Research Article

Scapular Stabilization Versus Elbow Strengthening in Athletes with Lateral Epicondylitis

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Article info:
Received: 8 Jan 2026
Accepted: 4 May 2026

Citation: Ghiami SMM, Minoonejad H, Shirzad Araghi E, Moghadas Tabrizi Y, Farjad Pezeshk SA. Scapular Stabilization Versus Elbow Strengthening in Athletes with Lateral Epicondylitis. Journal of Modern Rehabilitation. 2026;20(3):?-?

Running Title: Scapular Stabilization in Lateral Epicondylitis

Abstract

Lateral elbow tendinopathy is not merely a localized elbow condition and is often associated with proximal movement impairments such as scapular dyskinesis, which may contribute to persistent pain and functional limitations in racket sport athletes.

Purpose: This study aimed to compare the effects of scapular stabilization exercises and elbow strengthening exercises on pain, disability, and functional performance in racket sport athletes with lateral elbow tendinopathy accompanied by scapular dyskinesis.

Methods: In this semi-experimental study with a pretest–posttest control group design, 49 racket sport athletes aged 18–25 years and diagnosed with lateral elbow tendinopathy and scapular

dyskinesis were randomly assigned to elbow strengthening exercises, combined training (elbow strengthening plus scapular stabilization), or a control group. Interventions were conducted over eight weeks, three sessions per week. Outcome measures included pain intensity, upper limb disability, muscle strength, dynamic balance, upper limb power, and functional movement performance.
Results: Both intervention groups showed reductions in pain and disability and improvements in functional performance, with greater and clinically meaningful improvements observed in the combined training group.
Conclusion: Incorporating scapular stabilization exercises into elbow strengthening programs leads to superior clinical and functional outcomes and supports a kinetic chain–based rehabilitation approach for racket sport athletes with lateral elbow tendinopathy.
Keywords: Lateral elbow tendinopathy; Scapular dyskinesis; Scapular stabilization; Exercise therapy; Athletic performance

1.Introduction

Lateral epicondylitis (LE), commonly referred to as *tennis elbow*, is a prevalent overuse tendinopathy primarily affecting the wrist extensor musculature and is characterized by pain, reduced grip strength, and functional limitations in physically active individuals(1). Systematic reviews have demonstrated that exercise-based interventions, particularly wrist extensor strengthening programs, are effective in reducing pain and improving function in individuals with LE. Recent rehabilitation strategies in clinical practice have shown benefits in improving functional outcomes in musculoskeletal conditions similar to lateral epicondylitis, as reported in a physiotherapy intervention study published in *Journal of Modern Rehabilitation*(2).
However, the magnitude of these effects appears to be limited, and such approaches may inadequately address functional impairments across the entire upper extremity kinetic chain(3).
In recent years, research attention has shifted beyond distal forearm structures toward the contribution of proximal kinetic chain dysfunctions, particularly impairments of the scapula and shoulder girdle. Day et al. (2021) reported greater weakness in scapular stabilizing muscles—including the lower and middle trapezius and serratus anterior—in individuals with LE compared with asymptomatic controls. This proximal muscle dysfunction may increase mechanical loading on distal segments such as the elbow(4, 5).
Among racket sport athletes, especially those frequently performing overhead strokes and high-velocity upper limb movements, proximal impairments such as scapular dyskinesis have been reported more commonly than in the general population. These alterations have been associated with an increased risk of shoulder pain and modified muscle activation patterns, although their direct influence on distal performance and grip strength remains debated(6, 7).
Scapular dyskinesis is defined as an alteration in the normal position or motion of the scapula during shoulder movement and may lead to impaired proprioception, reduced muscular endurance, and inefficient scapulohumeral rhythm. Collectively, these factors can compromise motor performance and upper limb function(6, 8, 9). Moreover, scapular dyskinesis has been proposed as a risk factor for upper-quarter musculoskeletal disorders(10, 11). A systematic review reported that athletes presenting with scapular dyskinesis have a 43% greater risk of developing shoulder pain compared with those without dyskinesis(12). Consequently, scapular dysfunction may contribute to increased mechanical load, altered neuromuscular activation, and compensatory stress on distal structures such as the elbow, particularly during repetitive and high-speed movements typical of racket sports(11, 13, 14).

Currently, distal strengthening exercises—such as wrist extensor strengthening—form the cornerstone of LE rehabilitation and have been shown to reduce pain and improve grip strength. However, these interventions alone may be insufficient to correct underlying proximal impairments(15). Emerging evidence suggests that incorporating proximal-focused interventions may enhance clinical outcomes(8, 16).

Despite these promising findings, few studies have directly compared scapular stabilization exercise programs with traditional elbow-focused strengthening protocols in racket sport athletes. Most existing studies have examined proximal or distal interventions in isolation or within heterogeneous athletic populations, limiting the ability to draw population-specific conclusions.

Moreover, no consensus exists regarding whether targeting proximal impairments provides superior clinical and functional benefits compared with conventional elbow strengthening in racket sport athletes who commonly present with both lateral epicondylitis and scapular dyskinesis(17). Well-designed randomized controlled trials directly comparing these interventions within this specific subgroup remain limited (6).

Therefore, it remains unclear whether directly addressing proximal impairments leads to greater reductions in pain and disability and superior improvements in functional performance in racket sport athletes with concurrent lateral epicondylitis and scapular dyskinesis. Addressing this knowledge gap, the present study aimed to compare the effects of a scapular stabilization exercise program with those of an elbow strengthening protocol on pain, disability, and functional performance in this population.

2.Material and Methods

2.1. Study Design

This study was designed as a single-blind, randomized controlled trial with a pretest–posttest parallel-group design.

2.2. Participants

The study population consisted of racket sport athletes (tennis, badminton, and squash) aged 18–25 years. Participants were diagnosed with scapular dyskinesis based on Kibler's classification and with lateral elbow tendinopathy confirmed by positive findings on Cozen's, Maudsley's, and Mill's tests. The initial clinical diagnosis of lateral elbow tendinopathy was confirmed by an orthopedic specialist prior to participant enrollment.

Scapular dyskinesis was classified according to Kibler's observational system, which categorizes scapular movement patterns into three types based on abnormal prominence of the inferior angle (Type I), medial border (Type II), or excessive superior translation (Type III) during dynamic shoulder elevation. Visual assessment was performed bilaterally during repeated shoulder flexion and abduction tasks. Participants demonstrating visible dyskinetic patterns were included in the study.

Sample size estimation was performed using G*Power software, assuming a significance level of $\alpha \leq 0.05$, statistical power of 0.80, and an effect size of $f = 0.25$, which indicated a minimum required sample of 45 participants. To account for potential dropouts, 49 athletes were recruited and randomly allocated into three groups using simple randomization: elbow strengthening exercise group ($n = 18$), combined training group (elbow strengthening plus scapular stabilization exercises; $n = 16$), and control group ($n = 15$).

Allocation sequence was generated by an independent researcher using computer-based simple randomization. Outcome assessments were conducted by a physiotherapist blinded to group

allocation. The therapist delivering the interventions was not blinded due to the nature of exercise therapy.
Participants allocated to the control group did not receive any structured rehabilitation exercises during the intervention period and were instructed to maintain their usual activities. This group functioned as a wait-list control and was offered the exercise program after study completion. Participants were not informed about the comparative objectives of the study to minimize performance and expectation bias.
Following randomization, all participants underwent baseline (pretest) assessments, completed the assigned intervention protocol, and were reassessed at posttest.

2.3. Ethical Considerations

This study was approved by the Research Ethics Committee of Tehran University, Faculty of Sport Sciences and Health (IR.UT.SPORT.REC.1404.020; approved on April 16, 2025). The study procedures complied with the ethical principles for medical research involving human participants as outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants before participation.

2.4. Outcome Measures

Outcome measures included pain intensity assessed by the Visual Analog Scale (VAS); upper limb disability assessed using the Disabilities of the Arm, Shoulder and Hand questionnaire (DASH) and the Patient-Rated Tennis Elbow Evaluation (PRTEE); wrist strength measures including grip strength, wrist extension strength, and middle finger extension strength; and functional performance assessments including Functional Movement Screening (FMS)(18), dynamic balance, and the medicine ball side throw test.
Grip strength was measured using a JAMAR hand dynamometer, while wrist extension and middle finger extension strength were assessed using a handheld dynamometer (HHD; model 01165APP).

2.5. Intervention Protocols

The scapular stabilization exercise program was designed based on previous studies(19-21) and aimed to correct scapular movement dysfunctions through neuromuscular re-education and targeted activation of scapular stabilizing muscles. These exercises were performed for eight weeks, three sessions per week, with each session lasting approximately 60 minutes.
The elbow strengthening exercise protocol was conducted using a Powerball device over an eight-week period, with three sessions per week and a duration of 30 minutes per session(22, 23). Exercise intensity was determined by the rotational speed of the Powerball, starting at approximately 2,000 revolutions per minute during the initial weeks and progressively increasing to up to 10,000 revolutions per minute in the later weeks, according to participants' tolerance and ability.
Participants were instructed to perform a five-minute warm-up prior to each training session, focusing on the upper extremity and wrist muscles. The Powerball training program included ten exercises in the following sequence: wrist flexion, wrist extension, elbow flexion, elbow extension, shoulder abduction, shoulder flexion, shoulder internal rotation, shoulder external rotation, horizontal shoulder adduction, and horizontal shoulder abduction. Training volume and repetitions were progressively increased according to the principle of progressive overload, with a work-to-rest ratio of 2:1. Due to the centrifugal force generated by the gyroscopic rotor, all Powerball

exercises-imposed resistance on the fingers and contributed to strengthening of the wrist pronator and supinator muscles.
The detailed scapular stabilization exercise protocol is presented in **Appendix A**, and the elbow strengthening exercise protocol is provided in **Appendix B**.

2.6. Statistical Analysis

Data were analyzed using two-way mixed analysis of variance (Mixed ANOVA) with one within-subject factor (time: baseline and post-intervention after 8 weeks) and one between-subject factor (group: three study groups), including the time × group interaction effect. Participants were assessed at baseline prior to the initiation of the intervention and reassessed immediately after completion of the 8-week training period. Statistical analyses were performed using SPSS software (version 26), with the level of significance set at $p < 0.05$.
Effect sizes for within-group changes were calculated using Cohen's d and interpreted as small (0.2), medium (0.5), and large (0.8). The intraclass correlation coefficient (ICC) was used to assess the reliability of the medicine ball side throw test.

3. Results

Demographic characteristics of the participants are presented in **Table 1**. Data normality was confirmed using the Shapiro–Wilk test, homogeneity of variances was verified by Levene's test, and homogeneity of variance–covariance matrices was confirmed, indicating that the assumptions for two-way mixed repeated-measures ANOVA were satisfied.

Table 1. Demographic Characteristics of the Participants

Variable	Control Group (Mean ± SD)	Elbow Strengthening Group (Mean ± SD)	Combined Group (Scapular Stabilization + Elbow Strengthening) (Mean ± SD)	F	p-value
Age (years)	21.67 ± 2.41	21.56 ± 2.28	21.88 ± 1.70	1.745	0.482
Height (cm)	175.40 ± 3.92	177.28 ± 5.71	176.31 ± 5.13	0.571	0.569
Body weight (kg)	71.86 ± 2.97	72.44 ± 4.73	74.25 ± 4.13	1.470	0.239
Body mass index (kg/m²)	23.36 ± 0.67	23.04 ± 0.84	23.87 ± 0.63	2.590	0.077
Duration of symptoms (years)	3.36 ± 0.87	3.14 ± 0.84	3.87 ± 0.92	0.491	0.615

Data are presented as mean ± standard deviation (SD). No significant between-group differences were observed at baseline (one-way ANOVA).
Comparisons of mean values and changes in the study variables across the three groups from pretest to posttest, along with statistical significance, effect sizes, and clinical significance, are presented in **Table 2** and **Figure 1**. After eight weeks of intervention, significant reductions were observed in pain intensity (VAS), upper limb disability (DASH), and tennis elbow–specific disability (PRTEE) in both intervention groups ($p < 0.001$), whereas no significant changes were

found in the control group. The magnitude of improvement in pain and disability outcomes was greater in the combined training group (scapular stabilization plus elbow strengthening) compared with the elbow strengthening–only group. Importantly, these improvements were not only statistically significant but also exceeded the minimal clinically important difference (MCID) for most outcomes. In contrast, changes observed in the control group were neither statistically nor clinically meaningful.

For muscle strength variables, including grip strength, wrist extension strength, and middle finger extension strength, statistically significant improvements were observed in both intervention groups ($p < 0.001$). However, the magnitude of change and attainment of MCID thresholds were predominantly evident in the combined training group, suggesting a more clinically effective improvement in muscular performance when scapular stabilization exercises were incorporated.

Regarding the medicine ball side throw test, test–retest reliability for the medicine ball side throw was low (ICC ≈ 0.39), indicating limited measurement stability, and the minimal detectable change (MDC) was approximately 2.8. Therefore, only changes exceeding this threshold were considered indicative of a true functional improvement.

Table 2. Pre- to Post-Intervention Changes in Clinical and Functional Outcomes Across the Study Groups

Variable	Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Change (Mean ± SD)	p-value	Effect Size (Cohen's d)	MCID Threshold	Clinical Sig
Pain (VAS)	Elbow strengthening	4.33 ± 0.97	2.33 ± 0.97	−2.00 ± 0.76	<0.001	1.84	1.5	Yes
	Combined training	4.38 ± 0.80	0.75 ± 0.85	−3.63 ± 0.80	<0.001	3.88	1.5	Yes
	Control	4.07 ± 1.03	4.60 ± 0.63	+0.53 ± 0.64	0.060	0.48	1.5	No
Upper limb disability (DASH)	Elbow strengthening	32.27 ± 1.84	20.50 ± 5.71	−11.77 ± 3.22	<0.001	4.13	10	Yes
	Combined training	33.81 ± 2.16	15.37 ± 3.44	−18.44 ± 3.26	<0.001	5.55	10	Yes
	Control	32.80 ± 2.56	33.20 ± 2.75	+0.40 ± 1.50	0.320	0.24	10	No
Tennis elbow–specific disability (PRTEE)	Elbow strengthening	51.16 ± 8.50	33.50 ± 11.44	−17.66 ± 6.23	<0.001	3.11	11	Yes
	Combined training	52.12 ± 9.83	29.31 ± 11.01	−22.81 ± 5.07	<0.001	3.90	11	Yes
	Control	49.60 ± 9.21	50.00 ± 9.25	+0.40 ± 1.12	0.189	0.31	11	No

Grip strength (kg)	**Elbow strengthening**	28.66 ± 6.40	31.27 ± 6.71	+2.61 ± 1.22	<0.001	0.83	10%	No
	Combined training	28.32 ± 5.31	34.19 ± 6.00	+5.87 ± 2.48	<0.001	1.82	10%	Yes
	Control	24.66 ± 4.89	24.43 ± 4.83	−0.23 ± 0.45	0.068	0.17	10%	No

Table 2. continued

Wrist extension strength (kg)	**Elbow strengthening**	18.58 ± 1.50	20.15 ± 1.71	+1.57 ± 0.86	<0.001	0.92	10%	No
	Combined training	18.00 ± 1.55	21.29 ± 2.55	+3.29 ± 2.00	<0.001	1.65	10%	Yes
	Control	17.44 ± 1.42	17.25 ± 1.30	−0.19 ± 0.43	0.105	0.11	10%	No
Middle finger extension strength (kg)	**Elbow strengthening**	2.69 ± 0.45	2.88 ± 0.44	+0.19 ± 0.17	<0.001	0.42	10%	No
	Combined training	2.84 ± 0.45	3.30 ± 0.49	+0.46 ± 0.17	<0.001	0.92	10%	Yes
	Control	2.83 ± 0.39	2.74 ± 0.38	−0.09 ± 0.11	0.087	0.19	10%	No
Dynamic balance (YBT) (cm)	**Elbow strengthening**	69.05 ± 2.28	73.11 ± 3.04	+4.06 ± 2.31	<0.001	1.44	4	Yes
	Combined training	70.68 ± 3.43	81.75 ± 3.33	+11.07 ± 1.84	<0.001	2.46	4	Yes
	Control	69.46 ± 3.06	69.06 ± 3.59	−0.40 ± 0.91	0.111	0.13	4	No
Medicine ball side throw (m)	**Elbow strengthening**	3.55 ± 0.72	4.61 ± 0.88	+1.05 ± 0.80	<0.001	1.29	2.8	No
	Combined training	4.01 ± 0.87	6.65 ± 0.92	+2.64 ± 0.78	<0.001	3.13	2.8	No
	Control	4.16 ± 0.89	4.08 ± 0.89	−0.08 ± 0.18	0.091	0.20	2.8	No
Functional Movement Screening (FMS)	**Elbow strengthening**	16.88 ± 2.05	18.16 ± 1.72	+1.27 ± 0.82	<0.001	0.93	1.5	No
	Combined training	15.68 ± 1.35	19.50 ± 1.15	+3.82 ± 1.10	<0.001	2.46	1.5	Yes
	Control	17.06 ± 2.34	16.73 ± 2.52	−0.33 ± 0.72	0.096	0.36	1.5	No

Data are presented as mean ± standard deviation (SD).

Effect sizes are presented as Cohen's d.

MCID: minimal clinically important difference.
Clinical significance indicates whether the observed change exceeded the MCID threshold.
Statistical analysis was performed using a two-way mixed ANOVA (time × group).

Inferential analysis was conducted using two-way mixed ANOVA, with results illustrated in **Figures 1 and 2**. The main effect of time was significant for all variables, including pain, upper limb disability, tennis elbow–specific disability, grip strength, wrist extension strength, middle finger extension strength, dynamic balance, medicine ball side throw performance, and Functional Movement Screening (FMS) scores ($p < 0.001$), indicating significant overall changes over time across participants.
Additionally, a significant main effect of group was observed for most variables ($p < 0.05$ to $p < 0.001$), reflecting differential responses among the three study groups. Effect size values indicated moderate to large effects for both clinical and functional outcomes.

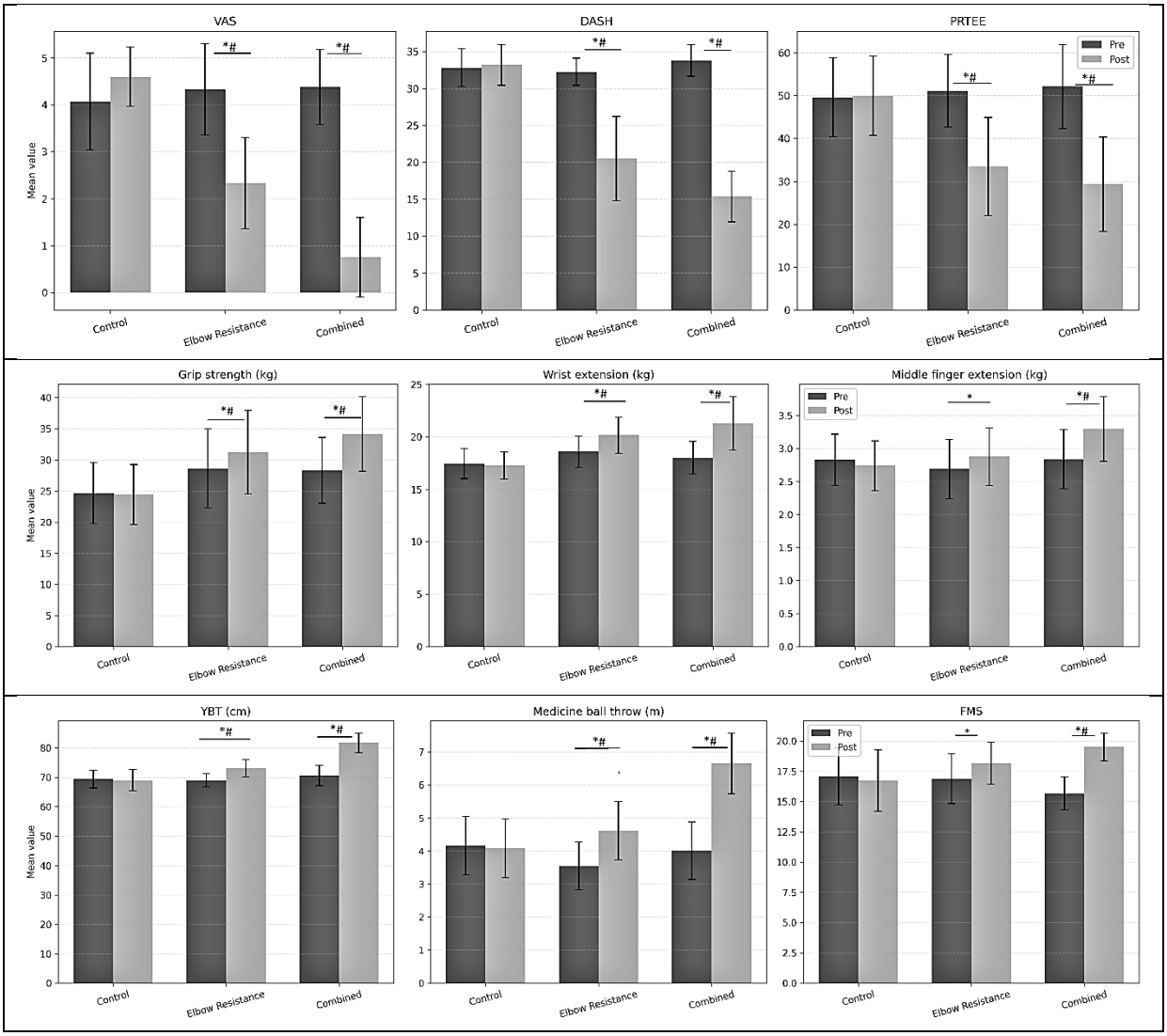

Figure 1. Comparison of mean in study variables across the control, elbow strengthening, and combined training groups. The asterisk (*) indicates a significant main effect of time (within-group differences between pretest and posttest), whereas the hash symbol (#) denotes

a significant time × group interaction effect (between-group differences accounting for the time factor).

Table 3. Results of Two-Way Mixed Analysis of Variance (Time, Group, and Time × Group Effects)

Variable	Time Effect (F, p, η^2p)	Group Effect (F, p, η^2p)	Time × Group Interaction (F, p, η^2p)
Pain (VAS)	**F(1, 46) = 253.33, p < 0.001, η^2p = 0.84**	**F(2, 46) = 18.51, p < 0.001, η^2p = 0.44**	**F(2, 46) = 122.36, p < 0.001, η^2p = 0.84**
Upper limb disability (DASH)	**F(1, 46)= 600.48, p < 0.001, η^2p = 0.92**	**F(2, 46)= 53.51, p < 0.001, η^2p = 0.69**	**F(2, 46)= 175.48, p < 0.001, η^2p = 0.88**
Tennis elbow–specific disability (PRTEE)	**F(1, 46)= 375.94, p < 0.001, η^2p = 0.89**	**F(2, 46)= 3.89, p = 0.027, η^2p = 0.14**	**F(2, 46)= 99.28, p < 0.001, η^2p = 0.81**
Grip strength (kg)	**F(1, 46)= 139.65, p < 0.001, η^2p = 0.75**	**F(2, 46)= 5.95, p = 0.005, η^2p = 0.20**	**F(2, 46)= 54.87, p < 0.001, η^2p = 0.70**
Wrist extension strength (kg)	**F(1, 46)= 71.47, p < 0.001, η^2p = 0.60**	**F(2, 46)= 9.49, p < 0.001, η^2p = 0.29**	**F(2, 46)= 28.57, p < 0.001, η^2p = 0.55**
Middle finger extension strength (kg)	**F(1, 46)= 66.78, p < 0.001, η^2p = 0.59**	F(2, 46)= 2.24, p = 0.118, η^2p = 0.08	**F(2, 46)= 44.24, p < 0.001, η^2p = 0.65**
Dynamic balance (YBT) (cm)	**F(1, 46)= 351.46, p < 0.001, η^2p = 0.88**	**F(2, 46)= 22.79, p < 0.001, η^2p = 0.49**	**F(2, 46)= 156.07, p < 0.001, η^2p = 0.87**
Medicine ball side throw (m)	**F(1, 46)= 156.39, p < 0.001, η^2p = 0.77**	**F(2, 46)= 12.84, p < 0.001, η^2p = 0.35**	**F(2, 46)= 64.77, p < 0.001, η^2p = 0.73**
Functional Movement Screening (FMS)	**F(1, 46)= 150.74, p < 0.001, η^2p = 0.76**	F(2, 46)= 0.66, p = 0.521, η^2p = 0.02	**F(2, 46)= 83.83, p < 0.001, η^2p = 0.78**

Values are reported as F-statistic, p-value, and partial eta squared (η^2p). Effect sizes are reported as partial eta squared (η^2p). Values of 0.01, 0.06, and 0.14 indicate small, medium, and large effects, respectively.
Significant results ($p < 0.05$) are shown in **bold**.
Mixed ANOVA revealed significant main effects of time for all variables ($p < 0.001$).

A significant main effect of group was observed for most variables, while some variables (e.g., middle finger extension strength and FMS) did not show significant between-group differences.
Significant time × group interaction effects were observed across all outcome variables ($p < 0.001$), indicating that the magnitude of change over time differed between groups (Table 3).
Post-hoc Bonferroni-adjusted pairwise comparisons revealed that the combined training group demonstrated significantly greater improvements compared with the elbow strengthening group ($p < 0.01$) and the control group ($p < 0.001$) across most primary outcomes.
Additionally, the elbow strengthening group showed significantly greater improvements compared with the control group ($p < 0.05$).

However, for some variables such as middle finger extension strength and Functional Movement Screening (FMS), no significant between-group differences were observed ($p > 0.05$), despite significant improvements over time.

4. Discussion

The present study aimed to compare the effectiveness of elbow strengthening exercises with a combined intervention consisting of scapular stabilization and elbow strengthening exercises in racket sport athletes with lateral epicondylitis accompanied by scapular dyskinesis. The main findings demonstrated that although both interventions resulted in statistically significant improvements in pain, disability, and selected functional outcomes, the combined training program produced significantly superior effects compared with elbow strengthening alone. Importantly, this superiority was evident not only at the statistical level but also in terms of clinical significance (MCID) and effect sizes, underscoring the clinical relevance of the observed changes.

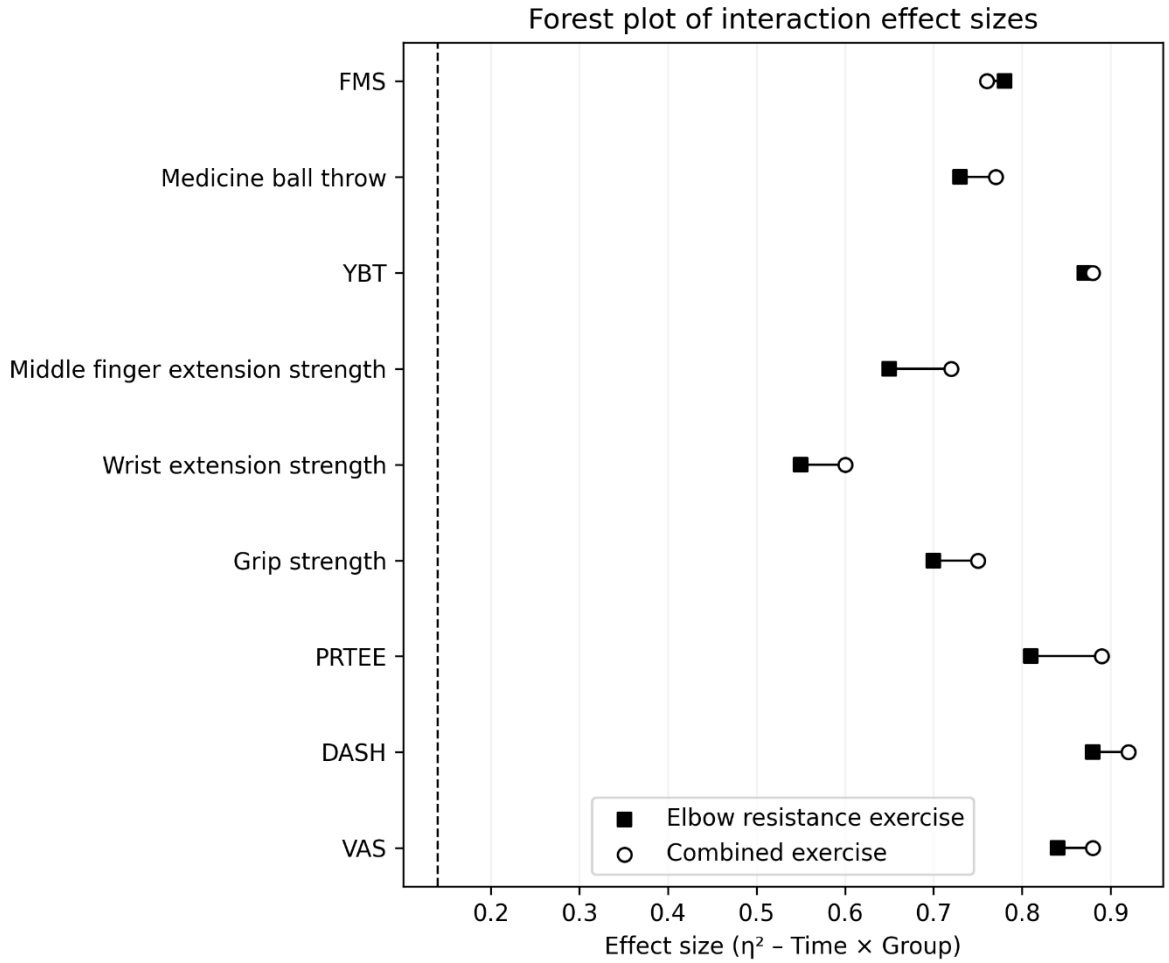

Figure 2. Forest plot illustrating effect sizes for between-group comparisons across the exercise interventions.

Recent literature has increasingly emphasized that lateral epicondylitis should not be viewed as a purely local disorder, but rather as a manifestation of dysfunction within the upper extremity kinetic chain(6, 11). Impaired scapular control may lead to compensatory increases in mechanical

load at the elbow joint and wrist extensor tendons. Several studies have reported that deficits in scapular stability compromise efficient force transfer from the trunk to the upper limb, thereby increasing stress on distal structures(8, 9, 13, 24). The findings of the present study align with this perspective and suggest that improving scapular function plays a key role in reducing elbow-related pain.

A particularly important finding of this study was that reductions in pain and disability in the combined training group not only reached statistical significance but also exceeded established MCID thresholds for VAS (1.5–2 units) (25, 26), DASH (10–15 units) (27, 28), and PRTEE (11 units) (29). In contrast, these clinically meaningful changes were not consistently observed in the elbow strengthening–only group. This distinction is clinically important, as many intervention studies in lateral epicondylitis focus primarily on statistical significance while overlooking clinical relevance. The present findings indicate that the combined intervention resulted in changes that were both numerically meaningful and perceptible to patients.

These results further support the notion that lateral epicondylitis—particularly in athletic populations—is not merely a localized tendon disorder. While elbow-focused strengthening may alleviate symptoms to some extent, it may be insufficient to induce sustained and functionally meaningful improvements when proximal impairments remain unaddressed(30, 31). In contrast, interventions that concurrently target proximal dysfunctions appear to have greater potential to produce clinically relevant outcomes(4, 32).

The present findings also provide direct support for biomechanical models of the upper extremity kinetic chain(13, 33). According to these models, impaired scapular control can result in inefficient force transmission and increased compensatory loading at the elbow joint(34). The scapular stabilization exercises used in this study likely improved scapular positioning, enhanced the function of stabilizing muscles, and optimized scapulohumeral rhythm, thereby creating more favorable mechanical conditions for elbow function(10, 35, 36). This biomechanical explanation is particularly compelling given that neither the control group nor the elbow strengthening group achieved improvements comparable to those observed in the combined training group. Therefore, the superior outcomes observed in the combined intervention group are likely related to the inclusion of scapular-focused exercises; however, given the multifactorial nature of rehabilitation responses, definitive causal attribution should be interpreted with caution.

Although statistically significant improvements in muscle strength were observed in both intervention groups, attainment of clinically meaningful thresholds—commonly reported as approximately a 10% increase in strength(37)—was predominantly evident in the combined training group. This finding highlights the important distinction between “statistical strength gains” and “functionally meaningful improvements”(13, 35). Isolated elbow strengthening may increase muscle force output; however, without adequate proximal stability, such gains may not translate into effective functional performance(11).

From a neuromechanical perspective, improved scapular stability may reduce pain-related inhibition of distal musculature and enhance neuromuscular activation timing, thereby facilitating more effective force production(38). Consequently, the strength improvements observed in the combined training group likely reflect a synergistic effect of pain reduction, enhanced motor control, and muscular strengthening. This interpretation is consistent with the principle of *proximal stability for distal mobility*, which posits that adequate proximal control is essential for efficient distal force generation(39). Recent electromyographic studies have shown that optimal activation of the serratus anterior and lower trapezius muscles can improve forearm extensor muscle activation patterns and mechanical efficiency(38).

Furthermore, the significant improvements observed in functional outcomes—such as dynamic balance (YBT), medicine ball side throw performance, and Functional Movement Screening (FMS)—in the combined training group indicate that the effects of this intervention extended beyond symptom reduction to improvements in movement quality and neuromuscular coordination of the upper extremity. This finding addresses a common criticism of rehabilitation studies, namely the lack of transfer from clinical improvements to real-world functional performance. The present results suggest that combined training may help bridge the gap between clinical recovery and functional readiness, a consideration of particular importance for racket sport athletes who are exposed to repetitive, high-velocity upper limb loading.

The presence of significant time × group interaction effects across all primary outcomes, accompanied by moderate to large effect sizes, further indicates that the observed differences between groups were not attributable to random variation or natural recovery over time. Rather, these findings suggest that the type of intervention may have influenced differential treatment responses between groups.

Despite certain limitations—including a relatively small sample size, lack of long-term follow-up, and incomplete control of individual variability— this study demonstrates strong internal validity through the use of validated outcome measures, appropriate statistical analyses, and a focus on clinical relevance. Overall, the findings support comprehensive rehabilitation approaches that extend beyond localized treatment and provide a solid scientific basis for future research and the development of more integrative rehabilitation protocols for athletes with lateral epicondylitis.

5. Conclusion

Based on the findings of this study, both elbow strengthening exercises and combined training programs resulted in significant improvements in pain, disability, and muscle strength in athletes with lateral epicondylitis. The combined intervention incorporating scapular stabilization exercises was associated with greater improvements compared with elbow strengthening alone, with changes that were both statistically and clinically meaningful.

These findings suggest that incorporating scapular stabilization exercises into rehabilitation programs may enhance clinical and functional outcomes in this population. However, further large-scale and long-term studies are warranted to confirm these findings and clarify the specific mechanistic contributions of proximal interventions.

6. Limitations of the Study

Several limitations should be considered when interpreting the findings of this study. First, the sample size was relatively modest, which may limit generalizability despite adequate statistical power. Second, the absence of long-term follow-up prevents determination of the sustainability of the observed improvements. Third, although assessor blinding was implemented, participant and therapist blinding was not feasible due to the nature of exercise-based interventions, which may introduce performance bias.

Additionally, the reliability of the medicine ball side throw test was relatively low, which should be considered when interpreting functional performance outcomes. Finally, while the study design allows comparison between intervention approaches, it does not permit definitive conclusions regarding the isolated mechanistic contribution of scapular stabilization exercises independent of other rehabilitation components.

Acknowledgements

The authors would like to express their sincere appreciation to the faculty members of the Department of Department of Sports injury and biomechanics at the University of Tehran and the University of Birjand for their valuable support and guidance. This article was derived from a doctoral dissertation in Sports Injury and Corrective Exercises and was approved by the Ethics Committee of the Faculty of Sport Sciences and Health, University of Tehran (Ethics Code: IR.UT.SPORT.REC.1404.020).

Authors' contributions

S.M.M.G. contributed to study design, data collection, data analysis, and manuscript drafting.
H.M. contributed to study conception, methodological supervision, statistical analysis oversight, and critical revision of the manuscript.
E.S.A. assisted in data collection and interpretation of results.
Y.M.T. contributed to data analysis and manuscript editing.
S.A.F.P. supervised the study process and critically reviewed the final manuscript.
All authors read and approved the final version of the manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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Appendix A. Scapular Stabilization Exercise Protocol

No.	Exercise	Description	Sets & Repetitions / Hold Time	Weeks
1	Scapular Retraction	The participant lies in a prone position with the hand clenched into a fist and the thumb pointing upward. The arm is positioned at 30°, 90°, and 130° of shoulder abduction while performing scapular retraction.	3 sets of 10 repetitions with 20-s hold	Weeks 1–2
			3 sets of 15 repetitions with 20-s hold	Weeks 3–4
			3 sets of 20 repetitions with 20-s hold	Weeks 5–6
			3 sets of 25 repetitions with 20-s hold	Weeks 7–8
2	Push-Up Plus	Hands are placed slightly wider than shoulder width with the body positioned at approximately 45°. The participant lowers the body, pushes upward, and adds an additional scapular protraction at the end of the movement.	3 sets of 10 repetitions with 5-s hold	Weeks 1–2
			3 sets of 15 repetitions with 5-s hold	Weeks 3–4
			3 sets of 20 repetitions with 5-s hold	Weeks 5–6
			3 sets of 25 repetitions with 5-s hold	Weeks 7–8
3	Scapular Retraction and Depression	A TheraBand is looped around the scapular region. The participant holds both ends of the band and pulls	3 sets of 10 repetitions with 10-s hold	Weeks 1–2
			3 sets of 15 repetitions with 10-s hold	Weeks 3–4

		upward at approximately 30° of shoulder elevation while performing scapular retraction and depression.	3 sets of 20 repetitions with 10-s hold	Weeks 5–6
			3 sets of 25 repetitions with 10-s hold	Weeks 7–8

Appendix A (continued)

4	Dipping	The participant supports the body with straight arms on a chair or bench, with hands shoulder-width apart. The elbows are flexed to lower the body until the elbow joint reaches approximately 90°, then extended to return to the starting position.	3 sets of 10 repetitions with 10-s hold	Weeks 1–2
			3 sets of 15 repetitions with 10-s hold	Weeks 3–4
			3 sets of 20 repetitions with 10-s hold	Weeks 5–6
			3 sets of 25 repetitions with 10-s hold	Weeks 7–8
5	Forward Leaning	The forearms are placed at 90° on a Swiss ball, with the knees and feet positioned on the ground at hip width. The participant moves the arms forward while maintaining trunk and scapular control.	3 sets of 10 repetitions with 5-s hold	Weeks 1–2
			3 sets of 15 repetitions with 5-s hold	Weeks 3–4
			3 sets of 20 repetitions with 5-s hold	Weeks 5–6
			3 sets of 25 repetitions with 5-s hold	Weeks 7–8

Appendix B. Elbow Strengthening Exercise Protocol

Week	Group Type❄	Exercise (Duration × Sets)	Exercise Name	Rest Between Sets (s)	Rest Between Exercises (s)	Execution Position
1	A	Exercise 1 (3 × 30 s)	Wrist flexion	60	120	Sitting at a table
	A	Exercise 2 (3 × 30 s)	Wrist extension	60	120	Sitting at a table
	B	Exercise 3 (3 × 30 s)	Elbow flexion	60	120	Standing
2	A	Exercise 1 (4 × 30 s)	Wrist flexion	60	120	Sitting at a table
	A	Exercise 2 (4 × 30 s)	Wrist extension	60	120	Sitting at a table
	B	Exercise 3 (4 × 30 s)	Elbow flexion	60	120	Standing
3	A	Exercise 2 (4 × 45 s)	Wrist extension	90	180	Sitting at a table

	B	Exercise 3 (4 × 45 s)	Elbow flexion	90	180	Standing
	B	Exercise 4 (3 × 30 s)	Elbow extension	60	120	Standing (trunk flexed)
	C	Exercise 5 (3 × 30 s)	Shoulder flexion	60	120	Sitting at a table

Appendix B. continued

4	A	Exercise 2 (5 × 45 s)	Wrist extension	90	180	Sitting at a table
	B	Exercise 3 (5 × 45 s)	Elbow flexion	90	180	Standing
	B	Exercise 4 (4 × 30 s)	Elbow extension	60	120	Standing (trunk flexed)
	C	Exercise 5 (4 × 30 s)	Shoulder flexion	60	120	Sitting at a table
5	B	Exercise 3 (5 × 60 s)	Elbow flexion	120	240	Standing
	B	Exercise 4 (4 × 45 s)	Elbow extension	90	180	Standing (trunk flexed)
	C	Exercise 5 (4 × 45 s)	Shoulder flexion	90	180	Sitting at a table
	D	Exercise 6 (3 × 30 s)	Shoulder abduction	60	120	Sitting at a table
	E	Exercise 7 (3 × 30 s)	Shoulder external rotation	60	120	Sitting at a table
6	B	Exercise 3 (6 × 60 s)	Elbow flexion	120	240	Standing
	B	Exercise 4 (5 × 45 s)	Elbow extension	90	180	Standing (trunk flexed)
	C	Exercise 5 (5 × 45 s)	Shoulder flexion	90	180	Sitting at a table
	D	Exercise 6 (4 × 30 s)	Shoulder abduction	60	120	Sitting at a table
	E	Exercise 7 (4 × 30 s)	Shoulder external rotation	60	120	Prone position
7	B	Exercise 4 (5 × 60 s)	Elbow extension	120	240	Standing (trunk flexed)
	C	Exercise 5 (5 × 60 s)	Shoulder flexion	120	240	Sitting at a table
	D	Exercise 6 (4 × 45 s)	Shoulder abduction	90	180	Sitting at a table

	E	Exercise 7 (4 × 45 s)	Shoulder external rotation	90	180	Side-lying on table
	E	Exercise 8 (3 × 30 s)	Shoulder internal rotation	60	120	Side-lying on table
	F	Exercise 9 (3 × 30 s)	Horizontal shoulder abduction	60	120	Prone on table

Appendix B. continued

8	C	Exercise 5 (6 × 60 s)	Shoulder flexion	120	240	Sitting at a table
	D	Exercise 6 (5 × 45 s)	Shoulder abduction	90	180	Sitting at a table
	E	Exercise 7 (5 × 45 s)	Shoulder external rotation	90	180	Side-lying on table
	E	Exercise 8 (4 × 30 s)	Shoulder internal rotation	60	120	Side-lying on table
	F	Exercise 9 (4 × 30 s)	Horizontal shoulder abduction	60	120	Prone on table
	F	Exercise 10 (3 × 30 s)	Horizontal shoulder adduction	60	120	Supine on table

All exercises were performed using a Powerball device. Exercise intensity was progressively increased across weeks according to the principle of progressive overload. Rest intervals are reported in seconds (s).

[*]Exercises were classified into six groups based on movement patterns: A (wrist flexion/extension), B (elbow flexion/extension; elbow strengthening), C (shoulder flexion/extension), D (shoulder abduction/adduction), E (shoulder internal/external rotation), and F (horizontal shoulder abduction/adduction).