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The Effects of Therapeutic Climbing on Pain, Function, and Muscle Thickness of the Supraspinatus and Infraspinatus in Sport Climbers with Shoulder Pain: A Randomized Controlled Trial

Geonwoo Sim †, Chunghyun Son †, Sangcheol Im † and Kyoung Kim *

Department of Physical Therapy, College of Rehabilitation Science, Daegu University, Gyeongsan 38453, Republic of Korea; 52313333@daegu.ac.kr (G.S.); handbug@daegu.ac.kr (C.S.); sc0942@daegu.ac.kr (S.I.)

* Correspondence: kykim257@daegu.ac.kr

† These authors contributed equally to this work.

Abstract

This study investigated the effects of therapeutic climbing on pain, function, and rotator cuff muscle thickness in sport climbers with shoulder pain using a prospective, single-blind randomized controlled trial design. Forty-five participants were randomly assigned to three groups: therapeutic climbing combined with sport climbing (EG1), shoulder stabilization exercise combined with sport climbing (EG2), and sport climbing alone (CG). Interventions were performed three times per week for six weeks, with assessments conducted at baseline, 3 weeks, and 6 weeks. Pain and disability were measured using the Shoulder Pain and Disability Index (SPADI), and muscle thickness of the supraspinatus and infraspinatus was assessed using ultrasound imaging. Both EG1 and EG2 demonstrated significantly greater improvements in pain and function compared to the control group ($p < 0.05$), with EG1 showing more consistent and progressive improvement over time. Changes in muscle thickness varied by muscle and intervention: supraspinatus thickness decreased over time in EG1, whereas it increased in EG2 and CG; in contrast, infraspinatus thickness remained stable in EG1 and EG2 but decreased in CG. These findings suggest that therapeutic climbing may promote more favorable neuromuscular adaptations, contributing to improved shoulder function. Therefore, therapeutic climbing may serve as an effective, sport-specific rehabilitation strategy for reducing pain and facilitating functional recovery in climbers with shoulder pain.

Keywords: therapeutic climbing; scapular stabilization exercise; sports climbing; pain; ultrasound

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1. Introduction

Sport climbing is a full-body activity that involves the coordinated use of both the upper and lower extremities, producing a wide range of movements depending on how the climber grips and steps on holds [1]. It is typically performed in indoor climbing facilities, where artificial walls are used to simulate rock climbing in a controlled and safe environment [2]. In recent years, sport climbing has gained substantial popularity, attracting increasing attention from researchers worldwide [3]. The discipline includes lead climbing, speed climbing, and bouldering, and was officially introduced as an Olympic sport at the Tokyo 2020 Olympic Games [4]. With the growing number of participants and increasing

specialization in sport climbing, the incidence of injuries has also risen due to greater training volume and intensity. In particular, beginners are reported to be more susceptible to injuries due to insufficient muscle strength, poor coordination, and overall lack of physical fitness [5]. Although injuries can occur in various parts of the body, the shoulder is recognized as the most frequently affected region [6]. Epidemiological analyses indicate that superior labral tears from anterior to posterior (SLAP lesions) and impingement syndrome are among the most common diagnoses [7]. Most shoulder injuries in climbing are attributed to chronic overuse. In particular, rotator cuff tears are associated with repetitive microtrauma caused by friction of the rotator cuff tendons within the subacromial space [8]. Furthermore, climbing movements involve sustained isometric contractions, explosive actions, and extreme ranges of overhead positioning, all of which further increase the risk of overuse injuries. Consequently, rotator cuff tendinopathy and biceps tendinitis are also frequently observed [9]. Meanwhile, it has been reported that the stiffness and thickness of the upper trapezius increase following repeated climbing activity, suggesting a potential association with excessive muscle use [10]. Therefore, for sport climbers who frequently perform overhead movements, improving both functional and morphological performance is essential for the prevention of shoulder pain and impingement syndrome. A systematic understanding of sport-specific injury patterns, as well as appropriate treatment strategies and return-to-sport protocols, is also required [8].

Shoulder pain is a highly prevalent musculoskeletal disorder that affects diverse populations [11]. It leads to significant functional impairment and psychological distress and is closely associated with reduced productivity and quality of life [12]. Moreover, shoulder pain carries a high risk of progressing to chronicity and disability, negatively impacting quality of life, psychological well-being, and the ability to maintain employment [13]. The etiology of shoulder pain is multifactorial and not yet fully understood; however, abnormal kinematics and impaired motor control of the shoulder complex have been proposed as important contributing factors [14]. The shoulder joint is the most mobile joint in the human body and relies heavily on soft tissues for stability because of its relatively shallow anatomical structure [15,16]. Consequently, soft tissue dysfunction may contribute to shoulder instability even in the absence of structural defects [17]. In particular, rotator cuff–related shoulder pain is considered a complex biopsychosocial condition associated with shoulder loading [18], while multidirectional instability and abnormal scapular positioning or movement may further impair shoulder function and normal kinematics [19]. Therefore, restoring scapular stability and normal shoulder kinematics is considered an important rehabilitation goal [20].

Shoulder stabilization exercises can be applied to patients with limited range of motion and functional impairment of the shoulder joint, such as those with impingement syndrome, adhesive capsulitis, and rotator cuff injuries, and are recognized as highly effective interventions in the rehabilitation of individuals with shoulder pain [21]. They are among the most widely used approaches in shoulder rehabilitation [14]. These exercises are effective in restoring trapezius muscle function and improving bilateral balance in accordance with scapular movement and coupled motion. In addition, they contribute to postural correction by normalizing thoracic alignment and restoring scapular alignment and kinematics [22]. The rotator cuff consists of the supraspinatus, subscapularis, infraspinatus, and teres minor muscles, which are anatomically adjacent to the glenohumeral joint and play a critical role in maintaining the dynamic stability of the shoulder [23]. These muscles are involved in various shoulder movements, including abduction, external rotation, and internal rotation, and contribute to joint stability by regulating the position of the humeral head [24]. Functionally, the muscles surrounding the scapula operate in a coordinated manner rather than in isolation to produce controlled movement [25]. Electromyographic

studies have also emphasized the importance of the rotator cuff and periscapular muscles in maintaining shoulder stability [17]. Therefore, optimal upper extremity function requires appropriate scapular movement and efficient neuromuscular coordination [26].

Climbing is an activity that reflects fundamental human movement patterns, allowing for high levels of motivation and adjustable exercise intensity, and can be performed in a relatively safe environment due to advances in safety equipment and techniques. These characteristics facilitate psychological motivation based on self-determination theory, thereby enhancing its potential as a therapeutic exercise modality. Accordingly, therapeutic climbing has been developed as a rehabilitation approach, representing a novel intervention based on artificial wall climbing movements [27]. Therapeutic climbing has been applied not only to musculoskeletal and neurological conditions, but also to psychological issues and trauma rehabilitation [28]. It provides both aerobic and anaerobic exercise effects, thereby contributing to improvements in cardiopulmonary endurance and muscular endurance [29]. In addition, the cognitively demanding nature of climbing enhances concentration and problem-solving abilities, while group-based participation promotes social interaction and motivation [30]. Previous studies have reported that shoulder stabilization exercises using therapeutic climbing increase joint range of motion, reduce functional impairment, and improve muscle activation around the shoulder in patients with impingement syndrome [31].

Shoulder strength and endurance are critical determinants of climbing performance, and exercises aimed at improving shoulder stability are expected to have a positive impact on sport climbing performance [32]. However, despite the high risk of injury among sport climbers due to repetitive overuse of the upper extremities, there remains a lack of understanding in clinical practice regarding the biomechanical demands, injury mechanisms, and return-to-sport considerations associated with climbing-related injuries [33]. Although it has been reported that climbing performance can be improved through the addition of systematic resistance training [34], evidence regarding specific intervention strategies remains limited. Furthermore, previous studies have primarily focused on evaluating the effects of therapeutic climbing in general patient populations, with relatively few studies targeting sport climbers, who are at a higher risk of injury. Therefore, there is a need for research on evidence-based rehabilitation and exercise interventions specifically for sport climbers, with particular emphasis on identifying the effectiveness of interventions aimed at improving shoulder stability. Accordingly, this study aimed to analyze the effects of therapeutic climbing on pain, functional outcomes, and the muscle thickness of the supraspinatus and infraspinatus in sports climbers with shoulder pain.

2. Materials and Methods

2.1. Study Design

This study was a prospective, single-blind, randomized controlled trial conducted in accordance with the CONSORT (Consolidated Standards of Reporting Trials) guidelines [35]. The study employed a three-arm parallel-group design, with an allocation ratio of 1:1:1 among the groups. The overall experimental procedure of this study is presented in Figure 1.

The participant flow, including recruitment, allocation, follow-up, and analysis, is reported in accordance with CONSORT recommendations and is illustrated in the CONSORT flow diagram (Figure 1).

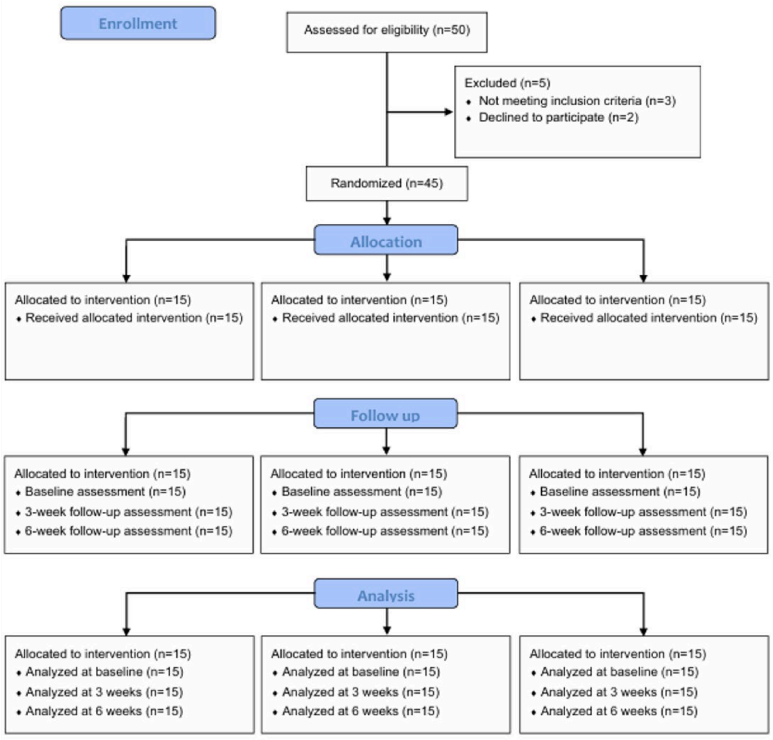


Figure 1. CONSORT 2025 flow diagram.

2.2. Sample Size Calculation

The sample size was calculated using G*Power software (version 3.1.9.7). The effect size (f = 0.40) was determined based on the most relevant previous study investigating therapeutic climbing interventions [31]. Because research examining therapeutic climbing in sport climbers with chronic shoulder pain is limited, few studies were available to provide precise estimates of expected treatment effects. Therefore, the effect size was selected based on the best available evidence from prior therapeutic climbing research. With a significance level of $\alpha = 0.05$, statistical power $(1 - \beta) = 0.80$, and three groups, the required minimum sample size was calculated to be 42 participants [36]. Considering an anticipated dropout rate of approximately 20%, a total of 50 participants were recruited. Of these, 5 participants were excluded due to refusal to participate or failure to meet the inclusion criteria, resulting in a final sample of 45 participants.

2.3. Randomization and Blinding

Randomization was performed by the principal investigator using a computer-generated random sequence obtained from the Randomizer.org website (https://www.randomizer.org; accessed on 15 September 2025). The random allocation sequence was generated before participant enrollment by an independent process and was not accessible to the investigators responsible for recruitment or outcome assessment. Participants were assigned to the study groups according to the random allocation sequence after enrollment. Allocation concealment was ensured using sealed, opaque, sequentially numbered envelopes, which were opened only after participant inclusion. To minimize selection bias, the allocation sequence was generated prior to participant recruitment and was not disclosed to the outcome assessor. The study employed a single-blind design in which the assessor responsible for outcome measurements remained unaware of group assignments throughout data collection. Due to the nature of the interventions, blinding of participants and therapists was not feasible. Because of the relatively small sample size, simple randomization was used without stratification; however, baseline characteristics were comparable across groups.

2.4. Participants

The participants were adult members of a climbing center in Daegu, Republic of Korea, who reported shoulder pain. Prior to participation, all participants were provided with a thorough explanation of the study objectives and procedures and gave written informed consent voluntarily.

A clinical screening was performed by the principal investigator to exclude participants with signs suggestive of complete rotator cuff tear or other severe structural shoulder pathology. This screening included a detailed medical history and a physical examination consisting of pain provocation tests, range of motion assessment, and manual muscle testing. Participants showing clinical signs indicative of severe structural damage were excluded from the study. No ultrasound or magnetic resonance imaging (MRI) was performed as part of the eligibility screening.

The final sample was allocated into three groups: experimental group 1 (EG1, n = 15), which performed sport climbing combined with therapeutic climbing; experimental group 2 (EG2, n = 15), which performed sport climbing combined with shoulder stabilization exercises; and the control group (CG, n = 15), which performed sport climbing alone. Inclusion criteria were: (1) adults with non-specific chronic shoulder pain persisting for more than 3 months, and (2) individuals with intact cognitive function, capable of understanding and following the investigator's instructions [37]. Exclusion criteria included: a history of shoulder surgery within the past 6 months [38], severe orthopedic conditions [30], and neurological or physical impairments that could influence study outcomes [39].

2.5. Procedure

The study was conducted over a period of 6 weeks, with interventions administered three times per week. Assessments were conducted at three time points: pre-test (before the intervention), mid-test (after 3 weeks of intervention), and post-test (after 6 weeks of intervention). All assessments were performed under standardized conditions in a consistent environment. Before the start of the study, written informed consent was obtained from all participants, and baseline characteristics (age, sex, height, weight, etc.) were collected to confirm homogeneity among the groups.

2.5.1. Therapeutic Climbing

The therapeutic climbing program was adapted and modified from the Potsdamer model to suit the objectives of this study [40]. All interventions were conducted three times per week over 6-week period, with each exercise performed in 3 sets of 10 repetitions [31]. A rest period of 1 min was provided between sets. Each therapeutic climbing session lasted approximately 30 min, including rest periods. Detailed descriptions of each program are presented in Figure 2. The Potsdamer model consists of four movement stages: initial position (first stability square), preparing movement (initiation of load triangle), movement (load triangle), and stabilization (second stability square). The therapist set the positions of holds and footholds according to the purpose of each movement, taking into account the stability square and load triangle.

The therapeutic climbing movements applied in this study emphasized correct posture and scapular stabilization throughout all exercises. In the first movement, "Straightening of the thoracic spine and depression of the shoulder girdle," participants stood facing the wall, grasping holds with both hands while placing the feet in a slightly externally rotated position to maintain their center of gravity. The thoracic spine was extended within a range that did not induce excessive kyphosis, while the scapulae were moved posteriorly and inferiorly, and both arms were extended. The chin was retracted to maintain cervical alignment before returning to the initial position. Pelvic and trunk stability were

maintained throughout, and compensatory movements were minimized (Figure 2a). In the subsequent movement, "Shoulder girdle retraction and shoulder joint adduction," participants assumed a similar starting position. During the preparing movement stage, the scapulae were retracted while the elbows moved posteriorly and inferiorly, inducing shoulder adduction. During the stabilization stage, participants returned to the initial position (Figure 2b). The final movement, "Diagonally climb with unilateral adduction and external rotation," was performed from the same initial position. Participants first moved the scapulae and elbows posteriorly, then reached the farthest diagonal hold using the non-affected upper limb. Next, the affected upper limb was used to grasp the next hold while stepping onto a higher foothold, performing upward movement. In the final stage, both arms were extended to form a stability square and maintain posture. This movement was repeated while ascending and descending the wall (Figure 2c).

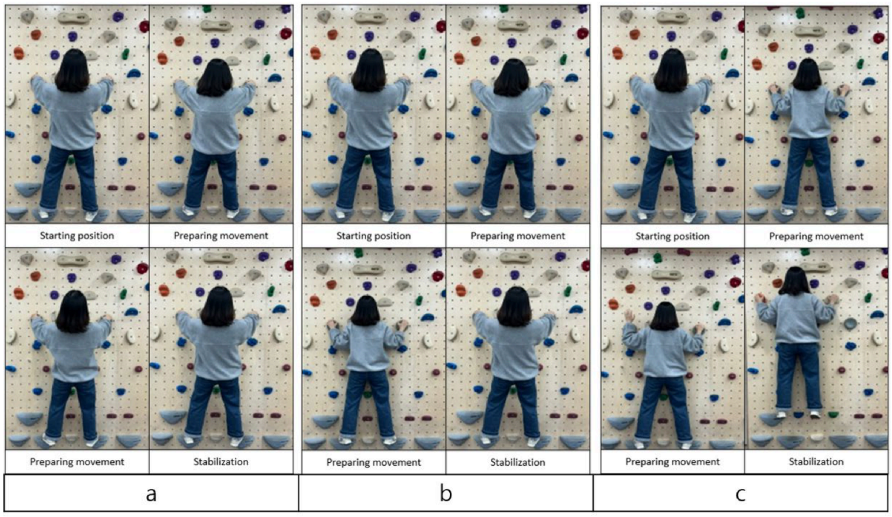


Figure 2. Therapeutic climbing program. (**a**) Straightening of the thoracic spine and depression of shoulder girdle; (**b**) Shoulder girdle retraction and shoulder joint adduction; (**c**) Diagonally climb with unilateral adduction and external rotation.

To ensure participant safety and proper execution of the therapeutic climbing tasks, the positions of the holds and footholds were individually adjusted by the therapist according to each participant's functional status and shoulder pain level. The intervention emphasized movement quality, scapular control, and postural alignment rather than climbing performance or maximal physical exertion. Therefore, route difficulty was progressively adjusted based on the therapeutic objectives of each exercise rather than according to a standardized climbing grade.

2.5.2. Shoulder Stabilization Exercise

Wall slides, push-up plus exercises, and external rotation exercises using a Thera-Band (Hygenic Corporation, Akron, OH, USA) were applied to promote shoulder stabilization and muscle activation. All exercises were performed with proper posture and within a pain-free range.

The wall slide exercise began with participants standing facing the wall, keeping their forearms in contact with the wall. They then slowly slid their arms upward in the direction of shoulder flexion to the maximal comfortable range while maintaining proper posture, before returning to the starting position. Participants were instructed to minimize excessive compensatory movements of the trunk during the exercise [41].

The push-up plus exercise was performed with participants' elbows fully extended and hands placed shoulder-width apart. The hips and knees were flexed at approximately

90°, and the shoulder flexion angle was set at 110–120°. Participants were then instructed to "push the shoulders forward" and maintain the position for 10 s. To enhance exercise effectiveness, the lower limb on the same side as the exercising arm was lifted, which increased serratus anterior activation while reducing overactivity of the upper trapezius [42,43].

Finally, the external rotation exercise with a Thera-Band was performed with participants in the side-lying position. The affected shoulder was maintained in a neutral position, and a towel was placed between the arm and trunk. Starting with the elbow flexed at 90° and the forearm supinated, participants rotated the shoulder externally through the available range of motion while holding the Thera-Band, and then returned slowly to the starting position. All exercises were performed at a controlled pace without using momentum or rapid acceleration [44,45]. No additional free weights or external loading devices were used during the stabilization exercise program. Resistance during the external rotation exercise was provided using a Thera-Band, and the resistance level was individually adjusted to ensure pain-free performance while maintaining correct movement patterns.

2.6. Outcome Measures

2.6.1. Shoulder Pain and Disability Index

The Shoulder Pain and Disability Index (SPADI) is a questionnaire developed to assess shoulder pain and functional disability. It consists of 13 items, including 5 items assessing pain and 8 items assessing functional impairment [46]. The SPADI demonstrates high reliability, with test–retest reliability of 0.99 and internal consistency of 0.94 [47].

2.6.2. Ultrasound Measurement of Muscle Thickness

Muscle thickness of the supraspinatus and infraspinatus was measured using an ultrasound imaging system (LS128 US, Telemed, Vilnius, Lithuania). The measurement protocol was based on previous studies, which reported an inter-rater reliability of 0.74 for this method [48]. All measurements were performed by the same assessor under consistent posture and environmental conditions to ensure measurement reliability.

Supraspinatus thickness was measured with participants in a seated position. The transducer was placed over the supraspinous fossa, aligned perpendicular to the skin and parallel to the muscle fibers. The hyperechoic line corresponding to the bony contour of the supraspinous fossa was used as a reference point to visualize the muscle fibers, and thickness was measured at the point where the muscle appeared thickest [48,49]. Infraspinatus thickness was also measured in a seated position. The transducer was positioned over the infraspinous fossa along the scapular spine, perpendicular to the skin and parallel to the muscle fibers. The hyperechoic line of the bony contour of the infraspinous fossa was used to identify the muscle fibers, and thickness was measured at the point of maximal muscle thickness [48,50].

2.7. Data Analysis

All data were analyzed using SPSS for Windows version 30.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean ± standard deviation. Normality of the data was assessed using the Kolmogorov–Smirnov test, and all variables were found to be normally distributed, allowing the use of parametric statistical analyses.

To examine both the time-dependent changes and differences among the three groups, a two-way repeated measures analysis of variance (ANOVA) was conducted (group × time). When significant interaction effects were observed, one-way repeated measures ANOVA was performed to analyze within-group changes, and one-way ANOVA was used for between-group comparisons. In cases of significant differences, Bonferroni post hoc tests were applied to control for Type I error due to multiple comparisons. The overall level of

statistical significance was set at $\alpha = 0.05$, and the significance level for Bonferroni-corrected post hoc tests was set at $\alpha = 0.017$.

3. Results

3.1. Baseline Characteristics of the Participants

The baseline characteristics of the participants are presented in Table 1. A total of 45 participants were included in the study, with 15 participants assigned to each of the three groups: EG 1, EG 2, and CG. There were no significant differences in baseline characteristics among the groups ($p > 0.05$).

Table 1. Baseline characteristics of the participants (mean ± SD).

	EG 1 (n = 15)	EG 2 (n = 15)	CG (n = 15)	*p*
Age (year)	39.40 ± 6.47	38.93 ± 4.16	39.13 ± 5.31	0.972
Gender (male/female)	7/8	6/9	5/10	0.757
Height (cm)	167.80 ± 6.08	166.87 ± 5.29	164.6 ± 8.65	0.426
Weight (kg)	59.6 ± 10.14	58.2 ± 9.26	58.27 ± 14.616	0.933
BMI (kg/m^2)	21.01 ± 2.15	20.92 ± 3.32	21.26 ± 3.55	0.950
On set (month)	12.53 ± 3.15	12.00 ± 3.46	13.87 ± 3.06	0.277
Damaged side (left/right)	7/8	5/10	8/7	0.532

EG 1: experimental group 1, EG 2: experimental group 2, CG: control group.

3.2. Comparison of Pain Index Within and Between Groups

The analysis of the pain index across groups and time points is presented in Table 2. A significant interaction effect between group and time was observed ($p < 0.05$), and significant main effects of both group and time were also found ($p < 0.05$). Post hoc analysis for the interaction effect is presented in Table 3. All three groups demonstrated significant changes over time. In EG 1 and EG 2, significant differences were observed between the pre-test and the 3-week assessment, as well as between the pre-test and the 6-week assessment. In the CG, significant differences were found between the pre-test and the 3-week assessment, and between the 3-week and 6-week assessments. Post hoc comparisons between groups at each time point revealed significant differences among EG 1, EG 2, and CG at 3 weeks, and all three groups differed significantly from each other at 6 weeks.

Table 2. The statistical analysis of pain index in each group.

S	SS	df	MS	F	*p*	Effect Size	95% CI
Group	2025.659	2	1012.830	13.559	0.000 *	0.392	(0.157, 0.563)
Time	1469.215	1.553	945.854	49.487	0.000 *	0.541	(0.374, 0.657)
Group × Time	1174.519	3.107	378.067	19.780	0.000 *	0.485	(0.299, 0.609)

* $p < 0.05$.

Table 3. Comparison of pain index within and between groups. (mean ±SD).

	Pre [a]	3 Week [b]	6 Week [c]	F	*p*	Effect Size	95% CI	Post Hoc
EG 1 (n = 15) [1]	38.40 ± 4.91	25.87 ± 3.02	22.80 ± 5.99	43.028	0.000 *	0.755	(0.519, 0.856)	a > b, a > c
EG 2 (n = 15) [2]	38.53 ± 6.02	34.27 ± 5.86	30.13 ± 5.53	14.174	0.000 *	0.503	(0.212, 0.675)	a > b, a > c
CG (n = 15) [3]	38.67 ± 7.62	36.93 ± 6.58	39.87 ± 6.44	15.907	0.001 *	0.532	(0.172, 0.729)	a > b, b < c
F	0.007	17.288	30.584					
p	0.993	0.000 *	0.000 *					
Effect size	<0.001	0.452	0.593					
95% CI	(0.000, 0.000)	(0.217, 0.610)	(0.386, 0.717)					
Post hoc		1 < 2, 1 < 3	1 < 2, 2 < 3, 1 < 3					

* $p < 0.017$. EG 1: experimental group 1, EG 2: experimental group 2, CG: control group.[a]: pre-test, [b]: after 3 week test, [c]: after 6 week test, [1]: EG 1, [2]: EG 2, [3]: CG.

3.3. Comparison of Disability Scale Within and Between Groups

The analysis of the disability scale across groups and time points is presented in Table 4. A significant interaction effect between group and time was observed ($p < 0.05$), and significant main effects of both group and time were also found ($p < 0.05$). Post hoc analysis for the interaction effect is presented in Table 5. All three groups showed significant changes over time. In EG 1, significant differences were observed between the pre-test and the 3-week assessment, between the pre-test and the 6-week assessment, and also between the 3-week and 6-week assessments. In EG 2, significant differences were found between the pre-test and the 3-week assessment, and between the pre-test and the 6-week assessment. In contrast, the CG showed a significant difference only between the pre-test and the 3-week assessment. Post hoc comparisons between groups at each time point revealed significant differences between EG 1 and CG, as well as between EG 2 and CG, at both the 3-week and 6-week assessments.

Table 4. The statistical analysis of disability scale in each group.

S	SS	df	MS	F	*p*	Effect Size	95% CI
Group	970.289	2	485.144	5.898	0.006 *	0.250	(0.043, 0.439)
Time	491.838	1.377	357.268	61.555	0.000 *	0.594	(0.428, 0.705)
Group × Time	587.835	2.753	213.500	36.785	0.000 *	0.637	(0.476, 0.734)

* $p < 0.05$.

Table 5. Comparison of disability scale within and between groups (mean ± SD).

	Pre [a]	3 Week [b]	6 Week [c]	F	*p*	Effect Size	95% CI	Post Hoc
EG 1 (n = 15) [1]	20.33 ± 6.47	15.33 ± 6.42	12.56 ± 5.23	32.601	0.000 *	0.700	(0.411, 0.827)	a > b, b > c, a > c
EG 2 (n = 15) [2]	20.58 ± 4.82	13.50 ± 4.01	12.75 ± 4.32	100.208	0.000 *	0.877	(0.731, 0.931)	a > b, a > c
CG (n = 15) [3]	20.00 ± 4.06	22.58 ± 4.66	21.92 ± 4.93	13.138	0.000 *	0.484	(0.191, 0.661)	a < b
F	0.047	13.134	18.289					
p	0.954	0.000 *	0.000 *					
Effect size	0.002	0.385	0.465					
95% CI	(0.000, 0.029)	(0.149, 0.557)	(0.232, 0.621)					
Post hoc		1 < 3, 2 < 3	1 < 3, 2 < 3					

* $p < 0.017$. EG 1: experimental group 1, EG 2: experimental group 2, CG: control group. [a]: pre-test, [b]: after 3 week test, [c]: after 6 week test, [1]: EG 1, [2]: EG 2, [3]: CG.

3.4. Comparison of Pain and Disability Scale Within and Between Groups

The analysis of pain and disability across groups and time points is presented in Table 6. A significant interaction effect between group and time was observed ($p < 0.05$), and significant main effects of both group and time were also found ($p < 0.05$). Post hoc analysis for the interaction effect is presented in Table 7. All three groups showed significant changes over time. In EG 1 and EG 2, significant differences were observed across all assessments, including pre-test, 3-week, and 6-week evaluations. In the CG, a significant difference was observed only between the pre-test and the 6-week assessment. Post hoc comparisons between groups at each time point revealed significant differences between EG 1 and CG, as well as between EG 2 and CG, at both the 3-week and 6-week assessments.

Table 6. The statistical analysis of pain and disability scale in each group.

S	SS	df	MS	F	*p*	Effect Size	95% CI
Group	1186.746	2	593.373	1544.545	0.000 *	0.360	(0.127, 0.537)
Time	802.936	1.597	502.853	89.808	0.000 *	0.681	(0.553, 0.764)
Group × Time	677.266	3.194	212.075	37.876	0.000 *	0.643	(0.498, 0.734)

* $p < 0.05$.

Table 7. Comparison of pain and disability scale within and between groups (mean ±SD).

	Pre [a]	3 Week [b]	6 Week [c]	F	*p*	Effect Size	95% CI	Post Hoc
EG 1 (n = 15) [1]	27.28 ± 5.16	19.38 ± 4.14	16.50 ± 4.10	62.602	0.000 *	0.817	(0.672, 0.884)	a > b, b > c, a > c
EG 2 (n = 15) [2]	27.49 ± 4.80	21.49 ± 4.17	19.44 ± 4.08	54.744	0.000 *	0.796	(0.637, 0.871)	a > b, b > c, a > c
CG (n = 15) [3]	27.18 ± 4.61	28.10 ± 4.34	28.82 ± 4.44	8.828	0.004 *	0.387	(0.063, 0.619)	a < c
F	0.016	17.457	35.065					
p	0.985	0.000 *	0.000 *					
Effect size	<0.001	0.454	0.625					
95% CI	(0.000, 0.000)	(0.219, 0.612)	(0.429, 0.741)					
Post hoc		1 < 3, 2 < 3	1 < 3, 2 < 3					

* $p < 0.017$. EG 1: experimental group 1, EG 2: experimental group 2, CG: control group. [a]: pre-test, [b]: after 3 week test, [c]: after 6 week test, [1]: EG 1, [2]: EG 2, [3]: CG.

3.5. Comparison of Ultrasound of Supraspinatus Muscle Thickness Within and Between Groups

The analysis of supraspinatus muscle thickness across groups and time points is presented in Table 8. A significant interaction effect between group and time was observed ($p < 0.05$). No significant main effect of group was found ($p > 0.05$), whereas a significant main effect of time was detected ($p < 0.05$). Post hoc analysis for the interaction effect is presented in Table 9. All three groups demonstrated significant changes over time. Significant differences were observed in all groups between the pre-test and the 6-week assessment, as well as between the 3-week and 6-week assessments. Post hoc comparisons between groups at each time point revealed significant differences among EG 1, EG 2, and CG at the 6-week assessment.

Table 8. The statistical analysis of ultrasound of supraspinatus muscle thickness in each group.

S	SS	df	MS	F	*p*	Effect Size	95% CI
Group	28.626	2	14.313	2.446	0.099	0.104	(0.000, 0.281)
Time	9.343	1.654	5.650	7.078	0.003 *	0.144	(0.020, 0.294)
Group × Time	42.223	3.307	12.766	15.994	0.000 *	0.432	(0.245, 0.561)

* $p < 0.05$.

Table 9. Comparison of ultrasound of supraspinatus muscle thickness within and between groups (mean ± SD).

	Pre [a]	3 Week [b]	6 Week [c]	F	*p*	Effect Size	95% CI	Post Hoc
EG 1 (n = 15) [1]	7.08 ± 1.27	6.80 ± 1.27	5.84 ± 1.09	52.116	0.000 *	0.788	(0.623, 0.866)	a > c, b > c
EG 2 (n = 15) [2]	7.19 ± 1.33	7.30 ± 1.72	8.36 ± 1.79	14.524	0.000 *	0.509	(0.219, 0.679)	a < c, b < c
CG (n = 15) [3]	7.12 ± 1.31	6.76 ± 1.80	8.53 ± 2.05	9.236	0.001 *	0.397	(0.105, 0.597)	a < c, b < c
F	0.028	0.528	11.874					
p	0.972	0.594	0.000 *					
Effect size	0.001	0.025	0.361					
95% CI	(0.000, 0.005)	(0.000, 0.146)	(0.128, 0.538)					
Post hoc			1 < 2, 1 < 3					

* $p < 0.017$. EG 1: experimental group 1, EG 2: experimental group 2, CG: control group. [a]: pre-test, [b]: after 3 week test, [c]: after 6 week test, [1]: EG 1, [2]: EG 2, [3]: CG.

3.6. Comparison of Ultrasound of Infraspinatus Muscle Thickness Within and Between Groups

The analysis of infraspinatus muscle thickness across groups and time points is presented in Table 10. A significant interaction effect between group and time was observed ($p < 0.05$), and significant main effects of both group and time were also found ($p < 0.05$). Post hoc analysis for the interaction effect is presented in Table 11. In the CG, significant changes over time were observed, with differences between the pre-test and the 3-week assessment, and between the pre-test and the 6-week assessment. Post hoc comparisons between groups at each time point revealed significant differences among EG 1, EG 2, and CG at the 6-week assessment.

Table 10. The statistical analysis of ultrasound of infraspinatus muscle thickness in each group.

S	SS	df	MS	F	*p*	Effect Size	95% CI
Group	19.592	2	9.767	4.032	0.025 *	0.161	(0.000, 0.349)
Time	9.654	2	4.827	9.524	0.000 *	0.185	(0.051, 0.323)
Group × Time	11.762	4	2.941	5.802	0.000 *	0.216	(0.057, 0.344)

* $p < 0.05$.

Table 11. Comparison of ultrasound of infraspinatus muscle thickness within and between groups (mean ± SD).

	Pre [a]	3 Week [b]	6 Week [c]	F	*p*	Effect Size	95% CI	Post Hoc
EG 1 (n = 15) [1]	5.78 ± 0.78	5.81 ± 0.80	5.86 ± 0.96	0.188	0.754	0.013	(0.000, 0.200)	
EG 2 (n = 15) [2]	5.77 ± 1.22	5.63 ± 1.21	5.35 ± 1.36	1.324	0.282	0.086	(0.000, 0.293)	
CG (n = 15) [3]	5.79 ± 0.87	4.78 ± 1.52	4.18 ± 0.56	11.510	0.000 *	0.451	(0.156, 0.637)	a > b, a > c
F	0.002	3.099	10.793					
p	0.998	0.056	0.000 *					
Effect size	<0.001	0.129	0.339					
95% CI	(0.000, 0.000)	(0.000, 0.311)	(0.109, 0.519)					
Post hoc			1 > 3, 2 > 3					

* $p < 0.017$. EG 1: experimental group 1, EG 2: experimental group 2, CG: control group. [a]: pre-test, [b]: after 3 week test, [c]: after 6 week test, [1]: EG 1, [2]: EG 2, [3]: CG.

4. Discussion

This study was conducted to investigate the effects of therapeutic climbing on pain and muscle thickness in sports climbers with shoulder pain. Pain and disability were assessed using the Shoulder Pain and Disability Index (SPADI), which consists of a pain subscale, a disability subscale, and a total index.

Analysis of the pain subscale revealed a significant interaction effect. Post hoc analyses showed that within-group comparisons indicated significant reductions in pain for EG 1 and EG 2 at both the 3-week and 6-week assessments compared to the pre-test. In contrast, CG showed a reduction in pain at the 3-week assessment relative to the pre-test, but pain increased again by the 6-week assessment. Between-group comparisons at each time point indicated that at 3 weeks, pain in EG 1 was lower than in EG 2 and CG. At 6 weeks, pain in both EG 1 and EG 2 was lower than in CG, with EG 1 showing a greater reduction than EG 2. Compared with the pre-test, pain decreased by 40% in EG 1 and 21% in EG 2, whereas pain in CG increased, with the greatest reduction observed in EG 1.

Analysis of the disability subscale also revealed a significant interaction effect. Within-group comparisons showed that EG 1 demonstrated a reduction in disability at both 3 weeks and 6 weeks compared to the pre-test, with a greater reduction at 6 weeks than at 3 weeks. EG 2 showed a decrease in disability at both 3 weeks and 6 weeks relative to the pre-test. In contrast, CG exhibited an increase in disability at 3 weeks compared to the pre-test. Between-group comparisons at each time point indicated that disability scores in both EG 1 and EG 2 were lower than those in CG at 3 weeks and 6 weeks. Compared with the pre-test, disability decreased by approximately 38% in EG 1 and EG 2, whereas it increased in CG.

Analysis of the total SPADI score, which combines pain and disability indices, also revealed a significant interaction effect. Within-group comparisons showed that both EG 1 and EG 2 exhibited reductions at 3 weeks and 6 weeks compared to the pre-test, with greater decreases at 6 weeks than at 3 weeks. In contrast, CG showed an increase at 6 weeks relative to the pre-test. Between-group comparisons at both 3 weeks and 6 weeks demonstrated that total SPADI scores in EG 1 and EG 2 were lower than in CG. Compared with the pre-test, total SPADI scores decreased by 39% in EG 1 and 29% in EG 2, whereas CG showed an increase, with the greatest reduction observed in EG 1.

Previous studies have reported that therapeutic climbing reduces pain and improves muscle strength, functional movement, and performance in activities of daily living in patients with shoulder impingement syndrome and decreased shoulder stability [31]. Consistent with these findings, the present study also demonstrated reductions in pain and disability. Therapeutic climbing is a closed-chain exercise that promotes postural control, muscle co-activation, and proprioceptive stimulation through axial loading [51,52]. Previous studies have suggested that enhanced proprioceptive input may contribute to pain modulation and is associated with reduced nociceptive activity [53–55]. Therefore, the improvements observed in EG1 may be partly explained by enhanced proprioceptive stimulation and improved neuromuscular control during therapeutic climbing.

Therapeutic climbing may serve as an effective and cost-efficient intervention for patients with pain, contributing to improved posture, enhanced trunk-centered awareness, and better muscle control [51]. Compared with other rehabilitation exercises, therapeutic climbing has been reported to promote higher levels of active patient engagement and to be effective in enhancing muscle strength, mobility, and overall body coordination [56]. The human body, including the brain, is more activated and facilitated during active participation than during passive involvement [57]. Therefore, the superior effects observed in EG 1 in terms of pain and disability are likely attributable to this active engagement. Indeed, previous research has shown that participants respond positively to interventions in which they are actively involved [58], highlighting the importance of active participation in rehabilitation.

Analysis of supraspinatus muscle thickness revealed a significant interaction effect between group and time. In EG1, muscle thickness decreased at 6 weeks compared to both the pre-test and the 3-week assessment, whereas EG2 and CG showed an increase at 6 weeks compared to both time points. Between-group comparisons indicated no significant differences at 3 weeks, whereas at 6 weeks, supraspinatus thickness was significantly greater in EG2 and CG than in EG1. The supraspinatus is the most commonly injured muscle of the rotator cuff, and repetitive mechanical stress on the shoulder can be associated with pain and alterations in surrounding musculature [59]. In patients with chronic shoulder instability, alterations in supraspinatus morphology have been reported, including changes in muscle size and structure [60]. Previous studies have also shown that sport climbing may influence supraspinatus thickness and subacromial space, likely reflecting sustained mechanical loading and altered shoulder biomechanics [61]. In addition, repetitive climbing activity has been associated with increased supraspinatus thickness and upper trapezius stiffness [10]. These findings suggest that climbing-related loading patterns may influence morphological adaptations of the shoulder musculature.

In the present study, EG1 underwent therapeutic climbing aimed at promoting controlled movement strategies and shoulder load management. The observed decrease in supraspinatus thickness in this group should be interpreted cautiously. Because ultrasound-based muscle thickness measurements reflect a combination of muscle geometry, fluid status, and measurement variability, they do not allow direct conclusions regarding muscle hypertrophy, atrophy, or tone changes. Therefore, the present findings do not permit a definitive interpretation that the observed reduction represents either a favorable or unfavorable adaptation. Instead, the results indicate that therapeutic climbing, stabilization exercise, and continued sport climbing may induce different patterns of supraspinatus morphological change over time. These differences may be related to variations in mechanical loading exposure, neuromuscular control strategies, and responses to repetitive shoulder use.

The shoulder joint is a synovial joint that exhibits three-dimensional movement, involving coordinated motion of the glenohumeral, acromioclavicular, sternoclavicular, and

scapulothoracic joints [62]. Stable movement requires coordinated activation of proximal stabilizers prior to distal motion [63]. The rotator cuff functions as a key stabilizer in this system [64], and therapeutic climbing may enhance shoulder stability by promoting coordinated multi-joint movement patterns. Previous studies have reported that therapeutic climbing reduces compensatory muscle activation patterns and facilitates more distributed muscular coordination [65].

Closed-chain exercises are widely used to provide overall axial loading to the shoulder joint and to stimulate proprioceptive input, thereby promoting appropriate contractions of the muscles surrounding the shoulder [31]. This mechanism can be explained by the transmission of proprioceptive signals from peripheral muscles and joint mechanoreceptors to the spinal cord and central nervous system, contributing both to spinal reflexes and to motor planning and adjustment at the central level, which enables motor control and regulation of muscle activation [66]. In the present study, therapeutic climbing likely stimulated proprioceptive fibers such as muscle spindles, induced spinal reflexes, and activated alpha motor neurons, thereby facilitating proper muscle contractions and stability around the shoulder. Moreover, diagonal movements have been shown to enhance scapular motion, and movements involving the shoulder adductors during therapeutic climbing are thought to contribute to this effect [67]. Compared with single-plane movements, diagonal patterns increase scapular rotation and tilt, suggesting that diagonal exercises can induce more complex shoulder movements [68]. Research on shoulder stabilization incorporating diagonal movements similar to those in therapeutic climbing has reported improvements in shoulder kinematics, range of motion, and muscle stability [69], with diagonal patterns contributing more effectively than single-plane movements to muscle activation, coordination, and stability [70]. Therefore, while these neuromuscular and biomechanical mechanisms may help explain the observed differences in shoulder muscle-related responses between groups, the present data does not allow a definitive interpretation of the specific physiological basis underlying the changes in supraspinatus muscle thickness observed in EG1. Accordingly, these findings should be interpreted as group-specific adaptive responses to different loading and movement patterns rather than evidence of a specific beneficial or adverse muscular remodeling process.

Analysis of infraspinatus muscle thickness revealed a significant interaction effect between group and time. Both EG 1 and EG 2 showed no significant changes before and after the intervention, whereas the CG demonstrated a decrease in thickness at 3 weeks and 6 weeks compared with pre-intervention. In the between-group comparisons at each time point, no differences were observed at pre-intervention and 3 weeks; however, at 6 weeks, EG 1 and EG 2 exhibited greater infraspinatus thickness than CG. The infraspinatus contributes to the dynamic stability of the shoulder joint by facilitating external rotation and depressing the humeral head. It also cooperates with the subscapularis in the horizontal plane to control rotational and anterior–posterior translation of the humeral head. Weakness of the infraspinatus can lead to overactivation of the posterior deltoid, resulting in increased anterior translation of the humeral head during external rotation. Particularly in patients with shoulder injuries, abnormal movement patterns may occur during external rotation, making selective activation of the infraspinatus an important factor for restoring shoulder stability [71]. Additionally, during overhead movements, the infraspinatus generates compressive forces to resist joint distraction, thereby contributing to the maintenance of dynamic joint stability [72]. However, the clinical and physiological significance of thickness changes cannot be determined based on muscle thickness measurements alone.

Therapeutic climbing goes beyond simple strength training by promoting whole-body coordination and functional movement, while providing appropriately graded stimuli according to the rehabilitation stage through adjustable difficulty levels [73]. Patient-

tailored, stepwise interventions have been reported to be more effective than standardized treatments in improving physical function and quality of life in individuals with chronic conditions [74]. Similarly, in patients with rotator cuff injuries, individualized progressive interventions have been shown to be more effective in reducing pain and enhancing function than standardized exercise protocols [75]. Recent guidelines for rotator cuff rehabilitation recommend a stage-based approach according to symptom severity and functional status, and therapeutic climbing can be considered an effective intervention that aligns with this approach [76]. The hold-based postural changes in therapeutic climbing, which require repetitive movements, facilitate coordinated neuromuscular activity of the upper extremity [77]. As the difficulty level increases, increased activation demands of the infraspinatus have been reported, reflecting the stabilization requirements to maintain the shoulder in a neutral position [73]. Additionally, diagonal three-dimensional movements and closed-chain exercises stimulate the myofascial chain, enhancing sensory feedback and contributing to neuromuscular control adaptations [27]. These findings from previous studies provide contextual support for the intervention rationale used in the present study.

This study applied therapeutic climbing to sport climbers with shoulder pain based on the theoretical foundations of previous research. The intervention may have contributed to a redistribution of mechanical load on the upper limbs, which was accompanied by reductions in shoulder pain and changes in joint stability-related outcomes. Prior studies reported that quasi-specific training, which includes movements similar to those in therapeutic climbing, is more effective than general strength-focused non-specific training in enhancing climbing performance, upper limb muscular endurance, maximal grip strength, and maximal muscle strength [78]. Although shoulder stabilization exercises may be effective due to the high-intensity physical demands of sport climbing, therapeutic climbing performed in actual climbing environments is likely more effective in addressing the specific needs of sport climbers and in promoting active engagement and motivation during exercise.

This study has several limitations. First, the small sample size limits the generalizability of the findings to the broader population of sport climbers. A small sample may fail to capture potential effects adequately or may allow the characteristics of specific participants to disproportionately influence the results. Although the sample size satisfied the a priori power calculation, the relatively small number of participants may have limited the ability to detect smaller treatment effects and may have reduced the generalizability of the findings. Given the limited availability of prior therapeutic climbing studies from which effect size estimates could be derived, the sample size calculation should be interpreted with caution. Future research should include larger-scale studies with more participants. Second, this study did not assess the muscle activation and thickness of other upper limb muscles or lower limb muscles, nor did it evaluate overall body alignment, making it unclear how therapeutic climbing affects the entire body. In addition, participants were recruited from a single climbing center, which may limit the generalizability of the findings to climbers from other settings or populations. Although all participants were recreational sport climbers, variability in climbing experience, skill level, and training characteristics may have influenced the observed outcomes. Furthermore, because the study targeted recreational sport climbers, physical activities performed outside the study protocol could not be fully controlled. Participants may have engaged in additional shoulder-related exercises or other forms of physical training that were not monitored, which may have influenced the intervention outcomes. Future studies should consider using physical activity diaries or objective activity-monitoring methods to better quantify and control external training loads. Furthermore, the control group continued participating in regular sport climbing activities and therefore did not represent a true non-intervention control group. Given

the substantial mechanical demands that sport climbing places on the shoulder complex, continued climbing exposure may have influenced symptom progression and contributed to the observed between-group differences. Therefore, the findings should be interpreted with caution. Another limitation is the use of a single-blind design. Although the outcome assessor was blinded to group allocation, participants and therapists could not be blinded because of the nature of the interventions. Consequently, participant awareness of group allocation may have introduced performance bias and expectation effects, which could have influenced engagement with the intervention as well as responses to subjective outcome measures such as pain and functional assessments. Future studies involving hospitalized patients or more controlled environments may be necessary. Recruiting participants with similar climbing skill levels could also improve the consistency of the results. Furthermore, categorizing participants based on the specific causes of shoulder pain may provide more precise insights. Finally, the long-term effects of therapeutic climbing were not investigated, warranting follow-up studies to examine sustained outcomes.

5. Conclusions

This study was a randomized controlled trial investigating the clinical effects of therapeutic climbing in sport climbers with shoulder pain, highlighting the utility of sport-specific rehabilitation approaches. The results demonstrated that interventions combining therapeutic climbing with shoulder stabilization exercises were associated with greater reductions in pain and improvements in function compared to sport climbing alone. Notably, the group receiving therapeutic climbing showed progressive functional improvements throughout the intervention period.

Changes in ultrasound-measured thickness of the supraspinatus and infraspinatus muscles were observed across groups; however, these findings should be interpreted as group-specific morphological changes rather than direct evidence of structural adaptation or functional improvement. These results suggest that therapeutic climbing may be associated with changes in neuromuscular and movement-related outcomes in sport climbers with shoulder pain.

Therefore, therapeutic climbing may serve as an effective strategy to complement conventional rehabilitation exercises for sport climbers with shoulder pain. Its clinical value lies in its sport-specific rehabilitation potential, as it allows exercise in climbing-like conditions that may facilitate neuromuscular control and functional movement relevant to return-to-sport training.

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