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Randomized Controlled Trial

Changes in Shoulder Strength, Mobility, and Muscle Recruitment Following Ultrasound-Guided Percutaneous Neuromodulation in CrossFit Athletes with Nonspecific Shoulder Pain: A Randomized Controlled Trial

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ABSTRACT

Study design: Randomized controlled trial with two experimental groups and blinded evaluators. Participants: 42 CrossFit athletes with nonspecific shoulder pain.

Interventions: Both groups received a single session of ultrasound-guided percutaneous neuromodulation (US-guided PNM) targeting the axillary and suprascapular nerves. One group received stimulation at 1 Hz, and the other at 10 Hz.

Objective: To analyze the effectiveness of two different frequencies (1 Hz vs. 10 Hz) of US-guided PNM on shoulder function in CrossFit athletes with nonspecific shoulder pain.

Materials and Methods: Pre- and post-intervention assessments included variables related to glenohumeral rotational mobility and strength, as well as scapular motor control, measured using goniometry, dynamometry, and surface electromyography, respectively.

Results: US-guided PNM at 10 Hz resulted in significant improvements in glenohumeral rotational mobility and strength, and scapular motor control. At 1 Hz, improvements in mobility and strength were observed, though to a lesser extent and without significant effects on motor control.

Conclusions: These findings support the effectiveness of US-guided PNM as a simple, clinically effective intervention to improve neuromuscular function in CrossFit athletes with nonspecific shoulder pain. However, results also underscore the importance of individualizing electrical stimulation parameters to optimize outcomes.

Keywords: Percutaneous Neuromodulation; Invasive Physiotherapy; Axillary Nerve; Suprascapular Nerve; CrossFit; Nonspecific Shoulder Pain.

1. Introduction

CrossFit is a high-intensity fitness training program that integrates exercises from various disciplines such as Olympic weightlifting, athletics, running, and gymnastics⁽¹⁾. Developed by Greg Glassman in 2000, it has gained increasing recognition within the scientific community in recent years⁽²⁾. This discipline is characterized by three core principles: functional movement execution, high-intensity effort, and constant variation of exercise routines⁽³⁾. CrossFit has been associated with improvements in strength, power, balance, flexibility, and cardiorespiratory fitness⁽⁴⁾.

The injury risk associated with CrossFit is comparable to that of sports like powerlifting and weightlifting⁽⁵⁾. Injury rates range from 0.2 to 18.9 per 1,000 hours of participation, falling within the normal range for conventional resistance training⁽⁶⁾. Several risk factors have been identified in the literature that predispose CrossFit athletes to injury, especially when training is poorly programmed or technique is lacking. High training volume and frequency can lead to early fatigue, increased perceived exertion, and movement inefficiency⁽⁷⁾. Other relevant risk factors include older age, male sex, previous injuries⁽⁸⁾, and pre-training stretching routines⁽⁹⁾.

Shoulder injuries are the most prevalent among CrossFit practitioners, surpassing common injury sites such as the lumbar spine or knee^(6,10). Among shoulder pathologies, nonspecific shoulder pain is highly prevalent in the adult population^(11,12). This diagnosis is used when a precise cause of pain cannot be determined due to a multifactorial etiology involving risk factors such as muscular imbalance between internal and external rotators, restricted rotational mobility, impaired scapular motor control, muscle fatigue, and frequent overhead activity^(13–15).

Overhead movements are especially relevant in CrossFit, where athletes frequently perform exercises above the head, thereby increasing the risk of shoulder injury⁽¹⁶⁾. These actions have been linked to internal rotation deficits in the glenohumeral joint, similar to observations in swimmers⁽¹⁷⁾ and throwing athletes⁽¹⁸⁾, further exacerbating internal/external rotator imbalances. From a biomechanical perspective, glenohumeral flexion and abduction are more efficient when accompanied by external rotation, and repetitive movement patterns may restrict internal rotation, compromising shoulder mobility. Over time, this leads to modifiable musculoskeletal changes (e.g., posterior capsular tightness, infraspinatus or teres minor shortening, and scapular dyskinesis) and non-modifiable changes (e.g., osseous torsion in young athletes)⁽¹⁹⁾.

Besides pain, individuals with nonspecific shoulder pain often present other symptoms, such as inhibition of the lower trapezius⁽²⁰⁾ and infraspinatus, detected during both dynamic⁽²¹⁾ and isometric⁽²²⁾ evaluations. Alterations in the joint capsule include decreased proprioception⁽²³⁾, capsular thickening⁽²⁴⁾, or inflammation, which contribute to mobility loss, especially during rotational movements⁽¹⁷⁾. Repetitive overhead exercises may also lead to neural-type symp-

toms or injuries⁽²⁵⁾. This collection of symptoms leads to biomechanical alterations at the glenohumeral, scapular⁽²⁶⁾, and cervical levels^(27,28), ultimately reducing functional performance and quality of life⁽²⁹⁾, especially critical in CrossFit athletes due to the heavy demand placed on shoulder function.

The standard clinical approach to nonspecific shoulder pain is conservative physiotherapy, usually combining manual therapy and therapeutic exercise, both of which have shown efficacy in improving glenohumeral mobility and functionality^(30,31). In recent years, however, interest in invasive physiotherapy techniques has increased. Among them, ultrasound-guided percutaneous neuromodulation (US-guided PNM) stands out. This technique delivers electrical stimulation via acupuncture needles placed near the targeted nerve (epineurium) or motor point. The goal is to restore optimal neuromuscular function in dysfunctional structures⁽³²⁾. US-guided PNM has shown efficacy in both lower⁽³²⁾ and upper limbs⁽³³⁾, in healthy individuals and in those with musculoskeletal conditions. Documented benefits include reduced pain⁽³⁴⁾, improved strength^(35,36), flexibility⁽³⁷⁾, balance and endurance⁽³⁸⁾, and normalization of neural excitability⁽³⁹⁾.

To date, therapeutic exercise protocols have been developed for evaluating and treating nonspecific shoulder pain in CrossFit athletes⁽⁴⁰⁾. Techniques such as instrument-assisted soft tissue mobilization and stretching have also been tested in healthy athletes⁽³⁰⁾. However, little information exists on the application of US-guided PNM in this population. Only one study has investigated its effects in healthy CrossFit athletes, showing increased shoulder rotational strength⁽³⁸⁾. The present randomized controlled trial was therefore designed to evaluate the efficacy of two different US-guided PNM protocols and determine which is more suitable for reducing the risk factors associated with nonspecific shoulder pain in CrossFit athletes.

2. Materials and Methods

2.1 Study design

This study was a randomized controlled trial (RCT) with a single-blind design (blinded evaluators) and two parallel experimental groups. The research was conducted at several CrossFit centers in Santander and Valladolid (Spain), all equipped with the necessary resources for evaluations and physiotherapy interventions. The study adhered to the CONSORT 2010 guidelines for parallel-group randomized trials⁽⁴¹⁾.

2.2 Ethics

This RCT complied with the ethical principles of the Declaration of Helsinki and the Spanish Biomedical Research Law. The study was approved by the Ethics Committee of Aragón (No. 13/2025) and registered at ClinicalTrials.gov (NCT06958276).

2.3 Objectives

The primary objective of the study was to evaluate the effectiveness of US-guided PNM, applied at two different stimulation frequencies (1 Hz and 10 Hz), in improving key shoulder injury risk factors (glenohumeral joint mobility, strength, and motor control) in CrossFit athletes with nonspecific shoulder pain.

Additionally, the following secondary objectives were established: 1) To analyze the proportion of athletes exhibiting an imbalanced strength ratio between internal and external shoulder rotators; 2) To assess the proportion of athletes demonstrating impaired scapular muscle motor control, and 3) To evaluate the proportion of athletes with an incomplete glenohumeral joint.

2.4 Participants

Participants were recruited through coaches at the participating CrossFit centers, who sent email invitations to their members. Eligible individuals received a verbal explanation of the study's aims and procedures and signed informed consent forms before enrollment. The inclusion criteria were: 1) Aged over 18 years; 2) Shoulder pain lasting more than 3 months; 3) No identifiable cause of shoulder pain (i.e., nonspecific pain diagnosis), and 4) Training in CrossFit at least 3 times per week. The exclusion criteria were: 1) Previous medical or physiotherapy treatment for nonspecific shoulder pain; 2) History of shoulder surgery, and 3) Belonephobia (fear of needles) or fear of the US-guided PNM intervention.

Sample size was calculated based on previous research in a similar population, reporting a mean and standard deviation of 113.1 ± 38.5 for internal shoulder rotation strength (measured via manual dynamometry). A minimum clinically important difference of 42.7 points was considered⁽⁴²⁾. Using an independent-samples t-test with 5% significance ($\alpha = 0.05$) and 80% power ($1 - \beta = 0.80$), the required sample size was 21 participants per group, for a total of 42 participants.

2.5 Randomization and blinding

Participants were randomly assigned to one of two intervention groups (Group 1 Hz or Group 10 Hz) using Epidat v.4.2. Since the study was single-blinded, evaluators were unaware of each participant's group assignment.

2.6 Intervention

Both groups received a single session of US-guided PNM targeting the axillary and suprascapular nerves. The procedure was performed by a physiotherapist with over 10 years of experience in invasive techniques and ultrasound-guided evaluations. Participants were placed in a prone position with the affected shoulder flexed to 90°, supported on the table, and the forearm hanging off the edge with 90° of elbow flexion. The physiotherapist stood on the same side as the treated shoulder. Skin was disinfected using isopropyl alcohol and chlorhexidine (Lainco® 2%). An ultrasound system (GE Logic R7, GE Healthcare, USA) with a linear 12L transducer was used in transverse view. Electrical stimulation was delivered using the "Physio Invasiva® CE0120" device (PRIM Physio, Spain) in PES mode. Sterile stainless-steel acupuncture needles (0.30 mm x 0.40 mm) were inserted near the perineurium of the axillary and suprascapular nerves (Figures 1 and 2), following the MvClinic protocol, consisting of 10 bursts of biphasic electrical current, each lasting 10 seconds with 10 seconds of rest between them. Pulse width was 240 μ s, and intensity was adjusted to elicit maximum pain-free muscle contraction⁽⁴³⁾. The only variable that differed between groups was stimulation frequency: Group 1 received 1 Hz stimulation, and Group 2 received 10 Hz stimulation.

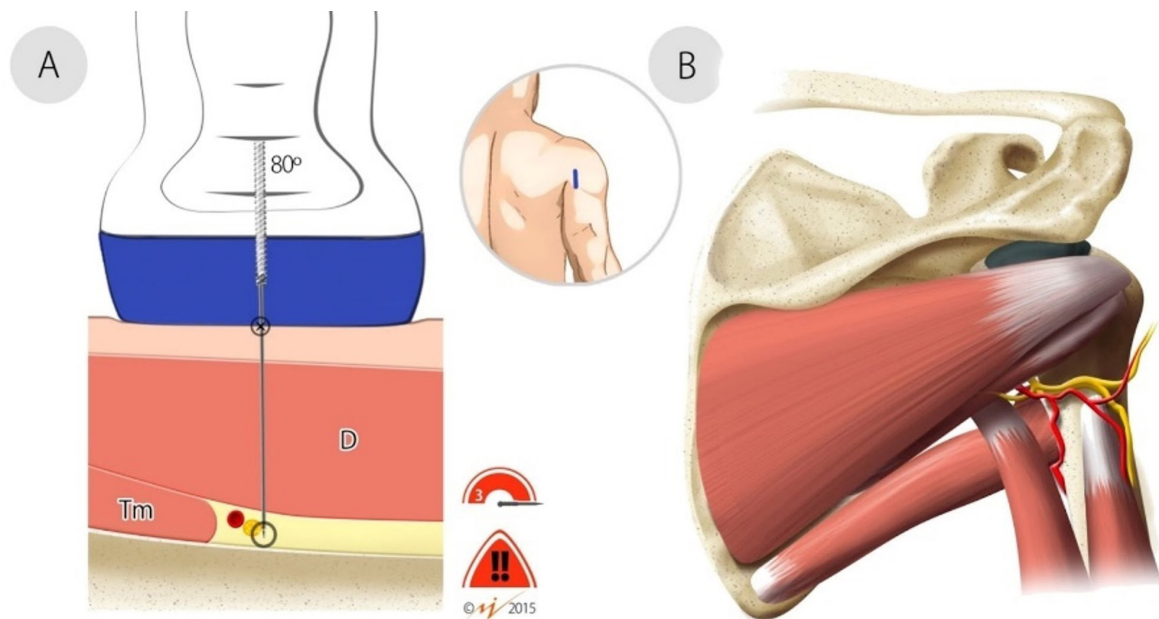


Figure 1. A) US-guided NMP of the axillary nerve; D: deltoid muscle; Tm: teres minor muscle. B) Anatomical pathway of the axillary nerve. Reproduced with permission from Course Materials of US-Guided Percutaneous Neuromodulation (PNM). Copyright © MVClinic Institute 2015. Approach to the axilar nerve.

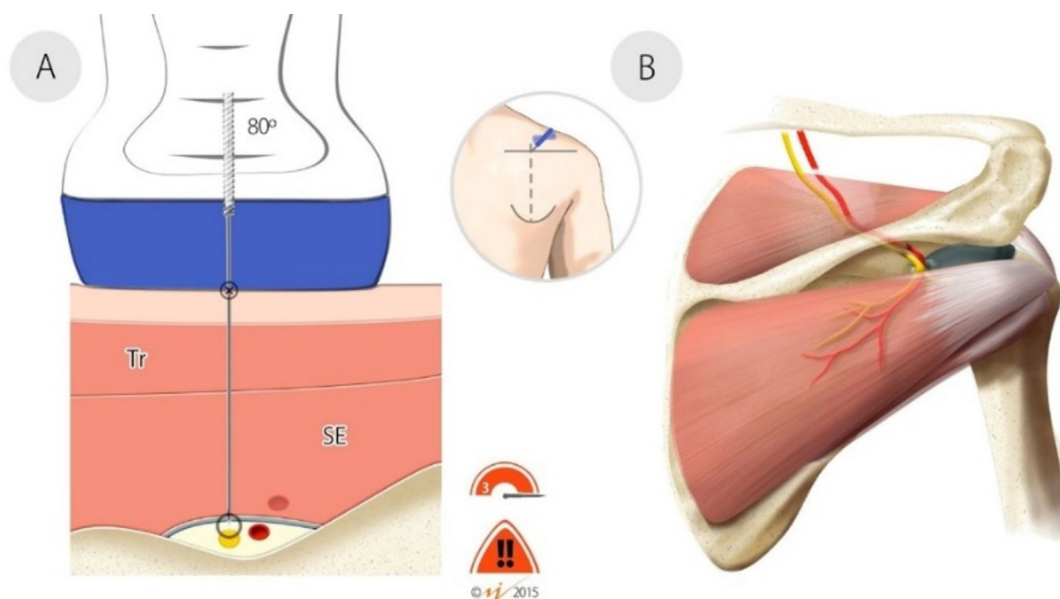


Figure 2. A) US-guided NMP of the suprascapular nerve; Tr: trapezius muscle; SE: supraespinatus muscle. B) Anatomical pathway of the axillary nerve. Reproduced with permission from Course Materials of US-Guided Percutaneous Neuromodulation (PNM). Copyright © MVClinic Institute 2015. Approach to the axilar nerve.

2.7 Outcomes

Two blinded evaluators conducted all measurements. First, sociodemographic data were collected from each participant. Then, a pre-intervention assessment of clinical variables was performed. Finally, immediately after the intervention, a post-intervention assessment of the same clinical variables was carried out, which were the following:

2.7.1. Glenohumeral Rotation Mobility: a digital goniometer (HALO) was used, which has demonstrated validity and reliability for shoulder joint measurements⁽⁴⁴⁾. For each participant, internal

rotation (IR) and external rotation (ER) were measured bilaterally. Subsequently, both rotations were added together to create a third variable: total arc of rotational movement (TAR). The patient was placed in the supine position, with the shoulder abducted to 90°, the elbow flexed to 90°, and the forearm perpendicular to the ground. One evaluator stabilized the scapula by pressing on the coracoid process, whereas the other evaluator performed passive internal/external rotation while placing the goniometer on the distal third of the dorsal side of the forearm. Passive mobilization ended at the first "end-feel" or when the scapula began to move. Two measurements of both rotations were taken on each shoulder, and the final value was the average of both. (Figure 3A).

2.7.2. Glenohumeral Rotation Strength: A handheld dynamometer (HHD) was used, measuring in kilograms of force (KgF). This instrument has demonstrated good to excellent reliability and validity for evaluating shoulder musculature strength⁽⁴⁵⁾. The participant was positioned according to Hams and colleagues (2019)⁽⁴⁶⁾: seated with 90° of hip and knee flexion, feet flat on the floor, an upright trunk, shoulders in 0° of abduction and neutral rotation, and elbows in contact with the trunk and flexed at 90°. The dynamometer was placed on the distal third of the inner forearm to assess IR and on the distal third of the outer forearm to assess ER. The evaluator stood on the same side of the tested rotation, holding the dynamometer with both hands. Participants were instructed to exert their maximum isometric force for 10 seconds, while the evaluator applied equal force in the opposite direction. Three bilateral tests were performed, allowing one minute of rest between each, and the final data point was the average of the three. The ER/IR strength ratio was then calculated by dividing the ER value by the IR value⁽⁴³⁾, with a ratio of 2:3 (0.66) considered ideal⁽⁴⁷⁾. (Figure 3B).

2.7.3. Scapular Motor Control: a surface electromyography device from the brand Mdurance was used, which has been validated and previously used in the literature⁽⁴⁸⁾. According to Kibler and colleagues (2013)⁽¹⁴⁾, proper scapular motor control is mainly achieved through the upper and lower trapezius and the serratus anterior muscles. Therefore, surface electrodes were placed bilaterally on these three muscles, and participants were asked to perform five repetitions of glenohumeral abduction in the scapular plane. The EMG software recorded the activation levels of all three muscles and the activation order of the musculature. (Figure 3C).

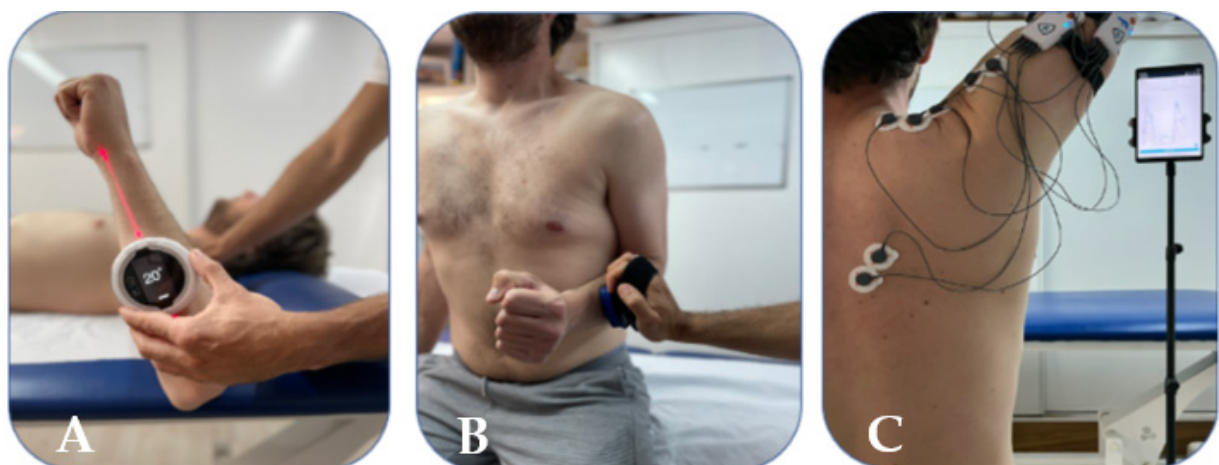


Figure 3. A) Assessment of glenohumeral rotation mobility with HALO goniometer. B) Assessment of ER/IR strength ratio with HHD dynamometer. C) Assessment of scapular motor control with mDurance electromyography.

2.8 Statistical analysis

All statistical analyses were conducted using R software (version 2024.09.0; build 375). First, sociodemographic variables were analyzed descriptively according to the study groups. To determine the appropriate statistical tests, data normality was assessed using the Shapiro-Wilk test. For clinical variables evaluated at two time points (before and after the intervention), intra-group analyses were conducted: paired t-tests for normally distributed variables and the Wilcoxon test for non-normally distributed variables. For between-group comparisons, the differences (Δ) between pre- and post-intervention measurements for each variable within each group were first calculated. Then, these Δ values were compared between groups. If the distribution was normal, an independent-samples t-test was used; otherwise, the Mann-Whitney U test was used. To enhance the interpretation of the results and better validate the p-values obtained, effect sizes were also calculated. Cohen's d was used for parametric tests, and the Mann-Whitney-based effect size was used for non-parametric tests. A p-value < 0.05 was considered statistically significant for all analyses.

3. Results

3.1 Participants flow

A total of 42 participants were evaluated, all of whom met the inclusion and exclusion criteria and were therefore included in the study. Recruitment began in May 2025 and ended in July of the same year. No dropouts occurred at any point (Figure 4). The sample was randomly divided into two study groups: 10 Hz Group (7 men and 14 women, with a mean age of 32 years) and 1 Hz Group (4 men and 17 women, with a mean age of 38 years). At baseline, age was the only variable that showed significant differences between groups. However, this was deemed irrelevant because none of the clinical variables showed significant intergroup differences. In both groups, the most frequent number of weekly training sessions was 5 (10 Hz Group: 38%, 1 Hz Group: 43%). All sociodemographic information is shown in Table 1.

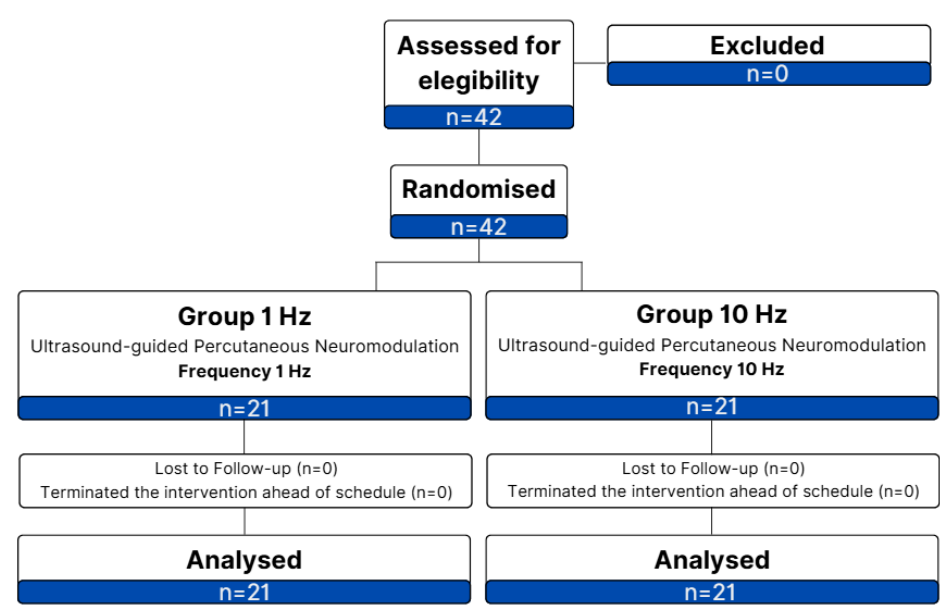


Figure 4. Participants' flow chart.

Table 1. Sociodemographic characteristics of the sample.

Variable		Total (n = 42)	Group 1 Hz (n =21)	Group 10 Hz (n =21)
Gender	Men	11 / 42 (26.0%)	4 / 21 (19%)	7 / 21 (33%)
	Women	31 / 42 (74.0%)	17 / 21 (81%)	14 / 21 (67%)
Age (years)		35 (7.62)	38 (9)	32 (6)
Dominant arm	Right	40 / 42 (95%)	20 / 21 (95.2%)	20 / 21 (95.2%)
	Left	2 / 42 (4.8%)	1 / 21 (4.8%)	1 / 21 (4.8%)
Affected shoulder side	Right	21 / 42 (50%)	11 / 21 (52%)	10 / 21 (48%)
	Left	21 / 42 (50%)	10 / 21 (48%)	11 / 21 (52%)
Treated arm	Right	21 / 42 (50%)	11 / 21 (52.3%)	10 / 21 (47.7%)
	Left	21 / 42 (50%)	10 / 21 (47.7%)	11 / 21 (52.3%)
CrossFit training (days/week)		4.67 (1.07)	4.33 (1.11)	5.00 (0.95)

Data are presented as mean and standard deviation for quantitative variables, and as frequency and percentage for qualitative variables.

3.2 Synthesis of results

3.2.1. Glenohumeral Rotation Mobility

No statistically significant differences were found between treatment groups. In the intra-group analysis, both groups showed significant improvements in IR and the external/internal rotation ratio (ER/IR) in both the treated and non-treated arms ($p < 0.001$), indicating a cross-education effect. In all cases, large effect sizes were observed ($d > 0.7$), with the most notable being the ER/IR ratio in the treated arm ($d = 1.32$ and $d = 1.36$ for the 1 Hz and 10 Hz groups, respectively), compared to the non-treated arm ($d = 0.81$ and $d = 0.79$). For ER, significant differences were found only in the treated arm of both groups ($p = 0.002$ and $p = 0.021$ for the 1 Hz and 10 Hz groups, respectively). In the non-treated arms, statistical significance was not reached for ER, although values were close to the established threshold ($p = 0.057$ and $p = 0.069$) (Table 2).

Table 2. Descriptive data and intra-group and between-groups analysis for the glenohumeral range of motion variable (goniometry).

Variable	Group	Arm	Descriptive data		Between-groups differences P-value ¹ (Effect size) ³	Intra-group differences P-value ² (Effect size) ³
			Pre-treatment	Post-treatment		
Int. Rot. ROM	Group 1 Hz	Treated	65.28 (16.52)	80.8 (10.35)	Treated arm:	<0.001 (0.79) *
		Non-treated	77.23 (7.79)	86.14 (6.52)	0.981 (-0.004)	<0.001 (0.81) *
	Group 10 Hz	Treated	58.71 (18.97)	74.19 (16.8)	Non-treated arm:	<0.001 (0.81) *
		Non-treated	65.14 (14.73)	71.14 (13.22)	0.732 (-0.107)	<0.001 (0.72) *
Ext. Rot. ROM	Group 1 Hz	Treated	91.8 (8.26)	95.52 (9.73)	Treated arm:	0.002 (<0.01) *
		Non-treated	92.42 (6.27)	93.9 (7.48)	0.243 (0.395)	0.057 (<0.01)
	Group 10 Hz	Treated	83.14 (17.57)	91.61 (8.15)	Non-treated arm:	0.021 (<0.01) *
		Non-treated	91.09 (13.62)	92.23 (13.36)	0.731 (-0.107)	0.069 (<0.01)
Total ROM (Int. Rot. + Ext. Rot.)	Group 1 Hz	Treated	157.08 (18.38)	176.32 (14.23)	Treated arm:	<0.001 (1.32) *
		Non-treated	169.65 (9.99)	180.04 (9.88)	0.446 (0.117)	<0.001 (0.81) *
	Group 10 Hz	Treated	141.85 (26.06)	165.8 (18.63)	Non-treated arm;	<0.001 (1.36) *
		Non-treated	156.23 (20.01)	163.37 (18.74)	0.243 (-0.396)	<0.001 (0.79) *

1 Student's t-test for independent samples or Mann-Whitney U test depending on normality. 2 Paired Student's t-test or Wilcoxon test depending on normality. 3 Cohen's d or Mann-Whitney effect size depending on normality. * Significance set at $p < 0.05$. Data are presented as mean and standard deviation.

3.2.2. Glenohumeral Rotation Strength

No statistically significant differences were found between the groups for any of the strength variables. In the intra-group analysis, significant improvements were observed only in ER strength of the treated arm in the 1 Hz group ($p = 0.011$), and in both the treated and non-treated arms of the 10 Hz group ($p = 0.010$ and $p = 0.047$, respectively), again showing a cross-education effect, but only in the higher frequency group. The remaining variables showed no significant differences. Notably, in the IR condition, the non-treated arms in both groups showed slightly lower post-intervention values than pre-intervention (15.11 (4.13) vs. 15.56 (3.99) for the 10 Hz group; 14.53 (5.47) vs. 15.1 (5.9) for the 1 Hz group) (Table 3).

Table 3. Descriptive data and intra-group and between-groups analysis for the glenohumeral rotation strength variable (dynamometry).

Variable	Group	Arm	Descriptive data		Between-groups differences P-value ¹ (Effect size) ³	Intra-group differences P-value ² (Effect size) ³
			Pre-treatment	Post-treatment		
Int. Rot. Strength	Group 1 Hz	Treated	14.91 (4.64)	14.98 (4.51)	Treated Arm: 0.722 (0.11)	0.829 (0.03)
		Non-treated	15.56 (3.99)	15.11 (4.13)		0.189 (-0.30)
	Group 10 Hz	Treated	13.33 (5.42)	13.63 (5.29)	Non-treated Arm: 0.124 (0.24)	0.514 (0.15)
		Non-treated	15.10 (5.90)	14.53 (5.47)		0.463 (-0.16)
Ext. Rot. Strength	Group 1 Hz	Treated	8.44 (2.17)	9.42 (2.13)	Treated Arm: 0.691 (0.12)	0.011 (0.56) *
		Non-treated	10.77 (3.25)	10.78 (2.85)		0.834 (0.05)
	Group 10 Hz	Treated	9.43 (5.85)	10.63 (5.49)	Non-treated Arm: 0.126 (0.24)	0.010 (0.43) *
		Non-treated	10.35 (5.13)	11.27 (6.32)		0.047 (0.37) *
Ratio Ext. Rot. / Int. Rot.	Group 1 Hz	Treated	0.59 (0.18)	0.66 (0.21)	Treated Arm: 0.623 (0.15)	0.144 (0.32)
		Non-treated	0.71 (0.21)	0.74 (0.22)		0.626 (0.11)
	Group 10 Hz	Treated	0.70 (0.31)	0.80 (0.27)	Non-treated Arm: 0.336 (0.30)	0.088 (0.37)
		Non-treated	0.70 (0.20)	0.78 (0.25)		0.088 (0.37)

¹ Student's t-test for independent samples or Mann-Whitney U test depending on normality. ² Paired Student's t-test or Wilcoxon test depending on normality. ³ Cohen's d or Mann-Whitney effect size depending on normality. * Significance set at $p < 0.05$. Data are presented as mean and standard deviation.

3.2.3. Scapular Motor Control

In the intra-group analysis, only the 10 Hz group showed a significant decrease in upper trapezius activation ($p = 0.021$; $d = 0.53$), reflecting an improvement in scapular motor control. This reduction resulted in significant differences between groups in favor of the 10 Hz group ($p = 0.021$; $d = 0.711$). Activation of the other assessed muscles (lower trapezius and serratus anterior) did not show significant differences in either the intra-group or between-group analyses (Table 4).

Table 4. Descriptive data and intra-group and between-groups analysis for the scapular motor control variable (electromyography).

Variable	Group	Descriptive Data		Between-groups differences	Intra-group differences
		Pre-treatment	Post-treatment	P-value ¹ (Effect size) ³	P-value ² (Effect size) ³
Average muscle activation - UT	Group 1 Hz	36.81 (5.76)	38.17 (5.94)	0.021 (0.71) *	0.381 (-0.19)
	Group 10 Hz	32.04 (11.62)	28.76 (8.2)		0.021 (0.53) *
Average muscle activation - LT	Group 1 Hz	35.07 (8.35)	35.12 (6.60)	0.832 (-0.07)	0.97 (-0.01)
	Group 10 Hz	30.72 (7.01)	31.16 (6.72)		0.563 (-0.13)
Average muscle activation - SA	Group 1 Hz	30.36 (6.09)	31.17 (4.88)	0.731 (0.13)	0.374 (-0.20)
	Group 10 Hz	665 (415)	679 (419)		0.576 (-0.12)
Maximum contraction - US	Group 1 Hz	565 (397)	580 (394)	0.942 (-0.01)	0.558 (-0.13)
	Group 10 Hz	651 (268)	652 (248)		0.421 (-0.17)
Maximum contraction - LT	Group 1 Hz	889 (661)	874 (661)	0.863 (0.02)	1 (<0.01)
	Group 10 Hz	826 (814)	630 (417)		0.752 (0.07)
Maximum contraction - SA	Group 1 Hz	256 (164)	259 (178)	0.436 (0.11)	0.446 (0.17)
	Group 10 Hz	36.81 (5.76)	38.17 (5.94)		0.653 (-0.10)

1 Student's t-test for independent samples or Mann-Whitney U test, depending on normality. 2 Paired Student's t-test or Wilcoxon test, depending on normality. 3 Cohen's d or Mann-Whitney effect size depending on normality. * Significance set at $p < 0.05$. Data are presented as mean and standard deviation. LT: lower trapezius; SA: serratus anterior; UT: upper trapezius.

4. Discussion

Regarding pre-treatment evaluation data, as in previous studies, our sample showed a clinical profile closely associated with three of the main risk factors for nonspecific shoulder pain. First, an imbalance in the ER/IR strength ratio, with 66% of the study athletes showing an altered ratio. This muscular imbalance has been documented as the most prevalent risk factor in the population with nonspecific shoulder pain^(49,50). Second, the deficit of glenohumeral internal rotation (GIRD), with 35.7% of athletes exhibiting pathological GIRD, defined as a reduction of at least 18 degrees of internal rotation and 5 degrees in the total rotational range compared to the contralateral, non-pathological side⁽⁵¹⁾. This internal rotation deficit is even more clinically relevant in overhead sports, such as CrossFit⁽⁵²⁾. Third, an impaired scapular motor control, with only 7% of athletes showing proper scapular motor control. In detail, 33% showed inhibition of the serratus anterior, 57% of the lower trapezius, and 3% of both muscles. This inadequate scapular motor control demonstrates the high prevalence of neuromuscular dysfunction in athletes with nonspecific shoulder pain, and it largely explains why US-guided PNM is a promising therapeutic option for this population.

After the application of ultrasound-guided percutaneous neuromodulation (US-guided PNM) on the axillary and suprascapular nerves in CrossFit athletes with nonspecific shoulder pain, the results demonstrated significant improvements in shoulder joint functionality.

4.1. Glenohumeral Rotation Mobility

In terms of joint mobility, both study groups showed significant improvements in total rotational range and IR, in both treated and non-treated limbs. These improvements showed large effect sizes ($d \geq 0.72$), indicating clinically relevant change. For ER, improvements were observed only in treated limbs of both groups, but the effect sizes suggested limited clinical relevance. These results are consistent with previous findings showing that a single session of US-guided PNM at 10 Hz⁽³²⁾ or 3 Hz⁽³⁶⁾ improved joint mobility in knee and lumbar spine conditions, respectively.

4.2. Glenohumeral Rotation Strength

Regarding rotational strength, significant benefits were observed only in ER, with moderate effect sizes ($d = [0.37 - 0.56]$). Both groups showed improvements on the treated side, while only the 10 Hz group showed a cross-education effect, with strength gains also in the non-treated side. These results suggest that cross-education effects on strength may depend on stimulation frequency, as 1 Hz may not produce a strong enough effect.

The other strength variables (IR and ER/IR ratio) did not improve. The recent study by Sangiacomo and colleagues (2025)⁽⁵³⁾ also evaluated the effect of US-guided PNM on shoulder strength in CrossFit athletes, but in healthy individuals without pain. Their methodology was similar to that of the current study, targeting the suprascapular and axillary nerves at 10 Hz. Their results also showed increased ER strength, but unlike the present research, they observed improvements in IR strength as well. This difference may be due to the inclusion of athletes with nonspecific shoulder pain in our study, a condition characterized by deficits in internal rotation.

Other studies applying 10 Hz PNM to the femoral nerve⁽³⁵⁾, 6 Hz to the superior gluteal nerve⁽⁵⁴⁾, and 3 Hz to the sciatic nerve⁽³⁶⁾ also demonstrated increases in isometric quadriceps strength, hip abductor strength, and general hip strength, respectively.

4.3. Scapular Motor Control

Regarding scapular motor control, only the 10 Hz PNM frequency produced a reduction in upper trapezius electrical activity, whereas the 1 Hz frequency showed no such benefit. This reduction was accompanied by a moderate effect size, suggesting moderate clinical relevance. CrossFit and other overhead athletes often present pathological overactivation of the upper trapezius. Reducing this overactivation improves scapular mobility, which is primarily driven by the serratus anterior and lower trapezius, and is essential for proper shoulder function, especially in overhead movements⁽¹⁴⁾. A previous case study involving a professional athlete (although PNM was applied to the lower limb) also found improvements in muscle activation as measured by electromyography⁽⁵⁴⁾.

4.4. Cross-Education Effects of US-Guided PNM

In addition to analyzing improvements in the treated shoulder, this study also examined the effects of US-guided PNM on the non-treated shoulder. Our results show that, for both mobility and strength, cross-education effects occurred in specific variables. Joint mobility showed the most evident cross-education effects. Both the 10 Hz and 1 Hz groups improved on the

non-treated side in IR and total rotational range (ER + IR). However, ER showed no cross-education effect in either group. For strength variables, cross-education effects were less evident than for mobility. Only the 10 Hz group showed increased ER strength in the non-treated shoulder. No other strength variables demonstrated cross-education effects in either group, consistent with the previously mentioned study on healthy CrossFit athletes⁽⁵³⁾, which found that strength gains were limited to the treated limb. However, another study applying PNM to the sciatic nerve found significant increases in hip strength in both the treated and untreated limbs, with all strength variables (flexion, extension, abduction, ER, and IR) showing cross-education effects⁽³⁶⁾.

This discrepancy suggests the need for specific studies to analyze the cross-education effects of US-guided PNM on strength, similar to a prior research comparing the contralateral effects of various treatments, including PNM, on passive range of motion⁽³⁷⁾. That study showed that only PNM applied to the sciatic nerve produced cross-education effects, while other techniques (e.g., dry needling, neurodynamics, passive stretching) did not. These findings suggest that the mechanical effect of dry needling alone on the sciatic nerve was insufficient, as cross-education effects on joint mobility appeared only when electrical current was applied (i.e., US-guided PNM), which matches the cross-education effect on rotational mobility seen in the present study.

This cross-education on mobility may be due to bilateral joint restrictions that are more susceptible to global improvement, even without direct stimulation. In contrast, strength likely depends on specific neuromuscular activation in the treated side, and may require a stronger or higher-frequency stimulus to induce a contralateral effect.

4.5. Limitations and Future Research

Despite promising results, the study has certain limitations that should be considered: 1) Lack of a control group: The design included only two experimental groups without a no-treatment group. Including a control group would have allowed a better understanding of the actual effect of PNM. Nevertheless, PNM has been extensively studied and shown to be effective versus control groups in other contexts, so its absence here was not considered critical. Still, it would have improved statistical power and interpretation; 2) Short-term assessment only: The study evaluated all clinical variables only twice, before and immediately after the intervention. This design limits the ability to assess medium- and long-term effects of PNM, especially for functional variables that may require time to show changes. Some previous PNM studies have shown meaningful immediate effects^(38,55), as seen in this study, but extended follow-up would likely yield even more robust data. 3) Age difference between groups: Although baseline clinical variables were similar, the two groups differed significantly in age (32 vs. 38 years on average). However, no clinical variable showed baseline differences, and no differences were found when adjusting for the "age" variable. This suggests the age difference was likely insufficient to affect shoulder function outcomes.

To address the scientific gaps identified in this study, it is necessary to continue research on the effects of US-guided PNM in overhead athletes. Future studies should include no-treatment control groups or groups treated with non-invasive methods (e.g., exercise protocols and health

education). The combination of exercise and PNM could also be explored, not only to assess clinical function but also to evaluate sports performance outcomes. Finally, future research should include long-term follow-up with successive assessments to gather more evidence on the medium- and long-term effects of PNM.

5. Conclusions

This study confirms the presence of key risk factors in CrossFit athletes with nonspecific shoulder pain. Additionally, it demonstrates that applying US-guided PNM to the axillary and suprascapular nerves results in functional improvements in glenohumeral rotational mobility and strength, as well as scapular motor control.

These improvements depend on the stimulation frequency used. The 1 Hz frequency produced gains similar to those at 10 Hz only in shoulder mobility. For rotational strength, 10 Hz yielded greater benefits than 1 Hz. Regarding scapular motor control, only the 10 Hz group achieved significant changes.

These findings add to the existing evidence supporting US-guided PNM as a simple and effective clinical intervention to improve neuromuscular function in CrossFit athletes with nonspecific shoulder pain. However, they also highlight the need to tailor PNM parameters to each athlete's individual needs to maximize benefits.

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Ethics Committee

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Aragón Ethics Committee (No. 13/2025).

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Informed consent was obtained from all subjects involved in the study.

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The raw data on which the study results are based may be obtained upon request to the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

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