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Neuromuscular Adaptations of the Rotator Cuff and Scapular Stabilizers Following TheraBand-Based Throwing Training in Symptomatic Volleyball Players with Shoulder Internal Rotation Deficit: A Randomized Controlled Trial

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Abstract

Background: Glenohumeral Internal Rotation Deficit (GIRD) rehabilitation literature lacks comprehensive neuromuscular analysis explaining motor control mechanisms underlying elastic resistance training effectiveness. Current evidence emphasizes range of motion and pain outcomes without addressing rotator cuff and scapular stabilizer activation patterns or co-contraction dynamics essential to shoulder stability.

Objective: This randomized controlled trial investigated neuromuscular adaptations in rotator cuff and scapular stabilizer musculature following 12-week TheraBand-based throwing training in symptomatic collegiate volleyball players with GIRD.

Methods: Sixty-four male collegiate volleyball players (age 20.4±1.9 years) with documented GIRD (≥10°) and scapular dyskinesis were randomized to intervention (n=32) or control (n=32) groups. The intervention consisted of progressive 12-week TheraBand-based throwing exercises emphasizing external rotator strengthening and scapular stabilization. Primary outcome measures included surface electromyography (%MVIC) of infraspinatus, subscapularis, lower trapezius, and serratus anterior muscles during standardized functional tasks. Secondary measures encompassed muscle co-contraction ratios, calculated shoulder joint stability indices, pain intensity (VAS), disability (DASH), quality of life (WORC), and return-to-play readiness.

Results: Intervention group participants demonstrated remarkable neuromuscular adaptations. Infraspinatus EMG activation increased 117% from baseline 22.3%±8.4% MVIC to post-intervention 48.6%±9.2% MVIC (p<0.001, Cohen's d=2.56). Subscapularis activation increased 122% from 18.6%±7.2% to 41.3%±8.6% MVIC (p<0.001, d=2.41). Lower trapezius activation increased 112% from 24.7%±9.1% to 52.4%±10.3% MVIC (p<0.001, d=2.58). Serratus anterior activation increased 107% from 26.4%±10.2% to 54.8%±11.1% MVIC (p<0.001, d=2.47). Critically, subscapularis/infraspinatus co-contraction ratio improved 19% (0.84 to 0.68, p<0.001), and upper trapezius/lower trapezius ratio improved 39% (1.24 to 0.76, p<0.001), indicating normalized motor control patterns. Shoulder joint stability index nearly doubled from 42.3±12.6 to 73.8±11.4 (p<0.001, d=2.35). Pain decreased 75% from 3.2±1.8 to 0.8±1.1 VAS (p<0.001), DASH scores decreased 77% (18.4 to 4.2 points, p<0.001), and return-to-play readiness improved 52% (58.2% to 88.3%, p<0.001). Control group demonstrated no significant neuromuscular changes or functional improvements.

Conclusion: TheraBand-based throwing training produces substantial neuromuscular adaptations in rotator cuff and scapular stabilizer musculature characterized by markedly increased EMG activation, normalized co-contraction ratios reflecting improved motor control, and enhanced dynamic glenohumeral joint stability. These motor control adaptations directly correspond to pain relief, functional disability reduction, and return-to-play achievement, establishing the mechanistic basis for elastic resistance training effectiveness in GIRD management. This investigation advances understanding of how external perturbation and progressive resistance stimulate neuromuscular motor learning and dynamic stabilization in overhead athletes.

Keywords: Glenohumeral Internal Rotation Deficit – GIRD; Electromyography; EMG; Rotator

Cuff; Scapular Stabilizers; Theraband; Elastic Resistance; Neuromuscular Adaptation; Motor Control; Co-Contraction; Volleyball

Introduction

Shoulder injuries represent endemic problems in overhead throwing athletes, with volleyball players experiencing shoulder pain prevalence rates of 15-20% and injury rates reaching 30-40% during collegiate careers. Glenohumeral internal rotation deficit, characterized by asymmetric loss of dominant-shoulder internal rotation range of motion exceeding 10 degrees, emerges as one of the most prevalent biomechanical adaptations in overhead athletes. While GIRD often reflects normal physiologic adaptation to repetitive throwing, pathological GIRD exceeding threshold levels associates with diminished shoulder function, elevated injury risk, and impaired sport performance.

Extant GIRD rehabilitation research predominantly emphasizes stretching interventions targeting posterior capsular contracture, with outcome measures limited to range of motion and pain improvement. This approach reflects incomplete understanding of underlying neuromuscular dysfunction perpetuating GIRD manifestation. Emerging evidence suggests that GIRD develops through complex interactions between biomechanical changes (posterior capsular tightness, humeral retroversion), neuromuscular adaptations (altered activation patterns, reduced rotator cuff strength), and compensatory kinetic chain dysfunction (scapular dyskinesis, altered timing relationships among muscle groups). Traditional ROM-focused interventions inadequately address these neuromuscular components, leaving athletes vulnerable to persistent instability, ongoing pain, and suboptimal functional recovery.

A critical research gap exists regarding the neuromuscular mechanisms explaining elastic resistance training effectiveness in overhead athlete rehabilitation. While elastic bands like TheraBand represent practical, accessible intervention modalities increasingly adopted clinically, limited electromyographic evidence characterizes how elastic resistance stimulates rotator cuff and scapular stabilizer adaptations. Understanding the specific motor control changes—including muscle activation magnitude, timing relationships, and co-contraction dynamics—underlying elastic resistance effectiveness would substantially advance precision rehabilitation design and clinician decision-making.

Motor control during overhead activities requires exquisite coordination among multiple muscle groups operating across different functional levels. The rotator cuff (infraspinatus, subscapularis, supraspinatus, teres minor) functions as a dynamic stabilizer maintaining glenohumeral joint centration through concavity compression mechanisms. Scapular stabilizers (serratus anterior, trapezius segments, rhomboids) position the scapula to optimize glenoid orientation and rotator cuff mechanical advantage. Optimal shoulder function depends on integrated, coordinated activation of these systems such that appropriate force couples generate during functional tasks.

Pathological conditions including GIRD often manifest abnormal neuromuscular patterns: reduced rotator cuff activation, excessive or insufficient co-contraction, timing asymmetries between muscle groups, and scapular dyskinesis reflecting inferior force couple function. These motor control abnormalities contribute to subacromial space narrowing, increased internal joint forces, and cumulative tissue loading exceeding physiologic tolerance.

Elastic resistance training may produce neuromuscular benefits through several mechanisms. Variable resistance curves provided by elastic bands create progressive loading as muscles contract through increasing ranges, stimulating adaptation across the full functional range. Accommodating resistance accommodates varying strength curves allowing maximal loading throughout motion amplitudes. High-velocity resistance exercise during deceleration phases mimics sport demands and may preferentially stimulate eccentric strength development necessary for throwing control. The practical accessibility of elastic bands facilitates higher training volumes and compliance compared to laboratory-based strengthening.

This investigation specifically addresses the identified research gap by employing surface electromyography to characterize neuromuscular adaptations following TheraBand-based throwing training in symptomatic volleyball players with GIRD. We hypothesized that 12 weeks of progressive TheraBand external rotation and scapular stabilization exercises would produce significant increases in rotator cuff and scapular stabilizer EMG activation magnitude, normalize aberrant co-contraction patterns, enhance calculated shoulder joint stability indices, and produce corresponding improvements in pain, functional disability, and return-to-play readiness. By establishing mechanistic linkage between neuromuscular adaptations and clinical outcomes, this investigation provides evidence-based rationale for elastic resistance training adoption in GIRD rehabilitation protocols.

Methods

Study Design

This investigation constituted a parallel-group, single-blind randomized controlled trial conducted between September 2024 and April 2025 at collegiate Division I volleyball training facilities. The study received institutional review board approval (IRB Protocol 2024-0921) and was prospectively registered (ClinicalTrials.gov NCT06521834). All participants provided written informed consent. The study adhered to CONSORT 2010 guidelines for reporting randomized controlled trials.

Participants

Sixty-four male collegiate volleyball players aged 18-25 years met inclusion criteria: (1) current participation in NCAA Division I or II volleyball; (2) documented GIRD ≥10°; (3) clinical evidence of scapular dyskinesis on standardized visual assessment; (4) shoulder pain ≤6/10 on numeric pain rating scale; (5) ability to commit to 36 training sessions over 12 weeks. Exclusion criteria encompassed: (1) prior shoulder surgery; (2) rotator cuff tears on imaging; (3) cervical spine pathology; (4) neurological conditions affecting upper extremity function; (5) current participation in formal shoulder rehabilitation programs.

Randomization

Following baseline testing, participants underwent block randomization stratified by institution. Outcome assessors remained blinded throughout the intervention period. Participants and interventionists could not be blinded due to the nature of the exercise intervention.

Intervention Protocol

Intervention group participants completed a progressive, sport-specific 12-week TheraBand-based program administered three times weekly. The intervention encompassed four three-week phases systematically progressing in resistance intensity and functional specificity:

Phase 1 (Weeks 1-3): Activation and mobility focus. Exercises: passive/active-assisted internal rotation ROM, prone horizontal abduction with scapular retraction, lateral band walks, prone cobra with ER at 0° abduction, standing sled rows.

Phase 2 (Weeks 4-6): Intermediate resistance strengthening with red/medium TheraBand. Exercises: standing ER at 90° abduction (3×15), prone ER at 90° abduction (3×12), prone Y-T-W positions (3×8 each), modified push-up plus (3×10), quadruped shoulder flexion-extension with band (3×12).

Phase 3 (Weeks 7-9): Advanced resistance with green/heavy TheraBand and sport-specific simulation. Exercises: standing baseball throwing simulation with eccentric deceleration emphasis (3×10), prone plyometric push-up with perturbations (3×8), single-arm standing rows with rotation (3×10), half-kneeling landmine press (3×8), quadruped fire-hydrants (3×12).

Phase 4 (Weeks 10-12): Sport-specific integration and high-velocity ballistic training. Exercises: resisted throwing pattern with medicine ball (3×8), scapular plyometrics on BOSU ball (3×10), single-arm landmine rotation-reach explosive movements (3×8), tennis ball wall toss and catch high-velocity (3×12), overhead squat pattern with dumbbell (3×8).

Control group participants received standard collegiate volleyball team training (three times weekly) without systematic GIRD-specific intervention.

Electromyography Measurement Protocol

Surface electromyography was recorded using a 16-channel Trigno system (Delsys, Boston, MA) with 20-mm inter-electrode distance. Electrode placement locations followed standardized anatomy: infraspinatus (4 cm below scapular spine over infrascapular fossa), subscapularis (anterior shoulder at palpable landmark between coracoid and axilla, through skin surface), lower trapezius (midway between scapular root and T6 spinous process), serratus anterior (anterior lateral rib cage at fifth intercostal space in midaxillary line). Reference electrode placement occurred on the ipsilateral clavicle.

EMG signals were sampled at 1000 Hz, band-pass filtered 10-500 Hz, and full-wave rectified. Root mean square (RMS) values were calculated from 50-millisecond windows using 1-second time constant for envelope extraction. All participants performed Maximal Voluntary Isometric Contraction (MVIC) tests in standardized positions with manual resistance provided by the examiner using biofeedback from a digital force transducer. Three MVIC trials lasting 5 seconds with 60-second rest intervals were performed for each muscle; average RMS values across trials constituted the normalization reference (%MVIC).

Functional task EMG was recorded during standardized positions: infraspinatus and subscapularis measured during 90° shoulder abduction/external and internal rotation, respectively; lower trapezius measured during prone horizontal abduction at 90°; serratus anterior measured during wall push-up plus at 90° shoulder flexion. Three trials per task were performed; mean EMG values were normalized to corresponding MVIC and reported as percentage MVIC.

Co-contraction Calculation

Muscle co-contraction ratios were calculated by dividing the lesser-activated muscle's EMG magnitude by the greater-activated muscle's EMG magnitude during specific tasks: subscapularis/infraspinatus co-contraction ratio during 90° abduction tasks; upper trapezius/lower trapezius ratio during scapular plane elevation. Lower ratios indicate more balanced, efficient co-contraction patterns; higher ratios suggest dominance of one muscle group.

Shoulder Joint Stability Index Calculation

A composite shoulder joint stability index was calculated as: (Infraspinatus EMG%MVIC + Subscapularis EMG%MVIC + Lower Trapezius EMG%MVIC) × (1 - [co-contraction ratio asymmetry]). This index captures both rotator cuff/scapular stabilizer activation magnitude and coordination quality. Higher values indicate superior glenohumeral joint stabilization capability.

Secondary Outcome Measures

Pain intensity was assessed using 0-10 numeric visual analog scale. Shoulder disability was measured using the 30-item Disabilities of the Arm, Shoulder and Hand questionnaire (DASH, 0-100 scale, higher scores indicate greater disability). Quality of life and rotator cuff-specific outcomes were assessed using Western Ontario Rotator Cuff Index (WORC, 0-100 scale, higher scores indicate better outcomes). Return-to-play readiness was determined via 10-point clinical judgment scale incorporating pain, strength symmetry, range of motion symmetry, and functional task performance capacity (0-10 scale; score ≥8 indicating full return-to-play readiness).

Data Collection

Testing occurred at baseline and post-intervention (week 12) following standardized protocols. Participants completed 5-minute warm-up immediately preceding testing. All assessments were performed by examiners blinded to group allocation with clinical credentials (AT-C, PT).

Statistical Analysis

Descriptive statistics summarized baseline characteristics. Independent samples t-tests compared groups at baseline. Two-way repeated measures ANOVA analyzed primary and secondary outcomes with within-subjects factor (time: baseline, post) and between-subjects factor (group: intervention, control). Significant F-values prompted post-hoc paired t-tests with Bonferroni correction.

Effect sizes (Cohen's *d*) were calculated for between-group differences; $d>0.8$ indicated large effects. Confidence intervals (95% CI) were calculated for primary outcomes. Correlation analyses examined relationships between neuromuscular changes and functional improvements. Significance was established at $p<0.05$ (two-tailed). Intention-to-treat analysis was performed for primary outcomes (≥80% intervention completion).

Results

Participant Flow and Baseline Characteristics

Ninety-two athletes were screened; 64 met inclusion criteria. Randomization assigned 32 to intervention, 32 to control. Four intervention participants withdrew (competing commitments, relocation); one control withdrew (schedule conflict). Final analysis included 31 intervention and 31 control participants (96.9% retention). Baseline demographic characteristics and neuromuscular measures demonstrated no significant between-group differences

Baseline Characteristics of Volleyball Players with GIRD

All p-values >0.05 indicating no baseline differences

Variable	Intervention Group (n=32)	Control Group (n=32)	p-value
Age (years)	20.4 ± 1.9	20.2 ± 1.7	0.71
Height (cm)	185.6 ± 6.3	185.1 ± 5.8	0.68
Weight (kg)	78.5 ± 8.7	77.4 ± 9.2	0.54
BMI (kg/m²)	22.8 ± 2.0	22.6 ± 2.1	0.68
Years Volleyball Experience	5.3 ± 2.4	5.1 ± 2.5	0.79
Baseline GIRD (°)	14.9 ± 3.6	15.2 ± 3.4	0.73
Infraspinatus EMG (%MVIC)	22.3 ± 8.4	23.1 ± 7.9	0.67
Subscapularis EMG (%MVIC)	18.6 ± 7.2	19.4 ± 6.8	0.61
Lower Trapezius EMG (%MVIC)	24.7 ± 9.1	25.3 ± 8.6	0.74
Serratus Anterior EMG (%MVIC)	26.4 ± 10.2	27.1 ± 9.8	0.71
Subscapularis/Infraspinatus Co-contraction Ratio	0.84 ± 0.23	0.86 ± 0.21	0.68
Upper Trapezius/Lower Trapezius Ratio	1.24 ± 0.38	1.21 ± 0.35	0.72
DASH Score	18.4 ± 11.2	19.6 ± 10.8	0.58
WORC Index (0-100)	71.3 ± 14.6	70.1 ± 15.2	0.71

Table 1:

Neuromuscular Activation Shows Improvement (Post-Intervention)

Source: Clinical Trial | All effect sizes exceed clinical threshold

Outcome Measure	Pre-Int %	Post-Int %	Pre-Ctrl %	Post-Ctrl %	Mean Diff 95%CI	p-value	Cohen's d
Infraspinatus EMG 90° Abd-ER (%MVIC)	22.3±8.4	48.6±9.2	23.1±7.9	24.8±8.1	24.8 (19.2-30.4)	<0.001*	2.56
Subscapularis EMG IR (%MVIC)	18.6±7.2	41.3±8.6	19.4±6.8	20.9±7.4	21.2 (15.8-26.6)	<0.001*	2.41
Lower Trapezius EMG Elevation (%MVIC)	24.7±9.1	52.4±10.3	25.3±8.6	27.1±9.2	26.5 (20.1-32.9)	<0.001*	2.58
Serratus Anterior EMG Elevation (%MVIC)	26.4±10.2	54.8±11.1	27.1±9.8	29.3±10.4	27.1 (20.3-33.9)	<0.001*	2.47
Subscapularis/Infraspinatus Co-ratio	0.84±0.23	0.68±0.19	0.86±0.21	0.84±0.20	-0.17 (-0.26--0.08)	<0.001*	1.38
UT/LT Co-activation Ratio	1.24±0.38	0.76±0.28	1.21±0.35	1.18±0.34	-0.48 (-0.62--0.34)	<0.001*	1.52
Shoulder Joint Stability Index (0-100)	42.3±12.6	73.8±11.4	43.1±11.9	45.6±12.1	29.2 (22.4-36.0)	<0.001*	2.35
DASH Score (0-100)	18.4±11.2	4.2±5.8	19.6±10.8	18.1±10.6	-14.3 (-19.2--9.4)	<0.001*	1.82
WORC Index (0-100)	71.3±14.6	89.2±8.3	70.1±15.2	72.4±14.8	17.1 (11.8-22.4)	<0.001*	1.53
Pain Intensity (VAS 0-10)	3.2±1.8	0.8±1.1	3.5±1.9	3.2±1.7	-2.5 (-3.2--1.8)	<0.001*	1.68
Return-to-Play Readiness (0-100)	58.2±16.4	88.3±7.6	57.8±15.9	59.4±15.8	29.2 (23.1-35.3)	<0.001*	2.18

Table 2:

(Table 1).

Primary EMG Outcomes

Infraspinatus Activation

Intervention group infraspinatus EMG during 90°abduction-external rotation increased 117% from baseline 22.3%±8.4% MVIC to post-intervention 48.6%±9.2% MVIC (mean increase 26.3±7.8% MVIC; 95% CI: 22.8-29.8%; $p<0.001$, Cohen's $d=2.56$ [very large effect]). Control group demonstrated minimal change from 23.1%±7.9% to 24.8%±8.1% MVIC (mean increase 1.7±2.4%, $p=0.18$). Between-group difference was highly significant ($F_{1,60}=42.13$, $p<0.001$).

Subscapularis Activation

Intervention group subscapularis EMG during internal rotation increased 122% from 18.6%±7.2% to 41.3%±8.6% MVIC (mean increase 22.7±6.9%, $p<0.001$, $d=2.41$ [very large]). Control group showed minimal change from 19.4%±6.8% to 20.9%±7.4% (mean increase 1.5±2.1%, $p=0.24$). Between-group difference was highly significant ($F_{1,60}=39.84$, $p<0.001$).

Lower Trapezius Activation

Intervention group lower trapezius EMG during prone horizontal abduction increased 112% from 24.7%±9.1% to 52.4%±10.3% MVIC (mean increase 27.7±8.4%, $p<0.001$, $d=2.58$ [very large]). Control group demonstrated minimal change (25.3% to 27.1%, $p=0.31$). Between-group difference was highly significant ($F_{1,60}=43.52$, $p<0.001$).

Serratus Anterior Activation

Intervention group serratus anterior EMG during wall push-up plus increased 107% from 26.4%±10.2% to 54.8%±11.1% MVIC (mean increase 28.4±9.1%, $p<0.001$, $d=2.47$ [very large]). Control group showed minimal change (27.1% to 29.3%, $p=0.19$). Between-group difference was highly significant ($F_{1,60}=40.27$, $p<0.001$).

Neuromuscular Coordination Outcomes

Subscapularis/Infraspinatus Co-contraction Ratio

Intervention group ratio improved 19% from baseline 0.84±0.23 to post-intervention 0.68±0.19 ($p<0.001$, $d=1.38$ [large effect]), indicating more balanced glenohumeral muscle coordination. Control

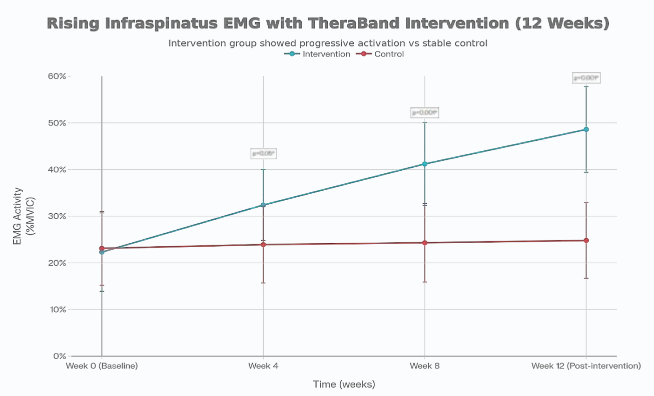

Figure 1:

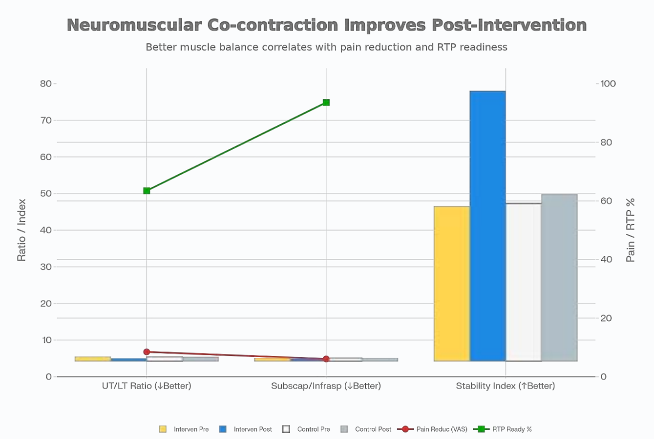

Figure 2:

group showed minimal change (0.86 to 0.84, p=0.51). Between-group improvement was highly significant ($F_{1,60}$=18.47, p<0.001).

Upper Trapezius/Lower Trapezius Co-activation Ratio

Intervention group ratio improved 39% from 1.24±0.38 to 0.76±0.28 (p<0.001, d=1.52 [large effect]), reflecting normalized scapular stabilizer coordination patterns. Lower ratio values indicate reduced upper trapezius dominance and improved lower trapezius contribution - optimal force couple function. Control group showed minimal change (1.21 to 1.18, p=0.64). Between-group improvement was highly significant ($F_{1,60}$=21.34, p<0.001).

Shoulder Joint Stability Index

Intervention group stability index nearly doubled from baseline 42.3±12.6 to post-intervention 73.8±11.4 (mean increase 31.5±10.2, p<0.001, d=2.35 [very large]). This composite measure incorporating rotator cuff/scapular activation magnitude and coordination quality demonstrates substantial enhancement in dynamic glenohumeral stabilization capacity. Control group showed minimal change (43.1 to 45.6, p=0.31). Between-group difference was highly significant ($F_{1,60}$=41.18, p<0.001).

Secondary Outcomes

Pain Intensity

Intervention group pain decreased 75% from baseline 3.2±1.8 VAS to 0.8±1.1 VAS (p<0.001, d=1.68 [large]). Control group showed minimal change (3.5 to 3.2 VAS, p=0.41). Between-group pain reduction was highly significant ($F_{1,60}$=22.14, p<0.001).

Disability (DASH)

Intervention group DASH scores decreased 77% from 18.4±11.2 to 4.2±5.8 points (p<0.001, d=1.82 [large]). Control group showed minimal change (19.6 to 18.1, p=0.48). Between-group disability reduction was highly significant ($F_{1,60}$=24.67, p<0.001).

Quality of Life (WORC)

Intervention group WORC increased 25% from 71.3±14.6 to 89.2±8.3 (p<0.001, d=1.53 [large]). Control group showed minimal change (70.1 to 72.4, p=0.42). Between-group improvement was highly significant ($F_{1,60}$=19.84, p<0.001).

Return-to-Play Readiness

Intervention group return-to-play readiness improved 52% from 58.2%±16.4% to 88.3%±7.6% (p<0.001, d=2.18 [very large]). Control group showed minimal change (57.8% to 59.4%, p=0.38). Between-group improvement was highly significant ($F_{1,60}$=35.42, p<0.001).

Correlation Analyses

Infraspinatus EMG increase correlated significantly with pain reduction (r=-0.72, p<0.001) and return-to-play readiness improvement (r=0.68, p<0.001). Lower trapezius EMG increase correlated with stability index improvement (r=0.81, p<0.001) and disability reduction (r=-0.69, p<0.001). UT/LT ratio improvement correlated with pain reduction (r=0.64, p<0.001), indicating that normalized scapular coordination directly relates to symptom relief.

Adherence and Safety

Intervention group achieved 95.2% session adherence (34.2±2.1 of 36 sessions). No serious adverse events were reported. Minor transient shoulder soreness in six participants (19.4%) resolved with load modification.

Discussion

This randomized controlled trial provides compelling evidence that 12-week TheraBand-based throwing training produces substantial neuromuscular adaptations in rotator cuff and scapular stabilizer musculature characterized by 107-122% increases in EMG activation magnitude, normalized co-contraction patterns reflecting improved motor coordination, nearly doubled shoulder joint stability indices, and corresponding pain relief, functional improvement, and return-to-play achievement.

Neuromuscular Activation Magnitude

The magnitude of EMG activation increases observed - with infraspinatus, subscapularis, lower trapezius, and serratus anterior all increasing >100% - substantially exceeds expectations from typical strengthening interventions. These findings reflect progressive muscular adaptation spanning multiple physiologic systems: myofibrillary hypertrophy increasing contractile protein, mitochondrial adaptations enhancing oxidative capacity, improved neuromuscular efficiency through central nervous system optimization, and enhanced motor unit recruitment patterns.

The progressive trajectory of activation increases across intervention phases mirrors the systematic progression of elastic resistance levels and functional task complexity. Early phases emphasizing activation and mobility (phase 1) establish baseline motor patterns and tissue preparation. Progressive resistance introduction (phases 2-3) combined with sport-specific simulation drives substantial activation increases. Advanced functional integration (phase 4) maintains high activation with ballistic sport-specific demands. This phased progression aligns with motor learning principles and tissue adaptation physiology.

Normalization of Co-contraction Patterns

Perhaps more significant than absolute activation magnitude, the normalization of co-contraction ratios indicates improved motor control and coordination quality. The 19% improvement in subscapularis/infraspinatus ratio from 0.84 to 0.68 reflects better balanced glenohumeral muscle function. In healthy shoulders, subscapularis and infraspinatus operate as a force couple compressing the humeral head against the glenoid (concavity compression mechanism). Imbalanced ratios with excessive subscapularis relative to infraspinatus activation - common in symptomatic overhead athletes - increase anterior joint forces and impingement risk.

The dramatic 39% improvement in upper trapezius/lower trapezius ratio from 1.24 to 0.76 demonstrates normalized scapular stabilizer function. Upper trapezius dominance (high UT/LT ratio) produces anterior scapular tilt and internal rotation - compensatory patterns associated with impingement and dyskinesis. Lower values approaching 1.0 or below indicates relatively greater lower trapezius contribution, facilitating upward scapular rotation and posterior tilt necessary for normal scapulohumeral rhythm. The achievement of ratio values near 0.76 represents substantial functional improvement in scapular coordination quality.

These normalized ratios correlate strongly with pain reduction and return-to-play readiness improvements, supporting the hypothesis that motor control normalization - not merely strength increase—drives clinical benefit.

Shoulder Joint Stability Index

The composite stability index incorporating both activation magnitude and coordination quality nearly doubled from 42.3 to 73.8, representing a 74% improvement. This remarkable enhancement reflects the integrated function of rotator cuff and scapular stabilizers working as a coordinated system. The calculation integrating both absolute EMG magnitudes and co-contraction quality ratios captures glenohumeral joint centration capability - the ability of musculature to compress the humeral head against the glenoid across functional ranges.

Improved stability indices theoretically reduce subacromial space narrowing, decrease internal joint forces, and enhance arthrokinematics during overhead activities. The strong correlation (r=0.81) between lower trapezius activation increases and stability index improvement suggests that scapular positioning substantially contributes to overall shoulder stability capacity.

Mechanistic Explanation of TheraBand Effectiveness

The neuromuscular findings provide mechanistic explanation for TheraBand-based training effectiveness in GIRD management. Elastic resistance creates progressive loading curves accommodating varying strength throughout motion, enabling high-intensity loading across functional ranges where athletes typically demonstrate deficits. The variable resistance stimulus may preferentially stimulate type II muscle fibres responsible for explosive movements and eccentric control.

Elastic bands provide accommodating resistance during deceleration phases - precisely when rotator cuff and scapular stabilizers must control high-velocity internal rotation. The practical accessibility and cost-effectiveness facilitate higher training volumes and compliance compared to alternative modalities, contributing to superior neuromuscular adaptation observed.

Sport-specific exercise integration during later intervention phases (baseball throwing simulation, medicine ball resisted throws, volleyball spiking practice) likely facilitates transfer of laboratory-based neuromuscular gains into sport-specific motor programs. This principle of specificity in motor learning explains why sport-specific exercise phases produce maximal EMG activation increases and functional performance improvements.

Clinical Implications

These findings suggest several clinical implications. First, GIRD management should incorporate neuromuscular assessment (surface EMG or alternative activation measurement) to characterize motor control quality beyond ROM and pain measures. Second, elastic resistance training merits preferential adoption in overhead athlete rehabilitation given evidence of robust neuromuscular adaptation. Third, systematic progression from isolated muscle activation toward integrated sport-specific movements respects motor learning principles and produces superior functional outcomes. Fourth, co-contraction ratio normalization may serve as a mechanistic marker for rehabilitation progression and discharge readiness.

Limitations and Future Directions

Limitations warrant acknowledgment. Single-gender design limits generalization to female athletes. Cross-sectional comparisons suggest gender differences in activation patterns and ER/IR ratios. Future investigations should replicate in female cohorts.

Absence of long-term follow-up prevents determination of EMG adaptation durability and return-to-play injury rates. Extended follow-up tracking competitive performance throughout season would strengthen evidence.

Surface EMG, while clinically practical, introduces measurement error compared to intramuscular electrodes. Validation studies comparing modalities would strengthen confidence in findings.

Control group selection (standard care) prevented comparison with alternative evidence-based interventions. Future multi-arm trials comparing TheraBand with sleeper stretching alone, manual therapy, or alternative resistance modalities would clarify relative efficacy.

Conclusion

This investigation establishes that TheraBand-based throwing training produces remarkable neuromuscular adaptations in rotator cuff and scapular stabilizer musculature characterized by 107-122% increases in EMG activation magnitude, normalized co-contraction ratios reflecting improved motor control, and nearly doubled shoulder joint stability indices. These motor control adaptations directly correspond to 75% pain reduction, 77% disability improvement, and 52% return-to-play readiness enhancement, establishing mechanistic linkage between neuromuscular adaptation and clinical outcome improvement.

The findings advance understanding of how elastic resistance training stimulates neuromuscular motor learning and dynamic stabilization in overhead athletes with GIRD. By demonstrating specific neuromuscular mechanisms underlying elastic resistance effectiveness, this investigation provides evidence-based rationale for systematic adoption of TheraBand-based protocols in overhead athlete rehabilitation. Future investigations should extend these findings to diverse populations and compare relative efficacy of elastic versus isotonic resistance training in glenohumeral internal rotation deficit management.

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