Title: Neuromuscular Effects of an 8-Week Aquatic Training Program on Pain, Range of Motion and Electromyography in Patients with Shoulder Impingement Syndrome: A Randomized Controlled Study

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Abstract

Purpose: Shoulder impingement syndrome (SIS) is the most prevalent issue among shoulder disorders. Given the promising outcomes of aquatic physiotherapy in rehabilitation, this study aimed to evaluate the impact of an 8-week aquatic training program on pain, range of motion, and electrical activity in the shoulder of pre-elderly patients suffering from SIS.

Methods: 30 men of military retirees aged 60 years and older, were voluntarily recruited and then randomly assigned into experimental and control groups. The experimental group participated in an eight-week program of aquatic training. Pain, range of motion, and shoulder muscle activity were investigated using a Visual Analog Scale (VAS), electrogoniometer, and electromyography, respectively—twice as pre and post-test.

Results: Results showed significant differences between groups in pain scale, shoulder external and internal rotation ($P < 0.001$), shoulder abduction ($P = 0.002$) and muscle electrical activity of serratus *anterior* ($P < 0.001$), but not in shoulder flexion ($P = 0.082$) and muscle activity of upper trapezius ($P = 0.075$).

Conclusions: Our aquatic training program may profoundly impact regaining shoulder range of motion and recovery from shoulder pain in patients with SIS. Further research is warranted to assess a different and more specialized aquatic program to properly affect shoulder flexion and trapezius muscle function, which were not improved by the present intervention.

Keywords: Shoulder impingement syndrome; Hydrotherapy; Electromyography; Pain; Range of motion.

Highlights:

The study found that an eight-week aquatic training program effectively reduced shoulder pain in patients with shoulder impingement syndrome (SIS). It notably improved shoulder internal and external rotation, as well as the range of shoulder abduction, though it had minimal impact on shoulder flexion. Additionally, the program led to an increase in muscle activity of the serratus anterior but did not significantly change the activity of the upper trapezius. These results highlight the potential of aquatic therapy as a low-impact, effective intervention for pain relief and mobility improvement in SIS patients.

Plain Language Summary:

Shoulder impingement syndrome (SIS) is a common cause of shoulder pain, often due to overuse and strain on shoulder muscles. It affects many older adults, especially those with physically demanding jobs or active lifestyles. Treatment options for SIS range from medication and physical therapy to, in severe cases, surgery. This study explored an alternative approach: an eight-week aquatic exercise program to manage pain and improve shoulder function for patients with SIS. Participants were divided into two groups: one underwent aquatic therapy, while the other did not. The exercises, performed in warm water, were designed to relieve pain and enhance shoulder movement without putting stress on joints. Results showed that the aquatic therapy group experienced reduced shoulder pain and better range of motion, particularly in shoulder rotation and abduction. Additionally, the exercises increased activity in the serratus anterior muscle, a key muscle for shoulder movement, though it didn't significantly impact the upper trapezius muscle or shoulder flexion. These findings suggest that water-based exercises can be an effective, low-impact treatment to help SIS patients manage pain and regain shoulder mobility. The study supports using aquatic therapy as a rehabilitation option for older adults with SIS, especially as an alternative to more invasive treatments like surgery.

1. Introduction

Shoulder disorders are a common and underestimated cause of pain and disability in geriatric patients[1] in which increasing in number of painful sites seem to be associated with lower physical work capacity, lower physical activity[2] and considerable disruption to patient's daily life[3]. Prevalence of shoulder disorders has reported high[4], accounting for 1.84 per 1000 person-years in US military personnel[5]. Research indicates that being subjected to a combination of physical workplace stresses—like overhead tasks, heavy lifting, and forceful movements—along with maintaining an inappropriate postures, heightens the risk of shoulder disorders. [6]. Lifetime prevalence of shoulder pain among middle-aged women were 27.6%[7]. Of all these shoulder complains, shoulder impingement syndrome (SIS) is the most commonly reported, accounting for 44–65% of all shoulder pain disorders and 25% of people within the UK who seek shoulder pain treatment from a general practitioner[8]. This syndrome has been found to originate from overusing the rotator cuff muscles in jobs, sporting, or other overhead activities[9], with complications occurring for different reasons such as anatomical changes in the acromion[10], and posterior capsule tightness[11] ; also, this can result in slower movement speeds and increased electromyography (EMG) activity in the shoulder stabilizer muscles, to maintain motor function and reduce the engagement of larger muscles in painful regions [12], as well as contribute to scapular dyskinesia [13].

Aging plays a key role as an irreversible physiological process that affects person's lives physiologically and musculoskeletal features[14], which may subsequently result in delayed muscle recruitment, pain, and musculoskeletal disorder over time[12]. Therefore, when all of these age-related impairments come together in patients with SIS, the importance of developing musculoskeletal data through broader intervention strategies to guide geriatric shoulder pathologies in later life are highly demanded as other therapeutic intervention programs have yet probably been insufficient[15].

Providing treatment scenarios for patients with SIS requires a better understanding of disease-related changes as well as how these changes interrelate in musculoskeletal injuries profile. Regular physical activity or specialized exercise programs then may minimize musculoskeletal changes accordingly and improve physical fitness, balance and independence among elderly[16, 17]. That is why various types of physical activity like strength training, aerobic, walking and aquatic exercise (AE) have been abundantly recommended to maintain overall health among older adults over the past years as like a recent systematic review[18] whose study confirmed the effectiveness of aquatic exercise in improving physical function of healthy older adults, another meta-analysis[19] has shown no considerable difference between the impact of combining surgery with physiotherapy versus physiotherapy alone on alleviating pain and enhancing function in patients with SIS, along with other studies that highlighted the significant benefits of pool-based neuromobilization.[20] and water-based exercise[21, 22] in the treatment of SIS.

A variety of treatment approaches like non-steroidal anti-inflammatory drugs, corticosteroid injections, physical therapy and whatever might help to avoid surgery, are strongly recommended. The reasons why water-based exercise supposed to be effective as a preventive approach for the older adults, is the fundamental features uniform all liquids. Viscosity of water and buoyancy with zero-gravity mechanism are the key drivers to improve muscle function in the fragile limb[23], through exploiting more integrated resistance than any other exercises do, leading to body floating and load reduction in joint and muscle during exert pressure[24]. Although aquatic therapy is commonly used in musculoskeletal rehabilitation, there remains a lack of substantial evidence regarding its potential effects on neuromuscular mechanisms, particularly in elderly patients with SIS. Therefore, this study aimed to investigate the effects of aquatic training program on the pain, range of motion, and electrical activity of the shoulder muscles among military retirees with SIS.

2. Materials and Methods

Present study was double-blind and performed as pre-test, post-test control group design. 30 retired men aged 60 and older, who suffering SIS and referred to rehabilitation center to receive physiotherapeutic treatment, voluntarily participated in the study after reading flyers posted online on the rehabilitation center website by the following procedures: first, written consent was obtained from all participants, followed by simple random sampling method according to the Morgan table. Then, a questionnaire capturing demographic characteristics, physical activity and medical / drug consumption reports of the patients was completed through face-to-face interview. Checking up on the participants by using clinical special tests of Hawkins-Kennedy validated with the pooled estimates of sensitivity 74% and specificity 57% [25], Neer[26, 27] and Painful Arc[26] , and completing diagnostic imaging data extracted by CT arthrography was the next steps managed by specialist and a qualified sonographer, respectively. Inclusion criteria were: (1) retired men between 60 to 70 years of age; (2) having activity limitations over one week; (3) pain in subacromial region and having symptoms of SIS with average 16 months duration; (4) written agreement with the research processes; (5) having at least elementary education; and (6) having physical and cognitive ability confirmed through documentation on their medical records. Each of these items that were not being met along with having cervical / thoracic spine pain and glenohumeral joint instability with more than three times of glucocorticoid injections into the shoulder, are considered as exclusion criteria. 30 subjects were then randomly divided into two experimental (n = 15) and control (n = 15) groups through a table of random numbers.

2.1. Intervention

The aquatic training program was 16 two time-weekly sessions, consisted of warm-up (5-10 min), muscle endurance training of walking and shoulder joint movements at 50 to 65% MHR measured by wrist-worn water proof, Apple Watch Series 4 (49) (20-30 min) and cool-down (5-10 min). The primarily intensity was 40 to 50% of maximum amount of fatigue limit and was gradually increased up to 65% during the last sessions. This model of training intensity progression is scientifically approved as high correlation coefficients (i.e. > 0.70) were found between heart rate and ratings of perceived exertion in aerobic exercises[28]. This protocol was also free of any direct physical and psychological hazards for the subjects and was implemented under the supervision of a well-qualified physical therapist in a warm pool adjusted to a temperature 29 C ± 2 C according to Wilk and Joyner (2024)[29] in a rehabilitation center. Each training session comprised the following phases:

(1) Familiarization: subjects started the protocol by walking slowly in the pool while making some simple movements they were comfortable with, up to 15 minutes. This phase was only for familiarizing participants with the aquatic environment.

(2) Warming-up, first focused on the shoulders as it is known to be the most intricate joint in the entire body and needs to be properly stretched by performing a series of rotations, and ended with arm-focused movements to extend stretches throughout upper body parts. They included five sets of 10 repetitions of forward shoulder rotation with one arm only, backward shoulder rotation with one arm, forward rotation using both arms, backward rotation using both arms, lateral arm raises, alternating arm raises moving on one arm forwards while another backwards and lateral arm raises ending the movement with straight arms.

(3) Special exercises of shoulder muscles via aqua-band workout in three sets of 10-15 reps on each side supported by Batalha et al. (2018) [21], were as follows: shoulder abduction to 90-degree, external rotation, internal rotation, band crawling, shoulder flexion 0 to 90 degree, and shoulder extension. The subjects who had either background of any kind of regular water-based therapeutic trainings prior to our study, or any experience of acute pain urging them to stop exercise trial and taking painkiller drugs during the sessions, were excluded from the study.

(4) Cool-down stretching and movements: walking sideways, forward and backward followed by some light shoulder stretches.

All procedures applied as intervention and experiments in this study were also in accordance with the declaration of Helsinki-Tokyo, and approved by the local ethics committee (approval ID: IR.ACECR.IBCRC.REC.1400.020).

2.2. Diagnostic tests

2.2.1. Hawkins-Kennedy

To diagnose subacromial impingement, Hawkins and Kennedy (1980) studied a population of symptomatic repetitive overhead athletes, whose supraspinatus and bicipital tendon tend to be impinged in the subacromial space of the shoulder. Given the force of repetitive overhead motions performed over the longer period of time and the subsequent gradual degeneration and tears may be seen in the rotator cuff, Hawkins established a diagnostic test known as the “impingement sign” that produces pain and facial expression. The Hawkins-Kennedy test in the present study was such that the patient was positioned sitting with arm at 90° of shoulder flexion, supported by an examiner who internally rotate the shoulder until the pain occurs. Reliability and diagnostic of this test for SIS has been reported acceptable, with sensitivity and specificity of 0.63 and 0.62, respectively[26].

2.2.2. Painful arc

This test is one of the most common and simple shoulder tests to identify possible subacromial impingement syndrome. In this study, the examiner instructed subjects who were sitting on chair to abduct the arm in the scapular plane until getting approximately 120 degrees of abduction—where the presence of pain between 60 and 120 degrees and its reduction after passing 120 degrees, would be considered as positive test. This test has also been found useful as a screening test to rule out SIS and its reliability has been acceptable for clinical use[26].

2.3. Evaluation tests

2.3.1. Neer test

This test was described originally in 1977 to identify demonstration of a pain during passive abduction of the arm with the scapula stabilized. In this study, the examiner lifted patient's arm up over the scapular plane with an internally rotation to check if the pain appears. The procedures were properly conducted in accordance with the specifications of Modified Neer Test (MNT) whose specificity and diagnostic accuracy in identifying SIS has recently been shown %95.56 and %90.59, respectively, by the research of Guosheng et al. (2017)[30] .

2.3.2 VAS for Pain

The visual analogue scale (VAS) is commonly used as a measure to characterize the intensity of pain, and in this study presented as a 100-mm horizontal line in which the patient's pain intensity was represented by a point between 0 "no pain at all" and 100 "worst pain imaginable." The simplicity, reliability, and validity that being reported[31] make this scale an optimal tool to assess pain severity.

2.3.3. Measurement of shoulder external & internal rotation

The subject was asked to lie on his back with arm abduction at 90 degrees to the trunk. The movable arm of the goniometer was then fixed to the subject's forearm axis and its stationary arm was placed perpendicular to the ground[32]. While a supporter had kept the subject's arm steady, the subject one time externally rotated and another time internally rotated the arm, until its peak, to evaluate range of motion of shoulder external rotation via goniometer.

2.3.4. Measurement of shoulder flexion

The subject was asked to lie on his back with the elbow extended and thumb pointing upward as possible. The stationary arm of goniometer was placed parallel to the surface of the floor, while the movable arm was placed parallel to the lateral aspect of the arm to evaluate range of motion of shoulder flexion[32] .

2.3.5. Measurement of shoulder abduction

Similar to the previous positions, the subject was instructed to lie on their back with the arm laterally rotated alongside the body and the elbow extended, keeping the palm facing upward without any flexion or extension of the shoulder. The fixed arm of the goniometer was positioned parallel to the floor, while the movable arm was aligned parallel to the front of the arm.

As like previous positions, the subject was asked to lie on his back with arm laterally rotated beside body and elbow extended while palm facing upward without flexion and extension of the shoulder. The fixed arm of goniometer was then placed parallel to the surface of the floor with the movable arm placed parallel to the anterior aspect of the arm[32] . Upon its reaching to peak, range of motion of the shoulder abduction has been recorded. The concurrent validity and consistency of this method was reported 0.976 and 0.990 for determining the values of active shoulder range of motion by[33].

2.3.6. Muscle electrical activity

Surface EMG data were collected from the serratus anterior and upper trapezius muscles by applying portable ME6000 sensors over the shaved and degreased skin according to the SENIAM European protocol while participants were in a seated position and the shoulder flexed at 90° in the scapular plane with electrodes placed (1) at the 6th to 8th rib in the mid-axillary line anterior to the fibers of the latissimus dorsi muscle for the serratus anterior muscle, and (2) at the midway between 7th thoracic vertebrae and medial boarder of the scapula for the upper trapezius muscle. EMG data were analyzed by averaging out of three tests at 1500 Hz and at a bandwidth of 10–450 Hz which being converted to root mean square values (filter constant of 100 ms). (figure 1)

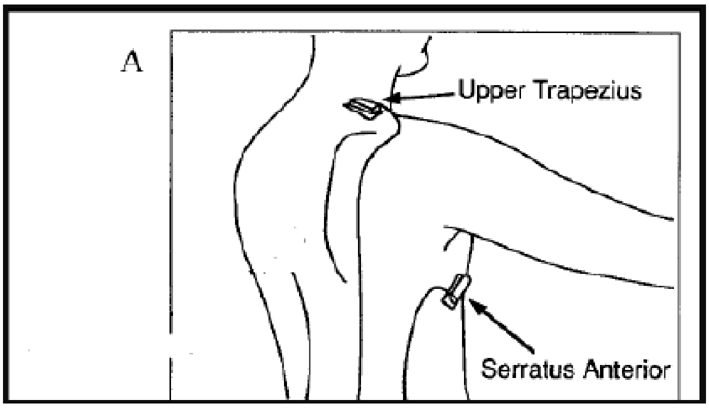

Fig 1: Electrode placement for recording sEMG (upper trapezius, Serratus Anterior).

2.4. Statistical analysis

Data were analyzed using SPSS version 26 (IBM, USA). Pre-test and post-test comparisons within groups were conducted using paired t-tests, and comparisons between the experimental and control groups were analyzed using independent t-tests. The data were checked for normality using the Shapiro-Wilk test, and results are presented as mean ± standard deviation (SD). For all analyses, a p-value of less than 0.05 was considered statistically significant.

3. Results

Table 1 presents the general characteristics and homogeneity of the subjects, including their height, weight, and age, in both the experimental and control groups. The data are shown as mean values with standard deviations to reflect the average characteristics and variability within each group.

Table 1. General characteristics and homogeneity of subjects.

Groups	Age (mean ±sd*)	Weight (mean ±sd)	Height (mean ±sd)
Experimental	**63 (3.15)**	**75.4 (8.92)**	**168.5 (3.42)**
Control	**64.7 (3.45)**	**75.8 (8.92)**	**179.20 (5.73)**

***Standard deviation**

Table 2. pre- and post-test comparison of the muscle activity of serratus anterior and upper trapezius between groups.

Variables	Groups		Means	Mean diff	t	P-value
Serratus anterior	Control	Pre-test	47.24 ± 0.41	0.24	1.77	0.097
		Post-test	47.00 ± 0.46			
	Experimental	Pre-test	47.12 ± 0.48	-9.28	-24.67	*0.000
		Post-test	56.4 ± 1.37			
Upper trapezius	Control	Pre-test	26.66 ± 0.97	-0.066	-0.217	0.831
		Post-test	26.73 ± 0.89			
	Experimental	Pre-test	26.73±0.78	0.16	1.92	0.075
		Post-test	26.57 ± 0.79			

*Statistical significance

Table 3. Post-test comparison of the pain scale, shoulder external and internal rotation, shoulder flexion and abduction.

Variables	Means		Means diff	t	P-value
	Control	Experimental			
Pain	۷۹ ± ۱۲/۶	۱۸/۷ ± ۱۳/۰۸	۶۰/۳	۱۰/۴۷	❊ ۰/۰۰۰
Internal range of motion	۲۸/۸ ± ۸/۹۵	۴۴/۸ ± ۵/۶۵	-16	-۴/۷۷	❊ ۰/۰۰۰
External range of motion	۲۵/۴ ± ۱۱/۱۴	۴۶ ± ۴/۸۷	-۲۰/۶	-۵/۳۵	❊ ۰/۰۰۰
Flexion	۱۱۶ ± ۱۹/۹۶	۱۲۸/۷ ± ۶/۴۶	-۱۲/۷	-۱/۹۱	۰/۰۸۲
abduction	۱۱۸/۴ ± ۱۵/۰۹	۱۳۹/۵ ± ۱۱/۵	-۲۱/۱	-۳/۵۱	❊ ۰/۰۰۲

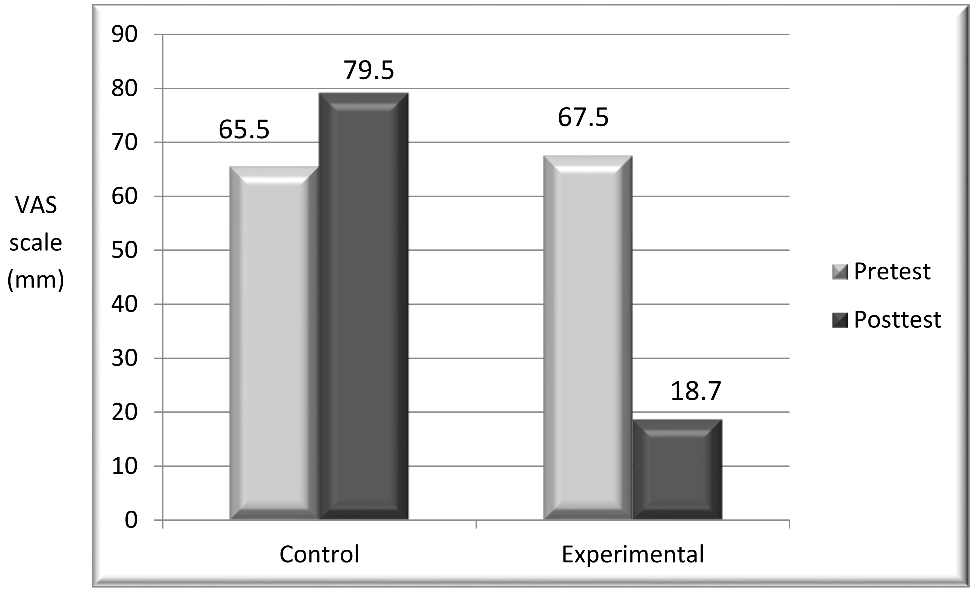

Figure 2. pre- and post-test comparison of the pain scale between groups

According to figure 2, a significant difference was observed in post-test pain scale ($P < 0.001$) between groups.

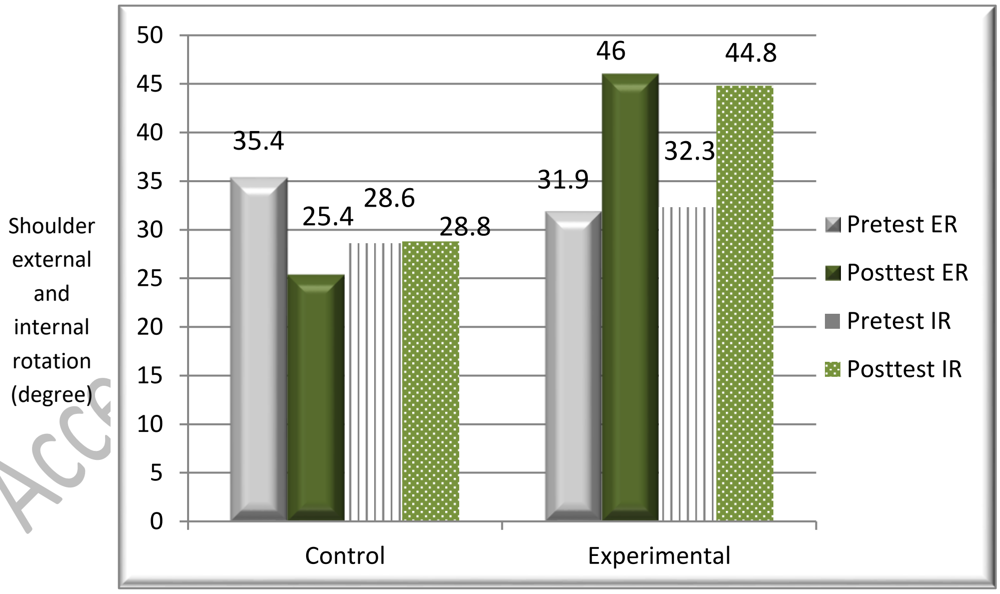

Figure 3. pre- and post-test comparison of the shoulder external (ER) and internal rotation (IR) between groups.

As shown in figure 3 and Table 3, the results revealed that there was a significant difference in post-test shoulder external and internal rotations between groups ($P < 0.001$).

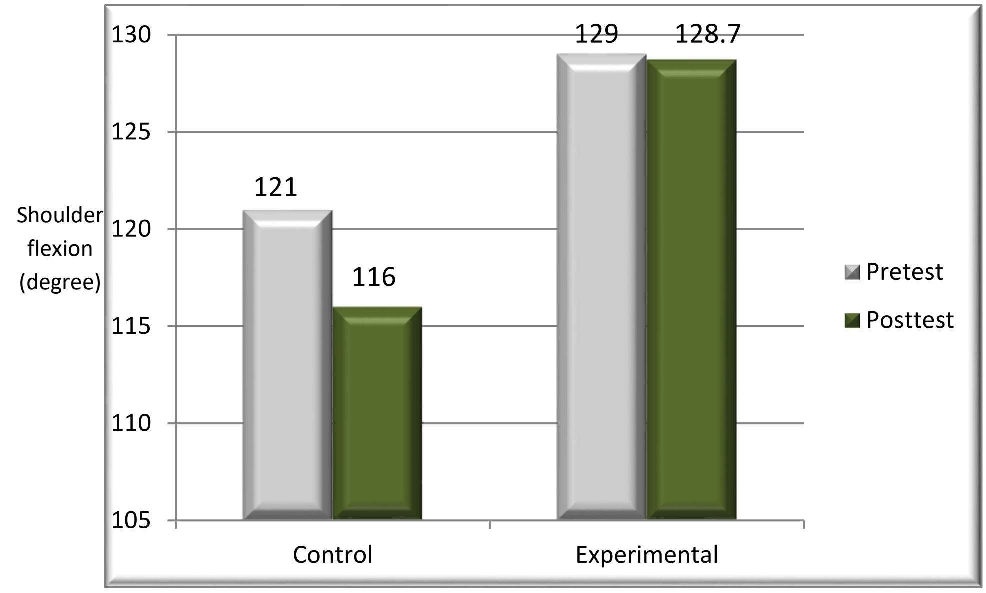

Figure 4. pre- and post-test comparison of the shoulder flexion between groups

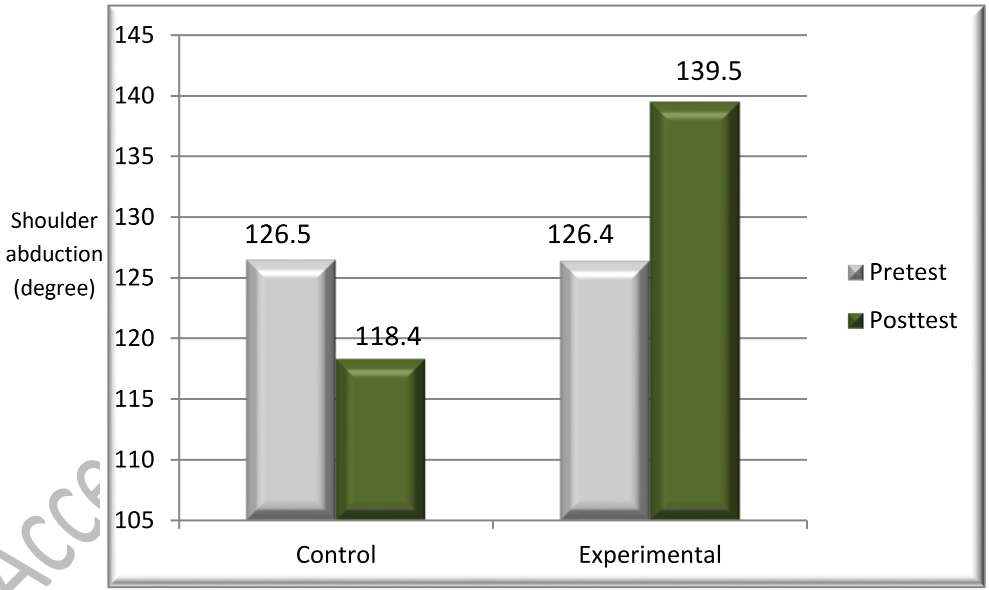

Figure 5. pre- and post-test comparison of the shoulder abduction between groups

While there has not been shown considerable difference in post-test shoulder flexion between groups in figure 4 ($p = 0.082$), Figure 5 and Table 3 illustrate a significant increase in post-test shoulder abduction of the experimental group compared to its pretest and control data ($p = 0.002$).

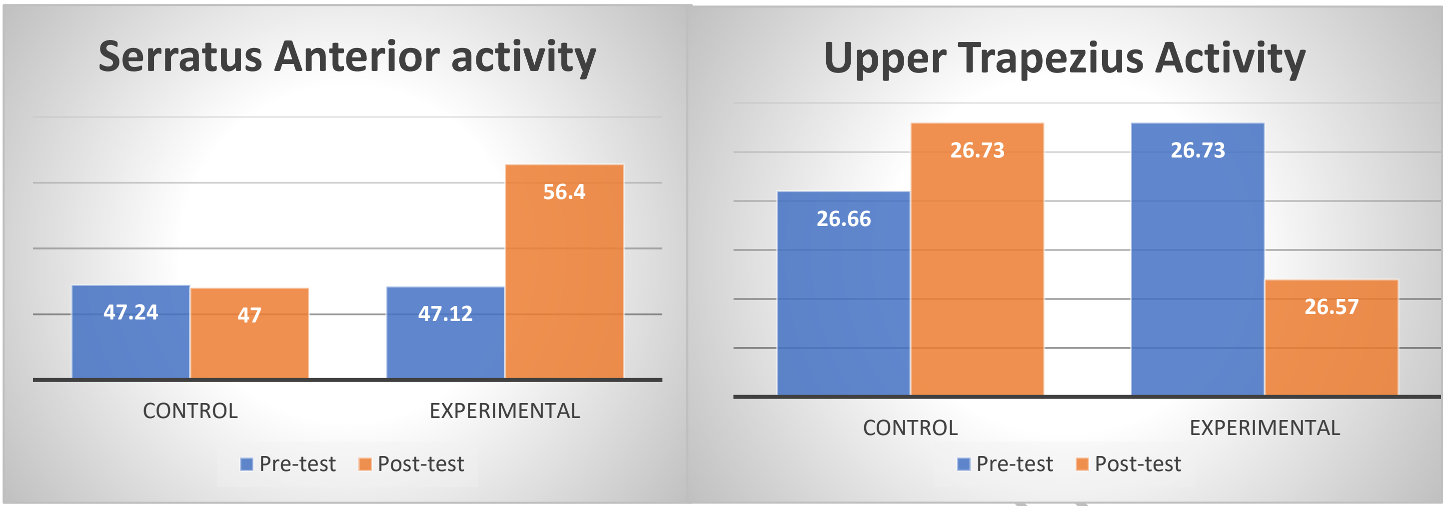

Figure 6. pre- and post-test comparison of the muscle activity of serratus anterior and upper trapezius between groups.

And lastly, figure 6 and Table 2 show a post-test significant difference of the serratus anterior muscle activity in experimental group (P = 0.000), while there was no considerable difference of muscle activity of upper trapezius in experimental group (p = 0.75).

4. Discussion

The results of the present study demonstrated the beneficial effects of an aquatic training program on neuromuscular profile - from relieving pain and improving range of motion in shoulder to restoring muscle function of serratus anterior, which these benefits would seemingly help the patients with SIS over their routine activities, particularly pain-free shoulder movements. However, this aquatic training protocol was found to not be able enough to affect upper trapezius activity and shoulder flexion, in which possible leading causes require to be scientifically justified.

Shoulder disorders has always been most common among regional pain syndromes and cause morbidity[6]. One of the primary factors contributing to the increased prevalence of this disorder across all age groups is regular exposure to a combination of physical workplace stresses, such as overhead tasks, heavy lifting, and forceful activities, particularly when individuals perform tasks that require circular arm movements in awkward postures.

Psychological and psychosocial factors may also be associated with upper limb musculoskeletal disorders and this is even going to be much worse now as a result of psychological fallout of COVID-19 pandemic[34]. One of these shoulder musculoskeletal disorders is SIS in which the treatment is recommended to be mostly scheduled through conservative strategies.

In recent years, many studies have been trying different non-pharmacological therapeutic modalities included exercise programs for the rotator cuff and scapular muscles, demonstrating neuromuscular adaptations with improvements in muscle activity[35]. It presents a strong recommendation for exercise therapy as the first-line treatment to improve pain, mobility, and function[36], after a variety of manual therapy techniques incorporated with balanced ligamentous tension (BLT)[37], modification of everyday activities[38], and electrotherapy as the next most easy-to-reach ways to cope with SIS symptoms[39]. But, despite all these moderate to strong preliminary evidence suggesting use of different methods in agreement with the present study's findings in treatment of SIS, therapeutic strategies are still lacking due to poor understanding of the neurophysiological and molecular mechanisms involved in SIS and exercise specifications. Some of the water-induced mechanical and reflex effects though would seemingly be a reason to put hydrotherapy into treatment priorities for patients with SIS, as it has been recently found that a water-based program may be used as preventive approach to improve fall risk awareness in other adults with musculoskeletal disorders[40]; and a recent study whose training protocol was similar to the present study, has also outlined that a water-based aerobic training programs induced some improvements in the functional capacity and quality of life (QoL) in older adults[41]. In line with these findings, recent reviews have explored current perspectives on water therapy and the physiological mechanisms that support its use in pain management. These reviews indicate that water therapy is effective in alleviating the clinical symptoms of fibromyalgia syndrome, particularly pain, which is a defining characteristic of this condition.[24]. Even people with neurological disorders such as parkinson and severe traumatic brain injury (TBI) has also been reported to somehow benefit from undertaking hydrotherapy sessions[42, 43], which shows some special features of this therapy focused on principles such as floatability, hydrostatic pressure, viscosity and buoyancy can efficiently work on neural signaling / networks to block nociceptors throughout the spinal cord[44].

This neural repair process will support the body by increasing blood flow, aiding in the removal of allogeneic chemicals to promote muscle relaxation, and ultimately helping to relieve pain by decreasing peripheral edema and sympathetic nervous system activity. However, it's important to note that the neural benefits induced by hydrotherapy will not be achieved immediately; they require time and careful planning[45], as much long as the aquatic protocol recently being proposed to patients with end-stage dementia, which has led to their clinical progress[46] .

One probable reason for the lack of increase in upper trapezius activity in this study is the force couple function between the upper trapezius and serratus anterior[47]. Specifically, the movement patterns provided to the patients likely elicited more contractions in the anterolateral movement of the scapula along the ribcage, primarily activating the serratus anterior rather than the upper trapezius [48]. There has to be also some other reasons behind why our hydrotherapy protocol has been failed to significantly affect the range of motion of shoulder flexion unlike the considerable effects reported on pain scale, shoulder external and internal rotation, and abduction. First, unsurprisingly, hydrotherapy methodologically is characterized with the ability to assist in rehabilitation and recovery from serious injury, as a very low-to-moderate intensity complementary therapy which in some cases, seems not to be enough working to affect muscle tensions as like it inherently does for pain and range of motion (RoM) by loosening muscle stiffness / tension[49]. That's why this study would dare to suggest a different hydrotherapy program with more specialized and more challenging movements / stimulus must be considered to properly affect neural networks as well as muscle activity of trapezius muscle group. Secondly, as a review has recently proved, water-based walking training would naturally provoke lower muscle activation compared to land walking, which again shows our protocol may did not provide enough training load with considering patients' base one-to-one neuromuscular fitness[50] . And ultimately, a small sample size of 30 individuals was another factor might have negatively impacted final findings – as with any other study whose sampling size is limited for economic and other relevant reasons. Our findings, therefore, would be more robust if all these above-mentioned parameters being taken into consideration.

Conclusion

To schedule a long term nonpharmacological therapeutic program for patients with SIS must be careful about the extent of their disease, disability intensity, age and other health characteristics. Employing an exercise training intervention as like hydrotherapy with special characteristics and implementation features to support patients' weight while improving pain and ROM of shoulder, could be considered as a part of rehabilitation program for patients with SIS. However further studies are required to support if this therapy alone with adding the modifications needed, would be enough to act as strength training to improve neuromuscular profile as well as ROM or just counting upon it as a complementary therapy would be more rewarding.

Authors' contribution:

M Soleimanifar contributed to conception, design, analysis, interpretation of data and drafting the manuscript. M Sarabzadeh participated in design and interpretation of data and drafting the manuscript. M Pakdel participated in data collection. Z Asadi involved in data analysis and interpretation. All authors read and approved the manuscript.

Ethical Considerations:

All procedures applied as intervention and experiments in this study were also in accordance with the declaration of Helsinki-Tokyo, and approved by the local ethics committee (approval ID: IR.ACECR.IBCRC.REC.1400.020).

Conflicts of interest:

This research did not receive any specific grant from funding agencies in the public and commercial sectors.

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