with cognitive training strategies on SAS dimensions, measured with US.
Methods: Cognitive movement control strategies, with visual and haptic feedback were applied on 21 healthy participants. SAS dimensions were measured through *in vivo* variations of acromiohumeral (AHD) and coracohumeral distances (CHD) using US.
Results: Our results show that as exercise repetitions are performed, an increasing trend in both measures can be observed, being wider for AHD (i.e. humeral head descent exercise) than CHD (i.e. scapular retraction exercise).
Conclusion: Specific cognitive and motor control exercises improve congruence joint and centering of the humeral head.

KEYWORDS
Motor control; acromiohumeral distance; coracohumeral distance; ultrasonography and shoulder

Introduction

Motor control can be defined as the ability of the central nervous system to execute a concrete and specific movement in a more precise, functional, and coordinated way by means of feedforward and/or feedback cues, to allow a more leisurely and conscious movement using sensory and proprioceptive information in forms of verbal, visual or haptic inputs [1–4]. In the last 25 years, the relationship between sensorimotor system andmusculoskeletal disorders has been stablished [5,6] and the importance of considering this relation in shoulder girdle sensorimotor retraining within the management of patients with shoulder conditions [7].

Altered motor control and proprioceptive deficits are associated with kinematic dysfunctions in the shoulder complex [8–10], which can lead to changes in totation axis and abnormal humeral head translation into the glenoid cavity during shoulder elevation [11,12], causing alterations in dimensions of the subacromial space [13,14], leading to rotator cuff pathologies (RCP) [15,16]. These shoulder pathologies are related to deficits in muscle activation, alteration in movement patterns, and proprioceptive mechanisms of the glenohumeral joint [17] and scapula [18,19] and also are one of the most common causes of referrals to physical therapy [20].

Subacromial space measures can be estimated using ultrasound (US) devices. US is a noninvasive imaging method that have demonstrated their usefulness in dynamic exams of the musculoskeletal system for their accuracy, reliability and low cost in the diagnosis of the shoulder complex [21,22]. Commonly used variables for description of subacromial space are acromiohumeral distance (AHD) [43,24] and coracohumeral distance (CHD) [23,25]. AHD and CHD have been used for assessing changes in subacromial space after glenohumeral and scapular exercises [26,27] and have been associated to glenohumeral pathologies [28,29].

Motor control exercises and neuromuscular (re) learning, proprioceptive and functional training are recommended for rehabilitation in the context of symptoms related to shoulder impingement syndrome (SIS) [6,30–32]. Previous studies have shown improvement in disability, functionality and pain in patients with RCP and SIS [20,24,30] using this type of specific exercises. Furthermore, in the medium and long term, it has been reported that this exercise strategy can reduce the need for arthroscopic subacromial

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decompression [33], as well as motor control exercises used in the clinical setting could be performed to improve arthrokinematic dysfunctions such as excessive humeral head ascension (with humeral head descent exercises) and humeral head anteriorization (with scapular retraction exercises) [18,34].

Moreover, different cognitive retraining strategies that influence motor learning in patients while executing a specific movement pattern can lead to better results during the treatment [31]. Consequently, focusing the rehabilitation on restoring the functionality of the patients from a cognitive and perceptual approach seems to be important to restore the neuromuscular disorders of the shoulder complex. To the best of our knowledge, variations in subacromial space have not been evidenced in real time when applying exercises involving both motor control and cognitive training strategies.

For this reason, the aim of this study was to describe the effect of two shoulder girdle motor control exercises with cognitive training strategies on AHD and CHD, measured with US. It was hypothesized that the humeral head descent exercise increases the AHD, and the scapular retraction exercise increases the CHD.

Materials and methods

A quasi-experimental with one group pretest-during test design was used in this study. All participants read and signed an informed consent for this study. The protocol for this investigation was approved by the ethics committee of the Faculty of Rehabilitation Sciences, Andrés Bello University, Chile.

Participants

A total of 21 healthy pain-free male participants were enrolled using sample size calculation (further details in statistical analysis subsection). Inclusion criteria consisted in no history of trauma or condition in the spine or dominant upper limb. All participants were evaluated in a single session. Prior to participants enrollment, an initial evaluation consisting in seven orthopedic tests was conducted to rule out RCP conditions: painful arc test for screening for glenohumeral joint; Neer Test, Hawkin–Kennedy Test, Yocum Test, Sulcus Test, Anterior Drawer test and Jobes Relocation test [11,35,36].

Protocol

Figure 1 summarizes the study protocol. Three physical therapists (PT) and one medical technologist applied the investigation protocol. PT-A and PT-B oversaw initial assessment of participants and motor control exercise education, respectively. Both had a master's degree in Orthopedic Manual Therapy, with post-graduate education on musculoskeletal area and active participation over 8 years on clinical experience on musculoskeletal and sport rehabilitation research. After initial assessment and education, PT-C oversaw motor control exercises execution while medical technologist registered US images. PT-C has a master's degree in Orthopedic Manual Therapy and had a master's degree in Orthopedic Manual Therapy and had more than 20 years in musculoskeletal academic and clinical experience. The medical technologist, who oversaw US imaging, has more than 20 years of experience with a major in radiology and medical physics and a bachelor in Radiological Sciences and certification in upper and lower limb musculoskeletal US.

Motor control exercises

Cognitive movement control strategies (verbal, visual, and haptic feedback) were chosen for this study and two motor control exercises: (1) humeral head descent exercise and (2) scapular retraction exercise. Table 1 gives detailed information regarding exercises.

Ultrasound measurements

A US device (General Electric, Logiq e pro model) was used with a linear transducer model 12 L-RS of 192 elements which have a footprint of 12.7 × 47.1 mm. A 10 MHZ average frequency was used. The imaging protocol used was the general musculoskeletal protocol proposed by US manufacturer. Participants were instructed to remain seated with their feet flat on the ground while their upper extremities were positioned in the scapular plane with 70° of abduction, since it allows a better US view of AHD and CHD. A manual goniometer was used to control testing position.

AHD distance was defined as the tangential distance between the humeral head and the edge of the acromion [37]. CHD was defined as the tangential distance between the coracoid and the humeral head in a longitudinal sonogram [38]. AHD was used for the exercise of descent of the humeral head while CHD was used for the scapular retraction exercise. Both AHD and CHD were measured in millimeters (mm).

An initial measurement was taken in the initial position of each exercise (i.e. abduction in scapular plane at 70°). During exercise execution, AHD and CHD distance were measured 5 times (on each repetition) with 10 seconds rest intervals between repetitions (Figure 2).

Statistical analysis

The sample size for this study was calculated on G*Power version 3.1.9.4 [39] based on the formula for comparing two means and a priori distances in mm reported in previous studies [11,40]. A 95% confidence

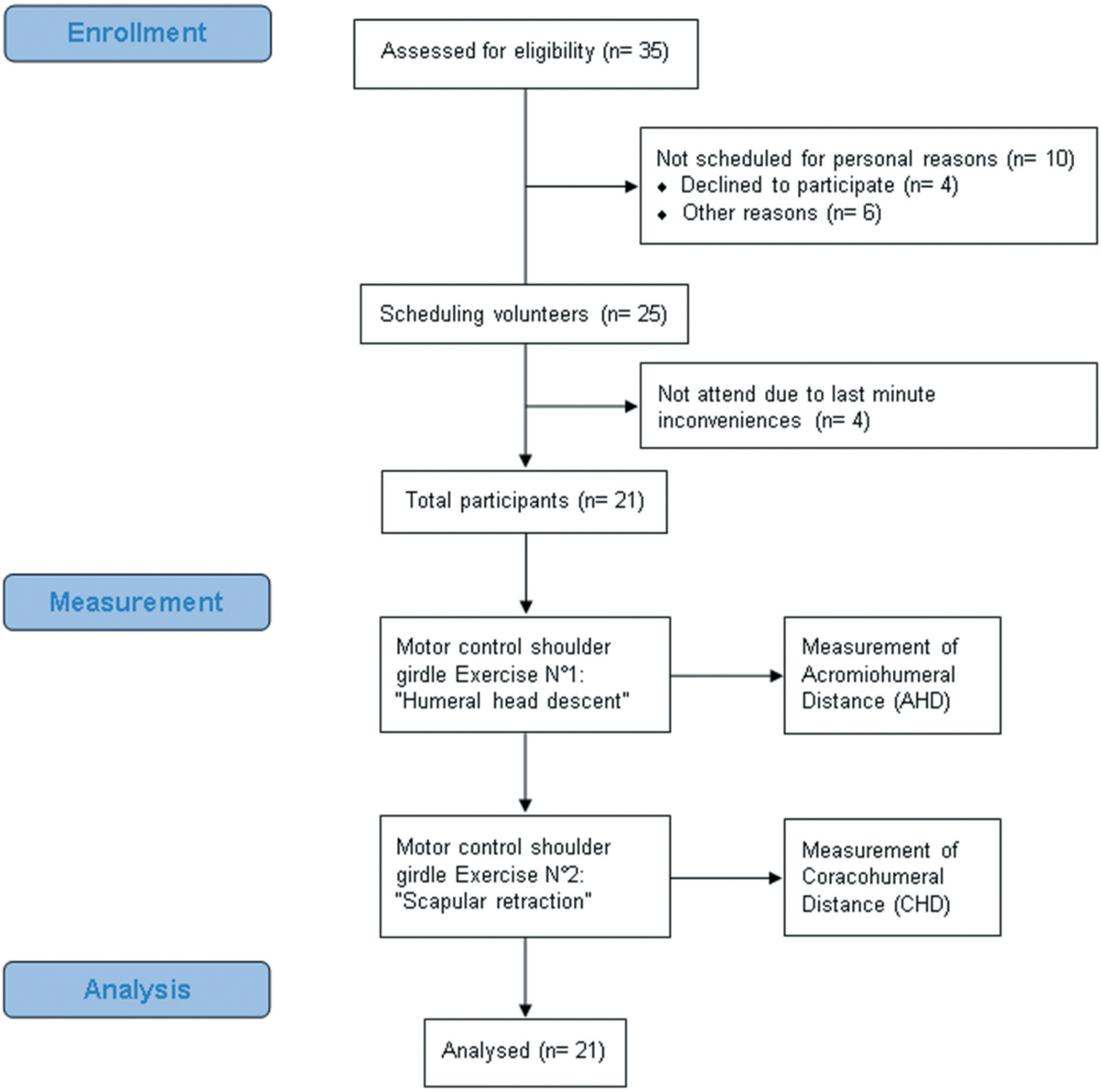


Figure 1. Protocol flow diagram.

level, 90% statistical power, a precision of 0.94 mm, a variance of 0.90 were selected for calculation, resulting in a sample size of 12 participants to detect significant differences. Notwithstanding the foregoing, we included additional participants in case of erroneous readings by the US. Further statistical analysis was carried out in the SPSS v25.0 program (IBM Corp., Armonk, NY). Demographics are presented as mean and standard deviation. The Shapiro Wilk statistical test was applied to assess data distribution. For normal distributions, data were expressed as mean standard deviation and for data with non-normal distribution medians and 25% and 75% percentiles were selected. For categorical variables, absolute frequency and percentage were used for data presentation.

A reliability analysis was conducted using the intraclass correlation coefficient (ICC) and its respective confidence interval [lower bound – upper bound] on the AHD and CHD measurements obtained, where a value lower than 0.5 was indicative of low reliability, values between 0.5 and 0.75 were indicative of moderate reliability, values between 0.75 and 0.9 as good reliability and values higher than 0.9 as excellent reliability [41].

Normalization of AHD and CHD was carried out to quantify the rate of change (ΔAHD and ΔCHD, respectively) in each repetition, using as base parameter the initial positioning of each exercise (i.e. scapular plane at 70° of abduction).

Results

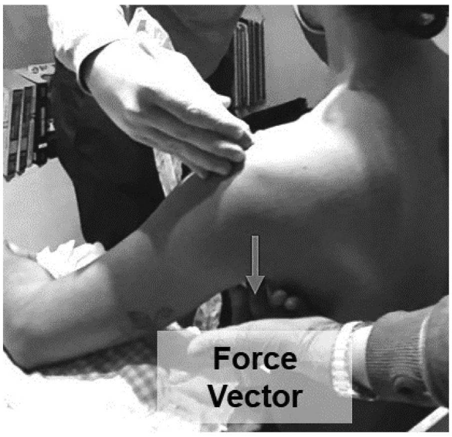
Demographic data is summarized in Table 2.

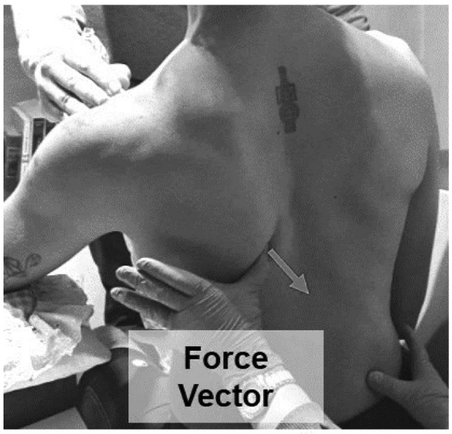
Data expressed as mean ± standard deviation and absolute frequency (absolute frequency percentage, %).

Table 1. Cognitive movement control strategies and motor control exercises.

Cognitive Movement Control Procedure	
Strategies Used	• Visualization: The anatomy of the shoulder girdle (bones-muscles) was visually displayed using a 3D anatomy application. • Haptic feedback: The physical therapist palpated the scapula and shoulder of each participant. Then, each participant felt with his own hands. • Visual feedback: Two videos were recorded with each of the exercises to show and visualize how the movements looked like. • Verbal command: A clear, short, and precise verbal instruction was given of the movement to be executed in each of the exercises.
Motor and Cognitive Learning	• Slow, conscious, and low effort repetitions of each of the exercises were requested. • Each exercise was practiced with verbal, haptic, and visual feedback facilitation. Five repetitions were performed pre-measurement.
Measurement	• Each exercise was performed with verbal and haptic facilitation. No visual feedback. • The exercise was repeated 5 times, with a 10-second rest between each repetition. Each repetition was hold by 5 seconds. • The participants were in a seating position without backrest, with their feet resting on the floor. Upper limb measured in scapular plane with 70 ° shoulder abduction.

Motor Control Exercises			
(1) Humeral Head Descent Exercise		(1) Scapular Retraction Exercise	
Objective	Recruitment of depressor muscles of the humeral head (supraspinatus, infraspinatus, teres minor, subscapularis, and long head biceps).	*Objective*	Recruitment stabilizing muscles of the scapula (serratus anterior, middle and lower trapezius portions, rhomboids, and pectoralis minor).
Outcome	Inferior gliding of the humeral head through the acromiohumeral distance on ultrasound.	*Outcome*	Posterior gliding of the humeral head through the coracohumeral distance on ultrasound.
Implementation	- The physical therapist palpated the humeral head with her index finger, middle finger, and ring finger below the shoulder (at the axillary level) of the participant. - The participant, without moving the arm, had to make a downward pressure with the shoulder on the physical therapist fingers for 5 seconds.	*Implementation*	- The physical therapist palpated the inferior angle of the scapula and simultaneously palpated the participant's contralateral hip. - The participant, without moving the arm, had to bring the lower angle of his scapula toward the contralateral hip for 5 seconds. To do this, the physical therapist palpated these two points.
Verbal Command	'Without moving your arm, imagine that with your humeral head you want to push down against the fingers of the physical therapist with your maximum force'.	*Verbal Command*	'Without moving the arm, push the physical therapist's fingers with your scapula with your maximum force, bringing the shoulder to the opposite hip'.





Reliability analysis

ICC values for AHD were 0.94 [0.92–0.95] and for CHD were 0.96 [0.95–0.97].

Acromiohumeral and coracohumeral differences

Table 3 summarizes mean AHD and CHD across repetitions. Figure 3 illustrates the variation across repetitions of normalized AHD and CHD. An increasing trend in both measures can be observed, being wider for AHD (i.e. humeral head descent exercise) than CHD (i.e. scapular retraction exercise).

Data expressed as mean ± standard deviation.

Discussion

The aim of this study was to describe the effect of two shoulder girdle motor control exercises with cognitive training strategies on AHD and CHD, measured with US. Our results suggest that these exercises, using the proposed cognitive training strategies, may increase subacromial space dimensions.

Our findings regarding humeral head descent exercise and its relationship with the AHD agreed with the findings of 32, who suggests that isometric exercises are associated with an increase in the AHD, indicating that this exercise favors the inferior translation of the humeral head by consciously activating the rotator cuff muscles [32]. Furthermore, in a quasi-experimental study conducted by 11, reported the use of two different dynamic neuromuscular control exercises (descent and posterior exercises of the humeral head) for the

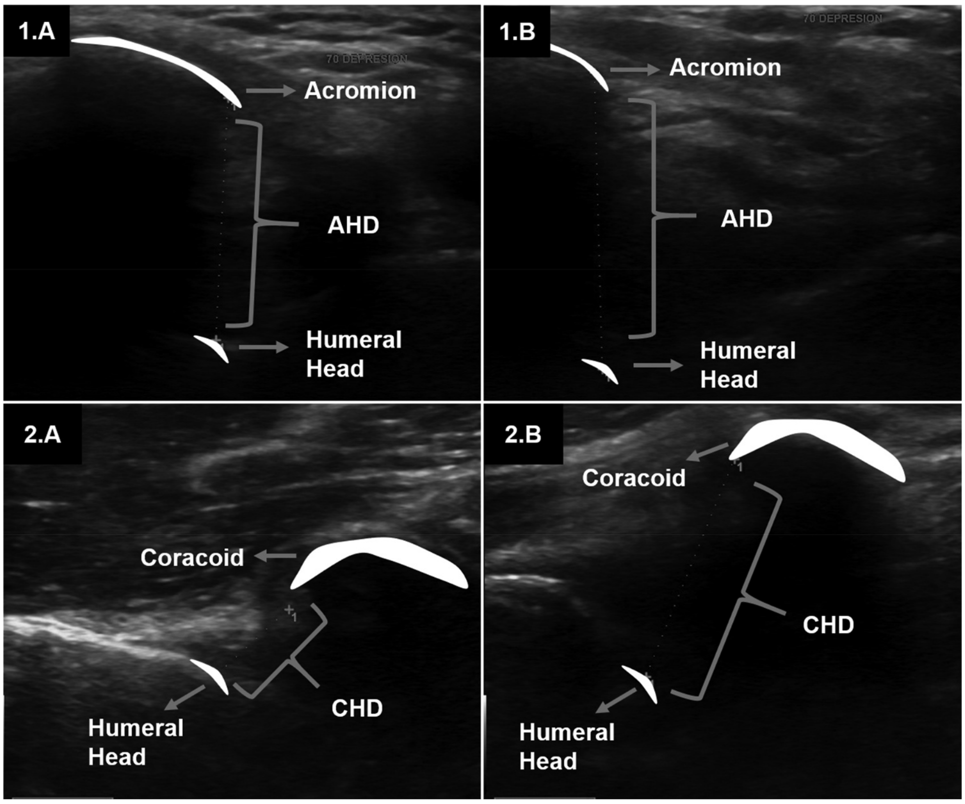


Figure 2. Ultrasound references are used to mark and calculate the acromiohumeral distance (AHD) (1.A and 1.B) and the coracohumeral distance (CHD) (2.A and 2.B). 1.A is on the participant's starting position and 1.B during the maximal effort to press the humeral head descent exercise. 2.A and 2.B are the same measurement steps, but for the coracohumeral distance (CHD), performing scapular retraction exercise.

AHD and for the anterior-posterior distance, demonstrating the increase shown on AHD with those exercises [11]. Regarding the scapular retraction exercise and its relationship with the CHD, our results were higher than previous studies. 42, found a CHD ranging 10.5–16.1 mm and 43, with 10.3 mm [23,42]. Considering these results and the ones obtained by 28, a CHD greater than 10 mm in healthy subjects can be reliable, since a measurement lower than this could indicate association with RCP [28]. Moreover, our ICC values indicated excellent reliability for both measurements, therefore, results obtained in this study are reliable for comparative purposes.

Table 2. Demographic characteristics of participants.

Variable	Participants (n = 21)
Age (year)	22.95 ± 1.40
Height (cm)	1.78 ± 0.05
Weight (kg)	77.67 ± 9.29
Dominance	16 (76.1)
Right	5 (24.9)
Left	
Shoulder measured	5 (23.8)
Right	16 (76.2)
Left	

Table 3. Base and between exercise repetition differences in acromiohumeral (AHD) and coracohumeral distance (CHD).

Repetition	AHD (mm)	CHD (mm)
Base	11.06 ± 3.92	20.79 ± 4.48
1st Repetition	13.58 ± 3.41	25.01 ± 5.94
2nd Repetition	14.82 ± 4.48	25.65 ± 5.29
3rd Repetition	15.17 ± 4.06	27.14 ± 6.81
4th Repetition	16.26 ± 5.19	27.58 ± 6.98
5th Repetition	16.53 ± 5.99	26.46 ± 6.48

Additionally, a better visibility of the CHD was achieved when positioning participants in 70° of abduction in a scapular plane. This can be considered an option to reduce mechanical compression between the coracoid, humeral head, and adjacent soft tissues and allows working both humeral and scapular stabilizing muscles. Thus, an interesting treatment proposal arises with the concept of motor control training with different sensory inputs, specifically for alterations of the subscapularis tendon and long head of the biceps. As stated, the most affected space in patients with pathologies in these tendons is the CHD [25,28,44].

As illustrated in Figure 3, AHD and CHD measures progressively increase with the repetitions. This increase may be due in part by a correct muscle recruitment, associated with visual, cognitive, and haptic learning (cognitive and motor control) done prior and during exercise execution. This approach, as pointed out by 31, is an important advance toward recognizing individual differences of each patient and highlights the need to adapt interventions based on evaluation, reaffirming the importance of including this type of cognitive commands at the time of teaching and perform a specific exercise [31]. Furthermore,

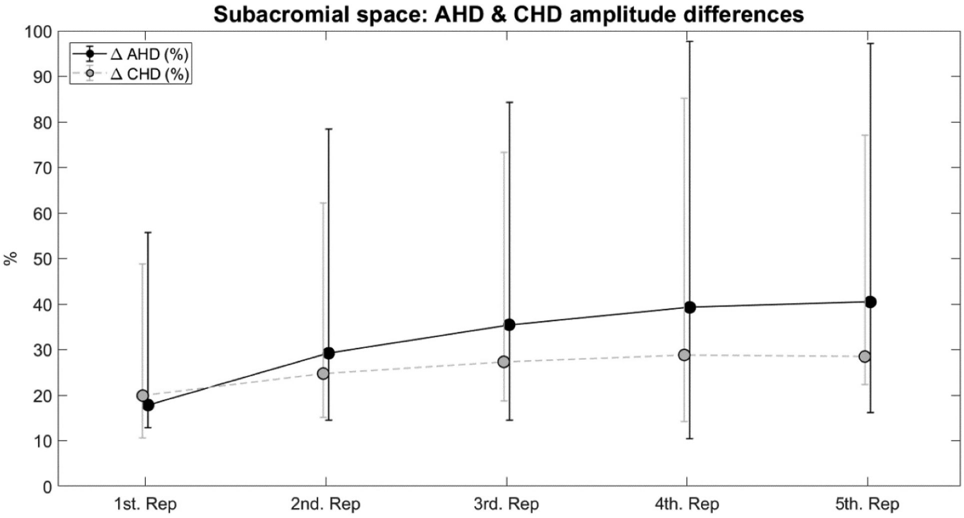


Figure 3. Normalized acromiohumeral (ΔAHD; black dots and line) and coracohumeral distances [ΔCHD; gray dots and dashed line) between humeral head descent and scapular retraction exercises repetitions. Data is expressed as median and 25th and 75th percentiles.

contemporary neuroscience and motor control theories [45] argue that pain alters motor pattern/control in different ways in response to the individual's conscious and unconscious perception of threat, and this can generate changes in motor function and movement. Moreover, characteristics of muscle synergies can change in the presence of pain [46] and they are associated with biomechanical, motor control, and performance variables [47].

Exercises analyzed in our research support the idea of including dynamic exercises of the rotator cuff muscles in humeral centering, through modification of subacromial space dimensions, and therefore improve shoulder function and decrease the subacromial pain [11,12,15,33,37]. In a randomized clinical trial, the effectiveness of dynamic humerus centering exercises in RCP was analyzed, stating that these exercises can reduce shoulder pain in subjects with SIS [20]. Furthermore, 48,conducted a systematic review and concluded than there is consistent information that supports the importance of involving the activation of the scapulohumeral musculature in patients with SIS, which is also related to the results of this study and the possibility of including cognitive and motor exercises for rehabilitation in RCP. Therefore, shoulder girdle lowering, and retraction exercises may have benefits in the prevention and treatment of RCP and other disorders related to the shoulder joint [48].

Another point to discuss is whether motor control exercises are superior to other therapeutic modalities. Dos Santos, et al. reported that shoulder neuromuscular exercise programs that incorporates strength, coordination, balance, proprioception, motor control, and functional kinetic chain work were superior to a standard care exercise program that emphasizes strength training to increase muscle mass in patients with traumatic shoulder instability [49]. On the other hand, strength-based exercise programs can directly affect the functional capacity of dynamic shoulder stabilizers, which by improving their performance can impact on joint stability and proprioception [50,51]. 50,found an improvement in glenohumeral joint repositioning after performing a strengthening exercise program without varying their intensity, while better neuromuscular control of the shoulder was observed in the group that performed exercises with different intensities. This differences are due part to the improvement in the sensitivity of muscle spindles, confirming that stimulating the muscle spindle, as well as the different structures active and passive shoulder, in different ways through various treatment strategies positively impact the outcomes involved in shoulder dysfunction such as pain [19], decreased function [7], motor control, stability, muscle weakness [52], proprioception and alteration in mobility [49]. Other studies based on motor control exercise programs in SIS and RCP use biofeedback and electromyography with controversial results. 53,demonstrated that using electromyographic biofeedback improved motor control in asymptomatic and symptomatic subjects, while 54, found no difference in pain and function [53,54]. As stated, motor control exercises should be included in the management of patients with RCP and SIS, considering a multidimensional perspective, rather than a single approach.

Physical therapists in clinical practice often teach several exercises for RCP, however, the proper understanding and execution of these exercises can be particularly difficult for some individuals, since they require a complex and atypical voluntary neuromuscular activation sequence [11]. According to this background, different cognitive movement control strategies are included in this study, so the participant can get optimal performance at both cognitive and motor levels during the execution of the exercise of descent and retraction of the shoulder girdle. The use of US in real time can be an alternative to complement the verbal and palpatory instructions during the execution of the movement. Besides the education phase of the exercises, visual feedback collaborates with exercise familiarization, accompanied by a previous anatomical visualization. Additionally, these strategies can help movement specialists to get a better understanding of clinical findings of movement evaluation, treatment guidance, ease interdisciplinary communication, and promote a modern pathophysiological approach within a multidimensional perspective since the clinical reasoning skills of the manual therapist are essential [31,55].

Limitations

We must state several limitations. Our results correctly describe an *in vivo* modification of subacromial space during the execution of the exercises, but it does not allow to determine the effect of these two exercises in the long term, as in a preventive rehabilitation program or a prospective cohort on the treatment of RCP. On the other hand, considering that the collected sample satisfied sample size calculation carried out, it is important to note that this study was during the global context of COVID-19 and even though the safety of each of the participants was protected, this context limited the possibility of taking a bigger data sample or population comparisons. Moreover, healthy pain-free males were selected, so findings cannot be extrapolated to individuals with shoulder mobility restrictions or shoulder pathologies. For future studies, it is recommended to increase the number of the total sample to have a better representation and statistical power at a national level and maybe complement with the use of surface electromyography, being able to determine if there is any type of correlation between the increase of both anatomical spaces (AHD and CHD) and increased muscle activity using the proposed cognitive and motor control exercises in musculoskeletal dysfunctions.

Conclusion

We can conclude that, through an *in vivo* exploration, specific cognitive and motor control exercises improve congruence joint and centering of the humeral head, through a progressive increase in AHD and CHD which favors the displacement of the humeral head.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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