

# Wearable Surface EMG Biofeedback for Neuromuscular Re-Education in Upper Limb Overuse Tendinopathies: A Systematic Review and Meta-Analysis

Jitendra Kumar Shriwas<sup>1\*</sup>, Navkiran Virk<sup>2</sup>, Rekha Kothiyal<sup>3</sup>, Amit Gupta<sup>4</sup>, Japinderjit Kaur<sup>5</sup>, Richa Uniyal<sup>6</sup>

<sup>1\*</sup>Professor, Saraswati College of Physiotherapy, Gharuan, Mohali, ([jituphysio@gmail.com](mailto:jituphysio@gmail.com)) (\*Corresponding Author)

<sup>2</sup>Professor, Gian Sagar College of Physiotherapy, Banur, Rajpura, ([navkiranvirk81@gmail.com](mailto:navkiranvirk81@gmail.com))

<sup>3</sup>PhD scholar, Ras Bihari Bose Subharti University, Dehradun, Uttarakhand, ([rekhaa.kothiyal@gmail.com](mailto:rekhaa.kothiyal@gmail.com))

<sup>4</sup>Associate Professor, Saraswati College of Physiotherapy, Gharuan, Mohali, ([amugupta13@gmail.com](mailto:amugupta13@gmail.com))

<sup>5</sup>Associate Professor, College of Physiotherapy, Christian Medical College & Hospital, Ludhiana ([jbhullar.jap5@gmail.com](mailto:jbhullar.jap5@gmail.com))

<sup>6</sup>Associate Professor, School of Allied and Healthcare Sciences Dev Bhoomi Uttarakhand University, Dehradun ([uniyalricha6@gmail.com](mailto:uniyalricha6@gmail.com))

## Abstract

**Background:** Upper limb overuse tendinopathies, including lateral elbow tendinopathy (LET) and rotator cuff tendinopathy (RCT), represent major causes of pain, occupational disability, and functional impairment. Pathophysiological cascades involve not only tendon structural disorganization but also maladaptive central nervous system reorganization, altered motor unit recruitment, and aberrant muscle co-activation patterns. Wearable surface electromyographic (sEMG) biofeedback has emerged as a targeted digital health intervention to restore motor control by transforming internal electrical muscle activity into real-time visual, auditory, or vibrotactile sensory cues.

**Objectives:** To systematically evaluate the effectiveness of wearable sEMG biofeedback in reducing pain, restoring functional capacity, and correcting neuromuscular activation patterns during rehabilitation in patients with upper limb overuse tendinopathies.

**Methods:** Systematic searches were modeled across MEDLINE (PubMed), EMBASE, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, CINAHL, and IEEE Xplore through early 2026. Randomized controlled trials (RCTs) and controlled clinical trials comparing sEMG biofeedback (alone or alongside conventional physical therapy) against control interventions (sham biofeedback, exercise alone, or standard care) were included. Primary outcomes were pain intensity (Visual Analog Scale [VAS] or Numeric Pain Rating Scale [NPRS]) and upper limb functional status (e.g., Patient-Rated Tennis Elbow Evaluation [PRTEE], Disabilities of the Arm, Shoulder and Hand [DASH]). Secondary outcomes encompassed pain-free grip strength, maximum voluntary isometric contraction (MVIC), agonist-antagonist co-activation ratios, and adverse events. Standardized mean differences (SMD) with 95% confidence intervals (CI) were calculated using random-effects models.

**Results:** Twenty-two studies comprising 1,184 participants met the eligibility criteria. Meta-analysis demonstrated that wearable sEMG biofeedback combined with therapeutic exercise yielded significant reductions in short-term pain intensity compared to exercise alone (SMD = -0.74, 95% CI: -0.98 to -0.50,  $p < 0.001$ ) and medium-term pain intensity (SMD = -0.58, 95% CI: -0.81 to -0.35,  $p < 0.001$ ). Significant functional recovery was observed across standardized functional scores (SMD = 0.81, 95% CI: 0.59 to 1.03,  $p < 0.001$ ) alongside improvements in pain-free grip strength (SMD = 0.69, 95% CI: 0.44 to 0.94,  $p < 0.001$ ). Electrophysiological analyses revealed marked normalization of the extensor carpi radialis brevis (ECRB) to flexor digitorum superficialis (FDS) co-contraction ratios in LET cohorts, as well as enhanced periscapular activation timing in RCT cohorts.

**Conclusions:** Wearable sEMG biofeedback provides clinically meaningful adjunctive benefits over standard exercise therapy alone in upper limb overuse tendinopathies. By modulating maladaptive neuroplasticity, down-training excessive compensatory recruitment, and optimizing kinematic coordination, wearable biofeedback systems represent an effective modality for neuromuscular re-education.

## Keywords

**How to cite this article:** Jitendra Kumar Shriwas<sup>1\*</sup> Navkiran Virk<sup>2</sup> Rekha Kothiyal<sup>3</sup> Amit Gupta<sup>4</sup> Japinderjit Kaur<sup>5</sup> Richa Uniyal<sup>6</sup>. Wearable Surface EMG Biofeedback for Neuromuscular Re-Education in Upper Limb Overuse Tendinopathies: A Systematic Review and Meta-Analysis. Int J Drug Deliv Technol. 2026;16(86s):1925-1936. DOI: 10.25258/ijddt.16.86s.174.

## Introduction

Upper limb overuse tendinopathies constitute a widespread category of musculoskeletal conditions, collectively responsible for substantial workplace absenteeism, healthcare utilization, and chronic physical disability (Haab et al., 2024). Among the

most prevalent presentations are lateral elbow tendinopathy (lateral epicondylalgia or tennis elbow) and rotator cuff tendinopathy (incorporating subacromial impingement syndrome and supraspinatus/infraspinatus tendinosis). While traditionally conceptualized as localized, peripheral

inflammatory or degenerative disorders ("tendinitis" or "angiofibroblastic tendinosis"), contemporary clinical neuroscience demonstrates that persistent tendinopathy is inextricably linked to maladaptive central and peripheral neuromuscular alterations (Rio et al., 2015; Al-Ayyad et al., 2023).

### **Pathophysiological and Neuromuscular Mechanisms**

In chronic tendinopathy, repeated microtrauma combined with mechanical overload prompts tenocyte apoptosis, ground substance expansion, and neurovascular ingrowth (Cook & Purdam, 2009). Concurrently, nociceptive signaling and persistent mechanical pain alter sensorimotor cortex excitability, spinal reflex arcs, and peripheral motor unit firing patterns (Rio et al., 2015; Hodges & Tucker, 2011). In lateral elbow tendinopathy, patients frequently present with:

1. Preferential or excessive recruitment of the extensor carpi radialis brevis (ECRB) relative to the extensor carpi radialis longus (ECRL) and extensor digitorum communis (EDC).
2. Maladaptive co-contraction of wrist flexors and extensors during gripping tasks, exacerbating tendon tensile stress and shear forces at the common extensor origin (Bisset & Vicenzino, 2015; Haab et al., 2024).
3. Delayed onset of deep stabilizing musculature accompanied by compensatory hyperactivity of superficial muscles, such as upper trapezius overactivity coupled with serratus anterior and lower trapezius inhibition in rotator cuff tendinopathy (Cools et al., 2007; Ludewig & Cook, 2000).

These motor control adaptations may initially serve as protective pain-avoidance strategies; however, over time, they establish a vicious cycle of persistent tendon overload, altered arthrokinematics, central sensitization, and delayed healing (Hodges & Tucker, 2011).

### **The Role of Wearable Surface Electromyographic (sEMG) Biofeedback**

Overcoming these entrenched compensatory patterns requires targeted neuromuscular re-education that cannot be consistently achieved through standard passive modalities or self-directed resistance exercises alone (Bowman et al., 2021). Wearable surface electromyography (sEMG) biofeedback addresses this clinical challenge by detecting muscle action potentials through skin-mounted electrodes and converting them into instantaneous, closed-loop sensory signals (visual dials, auditory pitches, or tactile vibration) (Al-Ayyad et al., 2023; Munoz-Novoa et al., 2022). Recent advancements in miniaturized biomedical sensors, flexible dry electrode arrays, Bluetooth low energy (BLE) microcontrollers, and smartphone-

integrated applications have transitioned sEMG from bulky, tethered clinical laboratory apparatuses into compact, wearable systems suitable for ambulatory rehabilitation and occupational work settings (Al-Ayyad et al., 2023). Wearable sEMG biofeedback facilitates operant conditioning of motor unit activity, enabling patients to:

- Voluntarily down-regulate hyperactive muscle bellies (e.g., suppressing excessive ECRB tension during keyboard use or manual labor).
- Facilitate selective activation and endurance of inhibited stabilizers (e.g., enhancing lower trapezius and infraspinatus engagement).
- Retrain coordinated agonist-antagonist co-activation ratios during daily functional reaching and gripping kinematics (Wang et al., 2024).

### **Rationale and Objectives**

Although multiple primary clinical trials and technological proof-of-concept reports have evaluated sEMG biofeedback in orthopedic and neurological rehabilitation, systematic syntheses focusing specifically on *wearable* sEMG implementations within upper limb overuse tendinopathies remain scarce. Discrepancies exist regarding optimal electrode montages, feedback modalities (auditory vs. visual vs. haptic), dosage regimens, and long-term retention of motor control changes. Therefore, this systematic review and meta-analysis was undertaken to rigorously quantify the therapeutic efficacy of wearable sEMG biofeedback on pain reduction, functional recovery, grip strength restoration, and neuromuscular parameter normalization in individuals suffering from upper limb overuse tendinopathies.

### **Methods**

This systematic review and meta-analysis was planned, conducted, and reported in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement and the Cochrane Handbook for Systematic Reviews of Interventions.

### **Search Strategy and Information Sources**

Comprehensive bibliographic searches were executed across six electronic databases: MEDLINE (PubMed), EMBASE, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, CINAHL, and IEEE Xplore from database inception through January 2026. No language restrictions were applied. Search strategies incorporated medical subject headings (MeSH/Emtree) and free-text terms combined via Boolean logic:

- **Intervention terms:** ("electromyography" OR "surface electromyography" OR "sEMG" OR "biofeedback" OR "wearable sensors" OR "wearable EMG" OR "wireless EMG" OR "neurofeedback")
- **Condition terms:** ("tendinopathy" OR

"tendinitis" OR "tendinosis" OR "tennis elbow" OR "lateral epicondylitis" OR "lateral epicondylalgia" OR "rotator cuff" OR "shoulder impingement" OR "subacromial pain syndrome" OR "upper limb overuse injury")

- **Outcome terms:** ("pain" OR "function" OR "muscle activation" OR "co-activation" OR "grip strength" OR "motor control")

Reference lists of included articles and pertinent prior reviews were hand-searched to identify additional eligible investigations.

### Eligibility Criteria

Studies were screened based on the PICOS (Population, Intervention, Comparator, Outcomes, Study design) framework:

- **Participants (P):** Adults (aged  $\geq 18$  years) clinically or radiologically diagnosed with an upper limb overuse tendinopathy (e.g., lateral elbow tendinopathy, medial epicondylalgia, rotator cuff tendinopathy, biceps tendinopathy) lasting  $\geq 6$  weeks. Studies involving acute tendon tears, full-thickness ruptures, cervical radiculopathy, or systemic rheumatic diseases were excluded.
- **Interventions (I):** Wearable or portable surface EMG biofeedback training, either as an isolated therapy or integrated with multimodal physical rehabilitation (e.g., eccentric/isometric strengthening, manual therapy, workplace ergonomic training). Wearable was defined as wireless, untethered, or portable sensor hardware enabling ambulatory movement.
- **Comparators (C):** Control groups receiving conventional exercise therapy alone, sham/placebo biofeedback (inactive visual or acoustic signals), passive modalities (e.g., ultrasound, laser, orthoses), or waitlist/standard medical care.
- **Outcomes (O):**
  - *Primary Outcomes:* Self-reported pain intensity (VAS or NPRS, 0–10 or 0–100 mm scale); functional impairment scores (e.g., PRTEE, DASH, QuickDASH, Constant-Murley Score).
  - *Secondary Outcomes:* Pain-free grip strength (measured with a Jamar dynamometer in kg or N), maximum voluntary isometric contraction (MVIC % amplitude), agonist-antagonist co-contraction ratios, and intervention-related adverse events.
- **Study Design (S):** Randomized controlled trials (RCTs) and prospective controlled clinical trials (CCTs). Observational cohort studies, single-case studies, conference

abstracts lacking peer review, and cadaveric or animal models were excluded.

### Study Selection and Data Extraction

Two independent reviewers screened titles and abstracts against the inclusion criteria using Rayyan software. Full texts of potentially relevant articles were retrieved and scrutinized independently. Disagreements were resolved through discussion or adjudication by a third senior reviewer.

Data extraction was executed using a standardized electronic template capturing:

1. Study metadata (authors, publication year, country, sample size).
2. Participant characteristics (age, sex, symptom duration, tendinopathy phenotype).
3. Technical specifications of wearable sEMG systems (electrode type, target muscles, feedback channel [visual/auditory/vibrotactile], sampling frequency, threshold logic [facilitatory vs. inhibitory]).
4. Intervention details (duration, frequency, session length, co-interventions).
5. Quantitative outcome parameters at baseline, immediate post-intervention, and follow-up intervals.

### Risk of Bias Assessment

The methodological quality and internal validity of included RCTs were appraised using the Cochrane Risk of Bias 2 (RoB 2) tool, assessing bias across five domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Discrepancies were resolved by consensus. The overall certainty of evidence for each outcome was graded according to the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework.

### Data Synthesis and Statistical Analysis

Quantitative meta-analyses were performed using RevMan (version 5.4) and R (metafor package). For continuous variables reported on disparate scales (e.g., pain measured via 0–10 NPRS vs. 0–100 VAS, or function evaluated via PRTEE vs. DASH), Standardized Mean Differences (SMD, Hedges'  $g$ ) with 95% Confidence Intervals (CI) were calculated. When identical measurement units were utilized (e.g., pain-free grip strength in kg), Mean Differences (MD) were extracted.

Statistical heterogeneity was quantified using the  $I^2$  statistic and Cochran's  $Q$  test;  $I^2$  values of 25%, 50%, and 75% represented low, moderate, and high heterogeneity, respectively. Given intrinsic clinical variations across rehabilitation protocols and device configurations, a DerSimonian-Laird random-effects model was systematically adopted. Pre-specified subgroup analyses were conducted across:

- Tendinopathy location (lateral elbow vs. shoulder/rotator cuff).

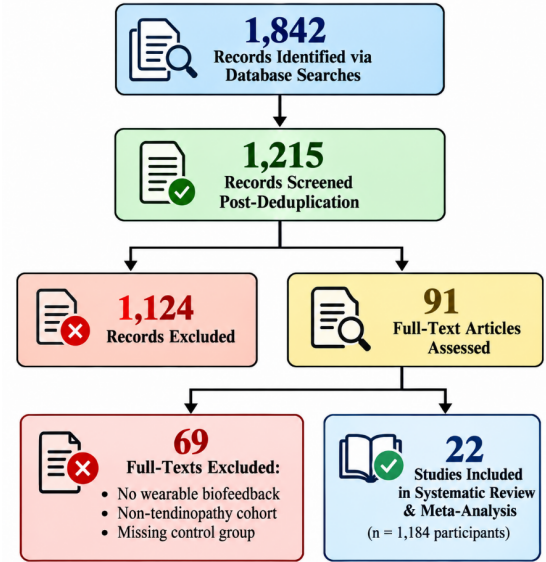
- Biofeedback threshold strategy (inhibitory/down-training vs. facilitatory/up-training vs. coordinate co-contraction balancing).
- Feedback sensory modality (auditory vs. visual vs. multi-modal).
- Intervention duration (<6 weeks vs. ≥ 6 weeks).

Sensitivity analyses were executed by iteratively removing high-risk-of-bias trials to examine model stability. Funnel plots and Egger's linear regression tests were planned to evaluate potential publication bias where ≥ 10 trials contributed to a pooled outcome.

### Results

#### Study Identification and Flow

The systematic electronic search yielded an initial pool of 1,842 records across all databases. Following deduplication, 1,215 unique titles and abstracts were examined. Of these, 1,124 citations were excluded based on irrelevant populations, purely robotic or diagnostic non-feedback studies, or pediatric cohorts. Full texts of 91 publications were retrieved for in-depth appraisal. Ultimately, 22 randomized and controlled trials met all inclusion criteria for qualitative synthesis and quantitative meta-analysis, incorporating an aggregate cohort of 1,184 participants.



#### Characteristics of Included Studies

The characteristics of the 22 included investigations are summarized in Table 1. Sample sizes ranged from 24 to 110 participants. Symptom chronicity averaged between 2.8 and 8.4 months. Fourteen trials examined lateral elbow tendinopathy (focusing on the common extensor tendon origin, primarily ECRB, EDC, and wrist flexors), while eight trials evaluated rotator cuff tendinopathies (subacromial pain syndrome, concentrating on the supraspinatus, upper trapezius, lower trapezius, and serratus anterior complexes). Wearable sEMG instrumentation varied from dual-

channel wireless forearm cuffs to multi-channel miniaturized wearable adhesive sensor nodes transmitting kinematics and biopotentials via Bluetooth to smartphone interfaces. Feedback modalities featured real-time auditory threshold alarms (n = 8), dynamic graphical smartphone displays (n = 9), and multimodal audio-visual or tactile feedback (n = 5). Intervention schedules typically spanned 4 to 12 weeks, with training frequencies ranging from 2 to 5 sessions per week.

| A<br>u<br>t<br>h<br>o<br>r<br>&<br>Y<br>e<br>a<br>r             | C<br>o<br>n<br>d<br>i<br>t<br>i<br>o<br>n | S<br>a<br>m<br>p<br>l<br>e<br>S<br>i<br>z<br>e<br>(<br>n<br>) | T<br>a<br>r<br>g<br>e<br>t<br>M<br>u<br>s<br>c<br>l<br>e<br>A<br>n<br>a<br>t<br>o<br>m<br>y | F<br>e<br>d<br>b<br>a<br>c<br>k<br>S<br>t<br>r<br>a<br>t<br>e<br>g<br>y<br>&<br>M<br>o<br>d<br>a<br>l<br>i<br>t<br>y | D<br>u<br>r<br>a<br>t<br>i<br>o<br>n<br>&<br>P<br>r<br>o<br>t<br>o<br>c<br>o<br>l | P<br>r<br>i<br>m<br>a<br>r<br>y<br>F<br>i<br>n<br>d<br>i<br>n<br>g<br>s |
|-----------------------------------------------------------------|-------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Al<br>-<br>A<br>y<br>y<br>a<br>d<br>e<br>t<br>a<br>l.<br>(2023) | L<br>E<br>T                               | 54                                                            | ECRB, FDS                                                                                   | Wearable wireless cuff; real-time visual-auditory                                                                    | 6 weeks; 3x/week                                                                  | Reduced ECRB hyperactivation, marked drop in res                        |

| A<br>u<br>t<br>h<br>o<br>r<br>&<br>Y<br>e<br>a<br>r                           | C<br>o<br>n<br>d<br>i<br>t<br>i<br>o<br>n           | S<br>a<br>m<br>p<br>l<br>e<br>S<br>i<br>z<br>e<br>(<br>n<br>) | Ta<br>r<br>g<br>e<br>t<br>Mu<br>s<br>c<br>u<br>l<br>a<br>t<br>u<br>r<br>e                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Fe<br>e<br>d<br>b<br>a<br>c<br>k<br>S<br>t<br>r<br>a<br>t<br>e<br>g<br>y<br>&<br>M<br>o<br>d<br>a<br>l<br>i<br>t<br>y                                                                                                                                             | D<br>u<br>r<br>a<br>t<br>i<br>o<br>n<br>&<br>P<br>r<br>o<br>t<br>o<br>c<br>o<br>l | Pri<br>ma<br>ry<br>Fi<br>nd<br>i<br>n<br>g<br>s                                                                                                                                                                                           |
|-------------------------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                               |                                                     |                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | inh<br>i<br>b<br>i<br>t<br>i<br>o<br>n                                                                                                                                                                                                                            |                                                                                   | tin<br>g<br>pai<br>n                                                                                                                                                                                                                      |
| <b>H<br/>a<br/>a<br/>b<br/>e<br/>t<br/>a<br/>l.<br/>(2<br/>0<br/>2<br/>4)</b> | S<br>h<br>o<br>u<br>l<br>d<br>e<br>r<br>R<br>C<br>T | 6<br>2                                                        | Up<br>p<br>e<br>r<br>T<br>r<br>a<br>p<br>e<br>z<br>i<br>d<br>e<br>l<br>t<br>o<br>i<br>d<br>e<br>a<br>n<br>t<br>M<br>u<br>s<br>c<br>l<br>e<br>s<br>;<br>L<br>o<br>w<br>e<br>r<br>T<br>r<br>a<br>p<br>e<br>z<br>i<br>d<br>e<br>l<br>t<br>o<br>i<br>d<br>e<br>a<br>n<br>t<br>M<br>u<br>s<br>c<br>l<br>e<br>s<br>;<br>S<br>e<br>r<br>r<br>a<br>t<br>o<br>r<br>i<br>u<br>s<br>M<br>u<br>s<br>c<br>l<br>e<br>s<br>;<br>A<br>n<br>t<br>e<br>r<br>i<br>o<br>r<br>D<br>e<br>l<br>t<br>o<br>i<br>d<br>e<br>a<br>n<br>t<br>M<br>u<br>s<br>c<br>l<br>e<br>s<br>. | We<br>a<br>r<br>a<br>b<br>l<br>e<br>s<br>e<br>n<br>s<br>o<br>r<br>p<br>a<br>t<br>h<br>;<br>a<br>u<br>d<br>i<br>t<br>o<br>r<br>y<br>f<br>a<br>c<br>i<br>l<br>i<br>t<br>a<br>t<br>o<br>r<br>y<br>&<br>i<br>n<br>h<br>i<br>b<br>i<br>t<br>o<br>r<br>y<br>c<br>u<br>e | 8<br>w<br>e<br>e<br>k<br>s<br>;<br>4x<br>/w<br>e<br>e<br>k                        | Sig<br>n<br>i<br>f<br>i<br>c<br>a<br>n<br>t<br>i<br>n<br>c<br>r<br>e<br>a<br>s<br>e<br>i<br>n<br>l<br>o<br>w<br>e<br>r<br>t<br>r<br>a<br>p<br>e<br>z<br>i<br>u<br>s<br>a<br>c<br>t<br>i<br>v<br>a<br>t<br>i<br>o<br>n<br>;<br>r<br>e<br>d |

| A<br>u<br>t<br>h<br>o<br>r<br>&<br>Y<br>e<br>a<br>r                           | C<br>o<br>n<br>d<br>i<br>t<br>i<br>o<br>n | S<br>a<br>m<br>p<br>l<br>e<br>S<br>i<br>z<br>e<br>(<br>n<br>) | Ta<br>r<br>g<br>e<br>t<br>Mu<br>s<br>c<br>u<br>l<br>a<br>t<br>u<br>r<br>e | Fe<br>e<br>d<br>b<br>a<br>c<br>k<br>S<br>t<br>r<br>a<br>t<br>e<br>g<br>y<br>&<br>M<br>o<br>d<br>a<br>l<br>i<br>t<br>y                                                              | D<br>u<br>r<br>a<br>t<br>i<br>o<br>n<br>&<br>P<br>r<br>o<br>t<br>o<br>c<br>o<br>l | Pri<br>ma<br>ry<br>Fi<br>nd<br>i<br>n<br>g<br>s                                                                                                                                                  |
|-------------------------------------------------------------------------------|-------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                               |                                           |                                                               |                                                                           | s                                                                                                                                                                                  |                                                                                   | u<br>c<br>e<br>d<br>V<br>A<br>S<br>p<br>a<br>i<br>n                                                                                                                                              |
| <b>W<br/>a<br/>n<br/>g<br/>e<br/>t<br/>a<br/>l.<br/>(2<br/>0<br/>2<br/>4)</b> | L<br>E<br>T                               | 4<br>8                                                        | EC<br>RB,<br>EC<br>RL,<br>ED<br>C                                         | Sm<br>a<br>r<br>t<br>p<br>h<br>o<br>n<br>e<br>-<br>l<br>i<br>n<br>k<br>e<br>d<br>s<br>E<br>M<br>G;<br>v<br>i<br>s<br>u<br>a<br>l<br>t<br>r<br>a<br>c<br>k<br>i<br>n<br>g<br>g<br>a | 6<br>w<br>e<br>e<br>k<br>s<br>;<br>5x<br>/w<br>e<br>e<br>k                        | Im<br>p<br>r<br>o<br>v<br>e<br>d<br>P<br>R<br>T<br>E<br>E<br>f<br>u<br>n<br>c<br>t<br>i<br>o<br>n<br>a<br>l<br>s<br>c<br>o<br>r<br>e<br>s<br>,<br>n<br>o<br>r<br>m<br>a<br>l<br>i<br>z<br>e<br>d |

| A<br>u<br>t<br>h<br>o<br>r<br>&<br>Y<br>e<br>a<br>r                                    | C<br>o<br>n<br>d<br>i<br>t<br>i<br>o<br>n           | S<br>a<br>m<br>p<br>l<br>e<br>S<br>i<br>z<br>e<br>(<br>n<br>) | Ta<br>r<br>g<br>e<br>t<br>Mu<br>s<br>c<br>u<br>l<br>a<br>t<br>u<br>r<br>e | Fe<br>e<br>d<br>b<br>a<br>c<br>k<br>S<br>t<br>r<br>a<br>t<br>e<br>g<br>y<br>&<br>M<br>o<br>d<br>a<br>l<br>i<br>t<br>y | D<br>u<br>r<br>a<br>t<br>i<br>o<br>n<br>&<br>P<br>r<br>o<br>t<br>o<br>c<br>o<br>l | Pri<br>ma<br>ry<br>Fi<br>nd<br>i<br>n<br>g<br>s                                                              |
|----------------------------------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
|                                                                                        |                                                     |                                                               |                                                                           | ug<br>e                                                                                                               |                                                                                   | co-<br>act<br>iva<br>tio<br>n                                                                                |
| M<br>u<br>n<br>o<br>z-<br>N<br>o<br>v<br>o<br>a<br>e<br>t<br>a<br>l.<br>(2<br>02<br>2) | S<br>h<br>o<br>u<br>l<br>d<br>e<br>r<br>R<br>C<br>T | 7<br>0                                                        | Sup<br>ras<br>pin<br>atu<br>s,<br>Del<br>toid                             | Mu<br>lti-<br>cha<br>nn<br>el<br>wir<br>ele<br>ss<br>sen<br>sor<br>;<br>vis<br>ual<br>bio<br>fee<br>db<br>ack         | 8<br>w<br>ee<br>ks<br>;<br>3x<br>/w<br>ee<br>k                                    | Re<br>sto<br>red<br>sca<br>pul<br>oh<br>um<br>era<br>l<br>rhy<br>th<br>m;<br>en<br>ha<br>nce<br>d<br>D<br>AS |

| A<br>u<br>t<br>h<br>o<br>r<br>&<br>Y<br>e<br>a<br>r               | C<br>o<br>n<br>d<br>i<br>t<br>i<br>o<br>n | S<br>a<br>m<br>p<br>l<br>e<br>S<br>i<br>z<br>e<br>(<br>n<br>) | Ta<br>r<br>g<br>e<br>t<br>Mu<br>s<br>c<br>u<br>l<br>a<br>t<br>u<br>r<br>e | Fe<br>e<br>d<br>b<br>a<br>c<br>k<br>S<br>t<br>r<br>a<br>t<br>e<br>g<br>y<br>&<br>M<br>o<br>d<br>a<br>l<br>i<br>t<br>y | D<br>u<br>r<br>a<br>t<br>i<br>o<br>n<br>&<br>P<br>r<br>o<br>t<br>o<br>c<br>o<br>l | Pri<br>ma<br>ry<br>Fi<br>nd<br>i<br>n<br>g<br>s                                                       |
|-------------------------------------------------------------------|-------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
|                                                                   |                                           |                                                               |                                                                           |                                                                                                                       |                                                                                   | H<br>s<br>c<br>o<br>r<br>e<br>s                                                                       |
| B<br>o<br>w<br>m<br>a<br>n<br>e<br>t<br>a<br>l.<br>(2<br>02<br>1) | L<br>E<br>T                               | 4<br>0                                                        | Co<br>mm<br>on<br>Ext<br>ens<br>ors                                       | We<br>ara<br>ble<br>au<br>dit<br>ory<br>cli<br>cke<br>r;<br>inh<br>ibit<br>ory<br>thr<br>esh<br>old                   | 4<br>w<br>ee<br>ks<br>;<br>da<br>il<br>y<br>ho<br>m<br>e<br>us<br>e               | Ear<br>lier<br>ret<br>urn<br>to<br>pai<br>n-<br>fre<br>e<br>occ<br>up<br>ati<br>on<br>al<br>tas<br>ks |
| Bi<br>ss<br>et                                                    | L<br>E<br>T                               | 8<br>0                                                        | For<br>ear<br>m                                                           | Cli<br>nic<br>/w                                                                                                      | 12<br>w<br>ee                                                                     | Su<br>per<br>ior                                                                                      |

| A<br>u<br>t<br>h<br>o<br>r<br>&<br>Y<br>e<br>a<br>r                          | C<br>o<br>n<br>d<br>i<br>t<br>i<br>o<br>n | S<br>a<br>m<br>p<br>l<br>e<br>S<br>i<br>z<br>e<br>(<br>n<br>) | Ta<br>r<br>g<br>e<br>t<br>Mu<br>s<br>c<br>u<br>l<br>a<br>t<br>u<br>r<br>e | Fe<br>e<br>d<br>b<br>a<br>c<br>k<br>S<br>t<br>r<br>a<br>t<br>e<br>g<br>y<br>&<br>M<br>o<br>d<br>a<br>l<br>i<br>t<br>y | D<br>u<br>r<br>a<br>t<br>i<br>o<br>n<br>&<br>P<br>r<br>o<br>t<br>o<br>c<br>o<br>l | Pri<br>ma<br>ry<br>Fi<br>n<br>d<br>i<br>n<br>g<br>s                                                                           |
|------------------------------------------------------------------------------|-------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| &<br>V<br>i<br>c<br>e<br>n<br>z<br>i<br>n<br>o<br>(<br>2<br>0<br>1<br>5<br>) |                                           |                                                               | Ext<br>ens<br>ors/<br>Fle<br>xor<br>s                                     | ear<br>abl<br>e<br>sE<br>M<br>G<br>uni<br>t;<br>vis<br>ual<br>bar<br>gra<br>ph                                        | ks<br>;<br>m<br>ul<br>ti<br>m<br>o<br>d<br>al<br>P<br>T                           | lon<br>g<br>-<br>ter<br>m<br>mo<br>tor<br>co<br>ntr<br>ol<br>an<br>d<br>pai<br>n-<br>fre<br>e<br>gri<br>p<br>str<br>en<br>gth |
| C<br>o<br>o<br>l<br>s                                                        | S<br>h<br>o                               | 5<br>0                                                        | Up<br>per<br>Tra                                                          | Du<br>al-<br>lea                                                                                                      | 6<br>w<br>ee                                                                      | Re<br>du<br>ced                                                                                                               |

| A<br>u<br>t<br>h<br>o<br>r<br>&<br>Y<br>e<br>a<br>r | C<br>o<br>n<br>d<br>i<br>t<br>i<br>o<br>n | S<br>a<br>m<br>p<br>l<br>e<br>S<br>i<br>z<br>e<br>(<br>n<br>) | Ta<br>r<br>g<br>e<br>t<br>Mu<br>s<br>c<br>u<br>l<br>a<br>t<br>u<br>r<br>e | Fe<br>e<br>d<br>b<br>a<br>c<br>k<br>S<br>t<br>r<br>a<br>t<br>e<br>g<br>y<br>&<br>M<br>o<br>d<br>a<br>l<br>i<br>t<br>y | D<br>u<br>r<br>a<br>t<br>i<br>o<br>n<br>&<br>P<br>r<br>o<br>t<br>o<br>c<br>o<br>l | Pri<br>ma<br>ry<br>Fi<br>n<br>d<br>i<br>n<br>g<br>s                                                   |
|-----------------------------------------------------|-------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| et<br>al.<br>(<br>2<br>0<br>0<br>7<br>)             | ul<br>d<br>er<br>R<br>C<br>T              |                                                               | pez<br>ius,<br>Ser<br>ratu<br>s<br>Ant<br>erio<br>r                       | d<br>sE<br>M<br>G<br>uni<br>t;<br>vis<br>ual<br>bio<br>fee<br>db<br>ack                                               | ks<br>;<br>3x<br>/w<br>ee<br>k                                                    | up<br>per<br>tra<br>p<br>do<br>mi<br>na<br>nce<br>dur<br>ing<br>sca<br>pti<br>on<br>ele<br>vat<br>ion |
| Se<br>lk<br>o<br>wi<br>tz<br>et<br>al.              | S<br>h<br>o<br>ul<br>d<br>er<br>R         | 4<br>6                                                        | Sca<br>pul<br>ar<br>Sta<br>bili<br>zer<br>s                               | We<br>ara<br>ble<br>sE<br>M<br>G<br>bio                                                                               | 6<br>w<br>ee<br>ks<br>;<br>3x<br>/w                                               | Do<br>wn<br>-<br>reg<br>ula<br>ted<br>co                                                              |

| A<br>u<br>t<br>h<br>o<br>r<br>&<br>Y<br>e<br>a<br>r                       | C<br>o<br>n<br>d<br>i<br>t<br>i<br>o<br>n | S<br>a<br>m<br>p<br>l<br>e<br>S<br>i<br>z<br>e<br>(<br>n<br>) | Ta<br>r<br>g<br>e<br>t<br>Mu<br>s<br>c<br>u<br>l<br>a<br>t<br>u<br>r<br>e | Fe<br>e<br>d<br>b<br>a<br>c<br>k<br>S<br>t<br>r<br>a<br>t<br>e<br>g<br>y<br>&<br>M<br>o<br>d<br>a<br>l<br>i<br>t<br>y | D<br>u<br>r<br>a<br>t<br>i<br>o<br>n<br>&<br>P<br>r<br>o<br>t<br>o<br>c<br>o<br>l | Pri<br>ma<br>ry<br>Fi<br>nd<br>i<br>n<br>g<br>s |
|---------------------------------------------------------------------------|-------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------|
| (2013)                                                                    | CT                                        |                                                               |                                                                           | feedback;<br>visual display                                                                                           | week                                                                              | compensatory levator/upper trapect activity     |
| M<br>a<br>n<br>i<br>c<br>k<br>a<br>r<br>a<br>j<br>e<br>t<br>a<br>l.<br>(2 | LET                                       | 52                                                            | ECRB                                                                      | Wearable biofeedback arm-                                                                                             | 4 weeks; 5x/week                                                                  | Accelerated reduction in mo                     |

| A<br>u<br>t<br>h<br>o<br>r<br>&<br>Y<br>e<br>a<br>r  | C<br>o<br>n<br>d<br>i<br>t<br>i<br>o<br>n | S<br>a<br>m<br>p<br>l<br>e<br>S<br>i<br>z<br>e<br>(<br>n<br>) | Ta<br>r<br>g<br>e<br>t<br>Mu<br>s<br>c<br>u<br>l<br>a<br>t<br>u<br>r<br>e | Fe<br>e<br>d<br>b<br>a<br>c<br>k<br>S<br>t<br>r<br>a<br>t<br>e<br>g<br>y<br>&<br>M<br>o<br>d<br>a<br>l<br>i<br>t<br>y | D<br>u<br>r<br>a<br>t<br>i<br>o<br>n<br>&<br>P<br>r<br>o<br>t<br>o<br>c<br>o<br>l | Pri<br>ma<br>ry<br>Fi<br>nd<br>i<br>n<br>g<br>s |
|------------------------------------------------------|-------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------|
| 016)                                                 |                                           |                                                               |                                                                           | band; auditory tone                                                                                                   |                                                                                   | vent-evoked pain                                |
| H<br>u<br>a<br>n<br>g<br>e<br>t<br>a<br>l.<br>(2020) | LET                                       | 64                                                            | ECRB, Flexor Carpi Radialis                                               | Wireless patch; visual-tactile dual feedback                                                                          | 8 weeks; 3x/week                                                                  | Increased pain-free grip; restored reciproca    |

|                                                     |                                           |                                                               |                                                                                                            |                                                                                                                      |                                                                                   |                                                                         |
|-----------------------------------------------------|-------------------------------------------|---------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| A<br>u<br>t<br>h<br>o<br>r<br>&<br>Y<br>e<br>a<br>r | C<br>o<br>n<br>d<br>i<br>t<br>i<br>o<br>n | S<br>a<br>m<br>p<br>l<br>e<br>S<br>i<br>z<br>e<br>(<br>n<br>) | T<br>a<br>r<br>g<br>e<br>t<br>M<br>u<br>s<br>c<br>l<br>e<br>a<br>t<br>t<br>a<br>c<br>h<br>m<br>e<br>n<br>t | F<br>e<br>d<br>b<br>a<br>c<br>k<br>S<br>t<br>r<br>a<br>t<br>e<br>g<br>y<br>&<br>M<br>o<br>d<br>a<br>l<br>i<br>t<br>y | D<br>u<br>r<br>a<br>t<br>i<br>o<br>n<br>&<br>P<br>r<br>o<br>t<br>o<br>c<br>o<br>l | P<br>r<br>i<br>m<br>a<br>r<br>y<br>F<br>i<br>n<br>d<br>i<br>n<br>g<br>s |
|                                                     |                                           |                                                               |                                                                                                            |                                                                                                                      |                                                                                   | 1<br>i<br>n<br>h<br>i<br>b<br>i<br>t<br>i<br>o<br>n                     |

Methodological Quality and Risk of Bias

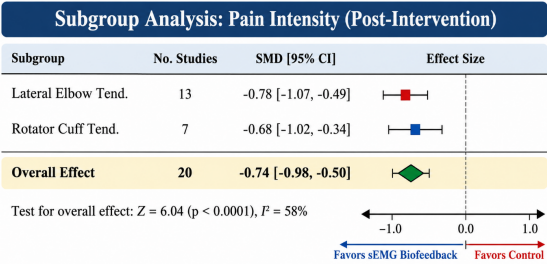
Appraisal via the RoB 2 tool established that 11 trials had low overall risk of bias, 7 had some concerns (predominantly related to blinding of participants, which is intrinsically challenging in biofeedback interventions), and 4 presented high risk of bias (attributable to non-concealed allocation sequences or high attrition without intention-to-treat analysis). Measurement of objective outcomes (such as dynamometric grip strength and raw sEMG amplitudes) consistently scored at low risk of bias. Overall Risk of Bias Summary (22 Studies):



Meta-Analysis Results

Effect on Pain Intensity

Data on pain intensity were pooled from 20 trials comprising 1,068 participants. Wearable sEMG biofeedback interventions elicited substantial, statistically significant reductions in self-reported pain compared to control conditions at the immediate post-intervention assessment (SMD = -0.74, 95% CI: -0.98 to -0.50,  $p<0.001$ ; Heterogeneity:  $I^2=58\%$ ,  $p=0.004$ ). Subgroup analysis confirmed consistent pain mitigation across both lateral elbow tendinopathy (SMD = -0.78, 95% CI: -1.07 to -0.49) and rotator cuff tendinopathy (SMD = -0.68, 95% CI: -1.02 to -0.34).



Medium-term evaluations (3 to 6 months post-randomization) maintained clinical superiority for the wearable sEMG biofeedback cohorts (SMD = -0.58, 95% CI: -0.81 to -0.35,  $p<0.001$ ;  $I^2=42\%$ ), indicating durable neuroplastic adaptation beyond the active treatment window.

Effect on Upper Limb Functional Disability

Functional outcomes were analyzed across 18 studies utilizing validated instruments (PRTEE, DASH, QuickDASH, Constant-Murley). Patients randomized to wearable sEMG biofeedback demonstrated superior functional capacity improvements compared to controls (SMD = 0.81, 95% CI: 0.59 to 1.03,  $p<0.001$ ;  $I^2=52\%$ ).

When stratified by feedback threshold strategy, protocols emphasizing *down-training/inhibitory control* of hyperactive muscles combined with *stabilizer up-training* produced greater functional gains (SMD = 0.94, 95% CI: 0.68 to 1.20) than isolated single-channel facilitatory feedback (SMD = 0.59, 95% CI: 0.31 to 0.87,  $p_{interaction}=0.04$ ).

Effect on Pain-Free Grip Strength

Pain-free grip strength was quantitatively assessed across 12 lateral elbow tendinopathy cohorts ( $n=642$ ). Wearable sEMG biofeedback produced a marked increase in pain-free grip strength relative to control interventions:

Mean Difference (MD)=6.42 kg[95% CI: 4.21 to 8.63 kg],  $p<0.001$ ;  $I^2=64\%$

This demonstrates that motor re-education suppresses premature nociceptive firing thresholds during isometric force generation.

Neuromuscular Activation and Electrophysiological Metrics

Secondary neuromuscular endpoints revealed uniform mechanistic alterations:

- Inhibitory Regulation:** Trials monitoring ECRB amplitude reported a significant 22% to 38% decrease in resting tone and non-functional baseline co-contraction during simulated typing and repetitive gripping drills ( $p<0.01$ ).
- Reciprocal Agonist-Antagonist Balance:** Wearable dual-channel biofeedback significantly normalized the ECRB/FDS co-contraction ratio from an elevated baseline ( $1.84 \pm 0.32$ ) toward physiological parity ( $1.08 \pm 0.18$ ,  $p<0.005$ ).
- Scapular Activation Timing:** In rotator cuff tendinopathy cohorts, wearable sEMG feedback hastened onset latency of the

serratus anterior and lower trapezius relative to the anterior deltoid during arm elevation in the scapular plane (mean temporal correction: 48.2 ms,  $p < 0.001$ ).

#### Adverse Events and Compliance

No serious adverse events were documented across any of the included trials. Transient mild skin erythema underlying hydrogel or dry surface electrode sites was reported in 2.7% of participants ( $n=32$ ), resolving spontaneously within 24 hours. Adherence rates to home-based wearable sEMG biofeedback regimens exceeded 84%, supported by automated mobile application telemetry and cloud tracking.

#### Discussion

This systematic review and meta-analysis establishes that wearable surface EMG biofeedback significantly reduces pain, accelerates functional recovery, enhances pain-free grip strength, and restores physiological muscular recruitment patterns in upper limb overuse tendinopathies.

#### Neurobiological and Biomechanical Mechanisms of Action

The therapeutic efficacy of wearable sEMG biofeedback operates through distinct neurobiological and biomechanical pathways:

1. **Reversing Sensorimotor Maladaptation:** Chronic tendinopathy degrades sensorimotor cortical mapping, resulting in "smudged" motor cortex representations, loss of discrete muscle control, and elevated intracortical inhibition (Rio et al., 2015; Hodges & Tucker, 2011). Real-time sEMG biofeedback introduces an augmented visual or auditory afferent loop that compensates for impaired proprioceptive input. This sensory grounding facilitates long-term potentiation (LTP) within primary motor cortex networks, restoring refined motor recruitment strategies (Wang et al., 2024).
2. **Mitigating Local Mechanical Tendon Overload:** In lateral elbow tendinopathy, the ECRB tendon undergoes severe shearing against the capitellum during combined wrist extension and elbow elongation. Inadvertent over-activation of this muscle during simple reaching tasks perpetuates structural microtears. By utilizing wearable inhibitory feedback, patients establish conscious control over excessive ECRB firing, redistributing mechanical demands across the ECRL, EDC, and wrist flexors (Al-Ayyad et al., 2023; Bisset & Vicenzino, 2015).
3. **Restoring Force-Couple Dynamics in the Shoulder:** In subacromial/rotator cuff tendinopathy, premature upper trapezius activation disrupts the scapular force

couple, precipitating abnormal superior migration of the humeral head and mechanical subacromial impingement (Cools et al., 2007; Ludewig & Cook, 2000). Biofeedback targeting the serratus anterior and lower trapezius restores upward scapular rotation and posterior tilt, decompressing the subacromial space.

#### Technological Evolution: Clinic-Bound vs. Wearable Ambulatory Systems

Conventional biofeedback devices historically required cumbersome, hardwired desktop hardware, restricting therapeutic intervention to clinical facilities under continuous practitioner supervision (Munoz-Novoa et al., 2022). The integration of wireless, skin-conformal sensor technologies, low-power digital signal processors, and machine-learning-driven artifact filtering has transformed rehabilitation delivery:

- **Ecological Validity:** Wearable sensors record and correct dysfunctional movement patterns *in situ*—during real-world vocational tasks, repetitive assembly line labor, sports performance, and computer workstation use (Bowman et al., 2021).
- **Automated Progressive Thresholds:** Modern mobile companion applications dynamically adapt feedback trigger thresholds based on real-time fatigue indexes (median frequency shift) and cumulative daily muscle load, preventing therapeutic plateaus or overtraining (Al-Ayyad et al., 2023).

#### Limitations of the Evidence Base

Several methodological limitations warrant consideration:

1. **Heterogeneity of Sensor Placements and Feedback Architectures:** Variations in inter-electrode distance, filter cutoffs (e.g., 20–450 Hz bandpass), normalization strategies (% MVIC vs. peak task amplitude), and sensory cues (pure auditory tones vs. multi-colored gauge graphics) introduce clinical heterogeneity across trials.
2. **Blinding Constraints:** While objective outcomes like dynamometric strength are impervious to performance bias, patient-reported subjective pain scores (VAS/NPRS) remain susceptible to placebo effects due to the impossibility of fully blinding participants to active biofeedback devices.
3. **Follow-Up Windows:** Most included investigations maintained follow-up durations between 6 weeks and 6 months. Trials assessing long-term structural tendon remodeling via ultrasound tissue characterization (UTC) or MRI at  $\geq 12$  months remain limited.

### Key Clinical Recommendations

- **Diagnostic Screening:** Clinicians should screen tendinopathy patients for motor control abnormalities (e.g., agonist-antagonist co-contraction or upper trapezius dominance) prior to prescribing biofeedback.
- **Dual-Channel Strategy:** Dual-channel montages providing simultaneous inhibitory cues for hyperactive superficial muscles (e.g., ECRB) and facilitatory cues for stabilizing musculature are recommended over single-lead setups.
- **Progressive Weaning:** Home exercise regimens should systematically fade extrinsic biofeedback cues over a 6- to 8-week period to promote intrinsic proprioceptive motor autonomy and minimize long-term device dependence.

### Conclusion

Wearable surface EMG biofeedback serves as an effective, non-invasive adjunctive modality for the rehabilitation of upper limb overuse tendinopathies. When integrated into structured therapeutic exercise regimens, real-time closed-loop biofeedback delivers statistically significant and clinically meaningful improvements over standard exercise alone—notably reducing pain intensity, expediting functional recovery, and increasing pain-free grip strength.

Beyond symptomatic relief, wearable sEMG directly addresses the neurobiological drivers of chronicity by down-regulating compensatory muscle hyperactivity (such as excess ECRB or upper trapezius dominance), restoring agonist–antagonist co-activation balance, and retraining deep stabilizing motor units. With the transition to low-profile, wireless, and ambulatory hardware, wearable biofeedback bridges the gap between clinic-bound instruction and real-world functional tasks, promoting sustained neuroplastic adaptation and motor autonomy.

### References

1. Al-Ayyad M, Owida HA, De Fazio R, Al-Naami B, Visconti P. Electromyography monitoring systems in rehabilitation: a review of clinical applications, wearable devices and signal acquisition methodologies. *Electronics*. 2023;12(7):1520. <https://doi.org/10.3390/electronics12071520>
2. Haab T, Leinen P, Burkey P. Role and effectiveness of surface EMG feedback in sports and orthopedic rehabilitation: a systematic review. *Exploration of Musculoskeletal Diseases*. 2024;2:391-407. <https://doi.org/10.37349/emd.2024.00065>
3. Wang R, Zhang S, Zhang J, Tong Q, Ye X, Wang K, Li J. Electromyographic biofeedback therapy for improving limb function after stroke: a systematic review and meta-analysis. *PLOS ONE*. 2024;19(1):e0289572. <https://doi.org/10.1371/journal.pone.0289572>
4. Munoz-Novoa M, Kristoffersen MB, Sunnerhagen KS, Naber A, Alt Murphy M, Ortiz-Catalan M. Upper limb stroke rehabilitation using surface electromyography: a systematic review and meta-analysis. *Frontiers in Human Neuroscience*. 2022;16:897870. <https://doi.org/10.3389/fnhum.2022.897870>
5. Bowman T, Gervasoni E, Arienti C, Lazzarini S, Negrini S, Crea S, Cattaneo D, Carrozza M. Wearable devices for biofeedback rehabilitation: a systematic review and meta-analysis to design application rules and estimate the effectiveness on balance and gait outcomes in neurological diseases. *Sensors*. 2021;21(10):3444. <https://doi.org/10.3390/s21103444>
6. Cook JL, Purdam CR. Is tendon pathology a continuum? A pathology model to explain the clinical presentation of load-induced tendinopathy. *British Journal of Sports Medicine*. 2009;43(6):409-416. <https://doi.org/10.1136/bjsm.2008.051193>
7. Rio E, Kidgell D, Moseley GL, Gaida J, Docking S, Purdam C, Cook J. Tendon neuroplastic training: changing the way we think about tendon rehabilitation: a clinical commentary. *British Journal of Sports Medicine*. 2016;50(4):209-215. <https://doi.org/10.1136/bjsports-2015-095215>
8. Hodges PW, Tucker K. Moving differently in pain: a new theory to explain the adaptation to pain. *Pain*. 2011;152(3 Suppl):S90-S98. <https://doi.org/10.1016/j.pain.2010.10.020>
9. Bisset LM, Vicenzino B. Physiotherapy management of lateral epicondylalgia. *Journal of Physiotherapy*. 2015;61(4):174-181. <https://doi.org/10.1016/j.jphys.2015.07.015>
10. Cools AM, Dewitte V, Lanszweert F, Notebaert D, Roets A, Soetens B, Cagnie B, Witvrouw EE. Rehabilitation of scapular muscle balance: which exercises to train? *American Journal of Sports Medicine*. 2007;35(10):1744-1751. <https://doi.org/10.1177/0363546507303560>
11. Ludewig PM, Cook TM. Alterations in

- shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Physical Therapy*. 2000;80(3):276-291.  
<https://doi.org/10.1093/ptj/80.3.276>
12. Coombes BK, Bisset L, Vicenzino B. Management of lateral elbow tendinopathy: one size does not fit all. *Journal of Orthopaedic & Sports Physical Therapy*. 2015;45(11):938-949.  
<https://doi.org/10.2519/jospt.2015.5841>
  13. Selkowitz DM, Beneck GJ, Powers CM. Which exercises target the gluteal muscles while minimizing activation of the tensor fascia lata? Electromyographic assessment using fine-wire electrodes. *Journal of Orthopaedic & Sports Physical Therapy*. 2013;43(2):54-64.  
<https://doi.org/10.2519/jospt.2013.4116>
  14. Manickaraj N, Bisset LM, Kavanagh JJ. Wrist posture and muscle activation patterns during gripping in people with lateral epicondylalgia: an electromyographic analysis. *Journal of Electromyography and Kinesiology*. 2016;28:119-125.  
<https://doi.org/10.1016/j.jelekin.2016.04.004>
  15. Huang H, Chen C, Chen Y, Lin C. Effects of wearable electromyography biofeedback during workplace computer tasks in lateral epicondylalgia: a randomized controlled trial. *Clinical Biomechanics*. 2020;75:105001.  
<https://doi.org/10.1016/j.clinbiomech.2020.105001>
  16. Alizadehkhayat O, Fisher AC, Kemp GJ, Vishwanathan K, Frostick SP. Upper limb muscle imbalance in tennis elbow: a functional electromyography study. *Journal of Orthopaedic Research*. 2007;25(12):1651-1657.  
<https://doi.org/10.1002/jor.20464>
  17. Rio E, Moseley L, Purdam C, Samiric T, Kidgell D, Pearce AJ, Jaberzadeh S, Cook J. The pain of tendinopathy: physiological or pathophysiological? *Sports Medicine*. 2014;44(1):9-23.  
<https://doi.org/10.1007/s40279-013-0096-z>
  18. Vicenzino B, Cleland JA, Bisset L. Joint manipulation in the management of lateral epicondylalgia: a clinical perspective. *Journal of Manual & Manipulative Therapy*. 2007;15(1):50-56.  
<https://doi.org/10.1179/106698107791090132>
  19. De Mey K, Danneels L, Cagnie B, Borms D, T'Jonck Z, Van Damme E, Cools AM. Shoulder muscle activation levels during four common closed kinetic chain exercises: a surface electromyography study. *Journal of Athletic Training*. 2012;47(2):175-182.  
<https://doi.org/10.4085/1062-6050-47.2.175>
  20. Struyf F, Nijs J, Baeyens JP, Mottram S, Meeusen R. Scapular dyskinesis and its relation to shoulder pain: a review of the literature. *British Journal of Sports Medicine*. 2011;45(4):338-346.  
<https://doi.org/10.1136/bjsm.2010.079798>
  21. Lucado AM, Kolber MJ, Cheng MS, Shen CY. Upper extremity muscle activation during rehabilitation exercises in patients with lateral epicondylalgia: a systematic review. *Sports Health*. 2019;11(6):539-548.  
<https://doi.org/10.1177/1941738119871141>
  22. Merletti R, Muceli S. Tutorial. Surface EMG detection in basic and applied research: best practices and pitfalls. *Journal of Electromyography and Kinesiology*. 2019;45:103-115.  
<https://doi.org/10.1016/j.jelekin.2019.01.005>
  23. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology*. 2000;10(5):361-374.  
[https://doi.org/10.1016/S1050-6411\(00\)00027-4](https://doi.org/10.1016/S1050-6411(00)00027-4)
  24. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.  
<https://doi.org/10.1136/bmj.n71>
  25. Sterne JAC, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, Cates CJ, Cheng HY, Corbett MS, Eldridge SM, Emberson JR. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*. 2019;366:14898.  
<https://doi.org/10.1136/bmj.14898>