

Article

Electromyographic Characterization of Core Muscle Activation During Steel Club Exercises in Trained Males

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Abstract

Background: Steel club training is a form of strength and conditioning exercise that involves swinging weighted clubs through circular and pendular movements, thereby imposing substantial rotational and multiplanar demands on the trunk. However, the core muscle activation patterns elicited by these exercises remain poorly characterized.

Purpose: This study aimed to characterize global, muscle-specific, and side-to-side core muscle activation across a battery of steel club exercises and compare it with that of conventional plank variations. **Methods:** A within-subject experimental design was used in a single-session laboratory setting. Fourteen trained males ($n = 14$) performed ten steel club exercise conditions (comprising seven distinct movement patterns, with unilateral variations performed bilaterally) using 8 and 16 kg clubs and four isometric plank variations; data from $n = 13$ were available for the Shield Cast 16 kg condition and the omnibus ANOVA due to one excluded signal. Surface electromyography was bilaterally recorded from the rectus abdominis, external oblique, internal oblique, and multifidus muscles and normalized to maximal voluntary contraction (% MVC). Repeated-measures ANOVA was used to assess global and muscle-specific differences across exercise conditions, and paired-samples t-tests were used to evaluate side-to-side differences. **Results:** Global core activation significantly differed across exercises ($p < 0.001$, $\eta^2 = 0.798$) and was generally greater during steel club exercises than during conventional planks. The Lateral Pendulum to Shoulder Cast ($54.77 \pm 9.32\%$ MVC), Gamma Cast ($47.79 \pm 8.96\%$ MVC), and Shield Cast ($43.96 \pm 11.25\%$ MVC), all performed with 16 kg, elicited greater global activation than each of the four plank variations (all adjusted $p < 0.05$). The internal oblique showed the greatest activation across most steel club exercises, reaching $69.40 \pm 12.18\%$ MVC during the Lateral Pendulum to Shoulder Cast. Several unilateral exercises also elicited significant side-to-side differences, particularly Mills and Reverse Mills (all $p < 0.05$). **Conclusions:** Among experienced steel club practitioners, these exercises elicited exercise-specific, dynamic, and multiplanar core activation patterns, with several exercises—particularly those performed with 16 kg—producing greater global activation than conventional plank variations. These findings support steel club training as a complementary modality for dynamic core training, although the independent contributions of movement pattern and external load, as well as long-term adaptations, remain to be established.

Keywords: steel club; clubbell; Indian club; electromyography; core training; trunk muscles; resistance training; biomechanics



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1. Introduction

The core, understood as the lumbopelvic–hip complex and its surrounding musculature, functions as the mechanical link through which forces are generated, stabilized, and transmitted between the upper and lower extremities during human movement [1]. Rather than acting as a single unit, the trunk musculature operates as an integrated system in which superficial global muscles and deep local stabilizers are recruited in a task-dependent manner to control spinal posture and resist multidirectional perturbations [2,3]. Efficient core function underpins the performance of ballistic and rotational sporting actions such as throwing, striking, sprinting, and rapid changes in direction, whereas impaired trunk control has been associated with diminished performance and an elevated risk of low back and musculoskeletal disorders [1]. Within this system, the rectus abdominis, external oblique, internal oblique, and multifidus contribute to distinct mechanical roles ranging from sagittal-plane flexion to rotational and anti-rotational control and segmental spinal stabilization and were therefore selected as the muscles of interest in the present investigation.

Among the strategies used to train the core, isometric plank exercises remain among the most widely prescribed, owing to their simplicity, accessibility, and capacity to recruit both superficial and deep trunk musculature [4–6]. Their demand is nonetheless largely anti-extensor and quasi-static: the trunk resists gravity from a fixed position while the direction of the external load changes little throughout the task. Athletic movement, by contrast, requires the trunk to continuously stabilize while external loads are accelerated, decelerated, and redirected across multiple planes. This mismatch has prompted growing interest in dynamic, multiplanar loading strategies, and evidence that even modest mechanical modifications—such as lengthening the lever arm of a standard plank—can substantially increase trunk muscle activation illustrates how sensitive core demand is to the external mechanical configuration of an exercise [7,8].

Steel clubs (also referred to as clubbells), derived from traditional wooden Indian clubs [9,10], have re-emerged within contemporary strength and conditioning practice as a modality specifically oriented toward rotational and multiplanar loading. Their defining mechanical feature is a mass displaced well beyond the grip, creating a long lever arm that generates continuously varying rotational moments as the implement is swung along circular and pendular trajectories. Controlling these moments requires coordinated recruitment of both local stabilizing and global force-producing musculature throughout the kinetic chain, a demand that qualitatively differs from that of axially loaded resistance exercises. Preliminary work has reported favorable effects of club-based training on shoulder range of motion and rotator-cuff strength in overhead athletes, including cricket fast bowlers [9] and handball players [10]; however, these studies have addressed shoulder kinematics and performance outcomes rather than the trunk neuromuscular mechanisms that might underlie them, leaving the core activation demands of steel club exercises essentially uncharacterized. Although the peer-reviewed literature on steel club training remains scarce, previous studies have primarily focused on shoulder kinematics, mobility, strength, and functional outcomes. Evidence from a mechanically comparable long-lever, offset-loaded implement is similarly scarce: a recent randomized controlled trial reported that a 12-week mace training program improved grip strength, shoulder mobility, and upper-extremity stability in elite wrestlers [11], although that study likewise did not examine trunk or core muscle activation. This scarcity of evidence further underscores the novelty of the present investigation.

Surface electromyography (sEMG) is a valid and widely used method for quantifying muscle activation and characterizing recruitment strategies during exercise, and it has been extensively applied to conventional stability and rehabilitation tasks, including advanced

approaches to motor control assessment [4,12,13], as well as comparisons of trunk activation across implements and unstable surfaces [8,14,15]. To the authors' knowledge, no study has systematically quantified core muscle activation during steel club exercises or compared it directly with that of conventional plank variations. This represents a notable gap given the increasing adoption of steel clubs in athletic conditioning, and its resolution would clarify whether—and how—this modality complements established core-training approaches.

Accordingly, the aim of this study was to characterize the electromyographic activation of the rectus abdominis, external oblique, internal oblique, and multifidus during a battery of unilateral and bilateral steel club exercises and to compare these responses with those elicited by four conventional plank variations. It was hypothesized that steel club exercises would elicit greater global core activation than traditional isometric planks and—more specifically—that their rotational mechanical demands would preferentially recruit the oblique musculature relative to the rectus abdominis.

2. Materials and Methods

2.1. Participants

Fourteen healthy male adults with previous experience in functional steel club training voluntarily participated in this study. The sample was restricted to male participants to increase sample homogeneity and minimize potential sex-related variability in the electromyographic responses. A dedicated study in female steel club practitioners is planned to specifically characterize these responses in women. Fixed absolute external loads (8 and 16 kg) were used for all participants rather than loads scaled to body mass or individual strength capacity. Participants were 30.79 ± 4.15 years old, with a body mass of 78.02 ± 9.19 kg, a height of 179.71 ± 7.02 cm, and a body mass index of 24.14 ± 2.14 kg/m². All participants were right-hand dominant, except for one who was left-hand dominant. This participant was among the most experienced practitioners in the sample and showed a side-to-side activation pattern consistent with the right-handed majority. They had 26.57 ± 30.08 months of specific steel club training experience, practicing approximately three hours per week. Additional anthropometric, body composition, and training characteristics are presented in Table 1. To standardize testing conditions and minimize the influence of residual fatigue, participants were instructed to refrain from strenuous physical activity for at least 48 h before the experimental session.

Table 1. Anthropometric, body composition, and training characteristics of the participants ($n = 14$).

Variables	Mean $\pm$ SD	Min	Max
Body Mass (kg)	78.02 $\pm$ 9.19	69.00	100.50
Height (cm)	179.71 $\pm$ 7.02	170.00	198.00
Body Mass Index (kg/m ²)	24.14 $\pm$ 2.14	20.83	27.14
Age (years)	30.79 $\pm$ 4.15	24.00	39.00
Body Fat (%)	9.96 $\pm$ 3.05	5.80	16.20
Fat Mass (kg)	8.09 $\pm$ 3.04	4.44	14.56
Muscle Mass (kg)	66.65 $\pm$ 6.79	59.35	86.15
Basal Metabolic Rate (kcal·day ^{−1})	2034.71 $\pm$ 230.98	1787.00	2696.00
Fat-Free Mass (kg)	70.12 $\pm$ 7.13	62.44	90.55
Steel Club Training Experience (months)	26.57 $\pm$ 30.08	12.00	96.00

Inclusion criteria required participants to be between 18 and 40 years of age, to have at least one year of steel club training experience with a minimum training frequency of two sessions per week, and to be free of any current musculoskeletal injury or diagnosed disease that could compromise safe participation. Participants were excluded if they reported a

recent or unresolved injury, a diagnosed medical condition, or any other contraindication to isometric or dynamic resistance exercise.

One participant had missing sEMG data for the Shield Cast 16 kg condition due to electrode detachment during the trial, which produced physiologically abnormal signal values that were excluded from analysis; consequently, statistical analyses for this exercise were performed with $n = 13$.

2.2. Experimental Design

A within-subject experimental design was used to characterize core muscle activation during steel club exercises and to compare these responses with conventional isometric core exercises. Each participant performed all steel club and plank conditions, allowing direct within-participant comparisons of electromyographic activity. Four conventional plank variations were included as reference exercises because they are widely used for core training [4,5] and provide a standardized isometric stimulus against which the dynamic, rotational, and multiplanar demands of steel club exercises could be compared [8]. Muscle activation was bilaterally assessed in the rectus abdominis, external oblique, internal oblique, and multifidus and expressed as a percentage of the maximal voluntary contraction (% MVC) obtained for each muscle during standardized isometric testing. The primary outcome was global core activation across exercise conditions, defined as the mean activation across the eight recorded muscle sites (bilateral rectus abdominis, external oblique, internal oblique, and multifidus). Muscle-specific activation was calculated as the mean of the right- and left-side values for each muscle, whereas side-specific global activation was calculated as the mean activation of the four recorded muscles within each side of the trunk. Muscle-specific activation and side-to-side activation differences were considered secondary outcomes.

2.3. Experimental Protocol

All measurements were completed during a single laboratory visit. Upon arrival at the laboratory, participants underwent anthropometric and body composition assessment using bioelectrical impedance analysis (Tanita RD-953, Tanita Corporation, Tokyo, Japan). They then performed a standardized warm-up, followed by skin preparation and surface electromyography (sEMG) electrode placement. Muscle-specific maximal voluntary contractions (MVCs) were subsequently recorded for signal normalization. Participants then completed the 14 exercise conditions (steel club and plank exercises) in an individually randomized order, with a minimum recovery period of 3 min between conditions; before proceeding to the next exercise, participants verbally confirmed that they felt fully recovered.

2.4. Warm-Up and Testing Conditions

Testing was conducted under controlled laboratory conditions in the Biomechanics Laboratory of the Department of Sports Science at Universidad Francisco de Vitoria (Madrid, Spain). The warm-up was based on the RAMP protocol (Raise, Activate, Mobilize, and Potentiate) and included 10 min of cardiovascular activation, approximately 5 min of general mobility exercises, three 30 s sets of front, side, and back planks for core activation, and a familiarization phase consisting of five repetitions of each steel club exercise performed with reduced loads at a cadence of $55 \text{ beats} \cdot \text{min}^{-1}$, controlled by a metronome.

All testing sessions were performed at the same time of day and under standardized environmental conditions ($20.18 \pm 0.37^\circ\text{C}$ and $34.12 \pm 1.46\%$ relative humidity) to minimize environmental and circadian variability.

2.5. Electromyography

2.5.1. Electrode Placement

sEMG activity was recorded using an eight-channel Delsys Trigno™ Wireless Surface Electromyography System (Delsys Inc., Boston, MA, USA) with a sampling frequency of 2000 Hz, bilaterally from the rectus abdominis, external oblique, internal oblique, and multifidus muscles. Before electrode placement, the skin was shaved when necessary, lightly abraded, and cleaned with alcohol to reduce impedance. Electrode placement followed established surface electromyography recommendations [12,16] and the SENIAM online sensor-location resource [17] (Figure 1a,b).

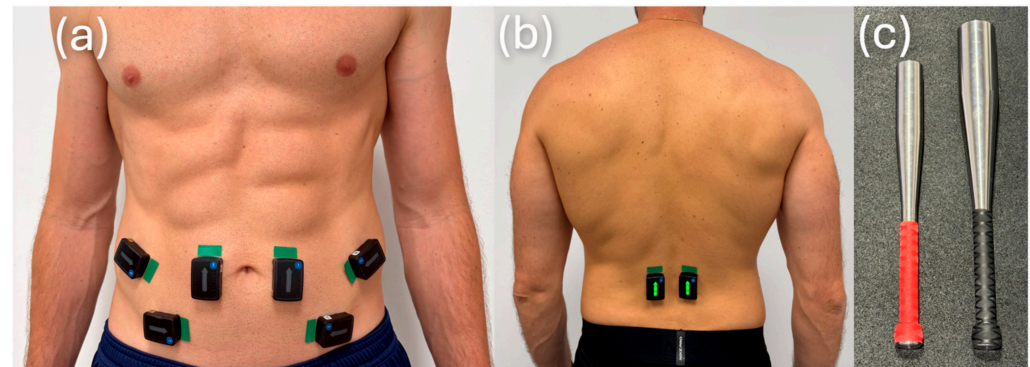


Figure 1. Experimental setup: (a) Anterior view showing the placement of surface electromyography (sEMG) electrodes over the rectus abdominis, external oblique, and internal oblique muscles. (b) Posterior view showing electrode placement over the multifidus muscles. (c) Steel clubs used during the experimental protocol (8 kg and 16 kg).

- Rectus abdominis: 3 cm lateral to the umbilicus.
- External oblique: 15 cm lateral to the umbilicus.
- Internal oblique: midway between the anterior superior iliac spine and the symphysis pubis, immediately above the inguinal ligament.
- Multifidus: along the line connecting the posterior superior iliac spine and the L1–L2 interspace, approximately 2–3 cm lateral to the midline at the level of L5.

2.5.2. Maximal Voluntary Contractions (MVCs)

sEMG signals were normalized using standardized maximal voluntary contractions (MVCs) performed under isometric conditions (Figure 2). Rectus abdominis MVC was assessed in a supine position with the hips and knees flexed to 90°, the lower limbs secured to the bench, and maximal trunk flexion performed against a fixed multipower bar for 8 s (Figure 2a). External oblique MVC was evaluated in a side-lying position with the hips flexed to 90°, while maximal lateral trunk flexion was performed against a fixed multipower bar for 8 s (Figure 2b). This procedure was selected based on previously described and evaluated normalization techniques for the external oblique using resisted lateral trunk flexion in a side-lying position [18,19]. Multifidus MVC was obtained in a prone position with the hips supported at the edge of the bench and the trunk unsupported, performing maximal trunk extension against a fixed multipower bar for 8 s (Figure 2c). Internal oblique MVC was assessed using a resisted forearm side-plank (lower-trunk bending) procedure, with resistance applied at the pelvic/gluteal region against a fixed multipower bar for 8 s [19] (Figure 2d).

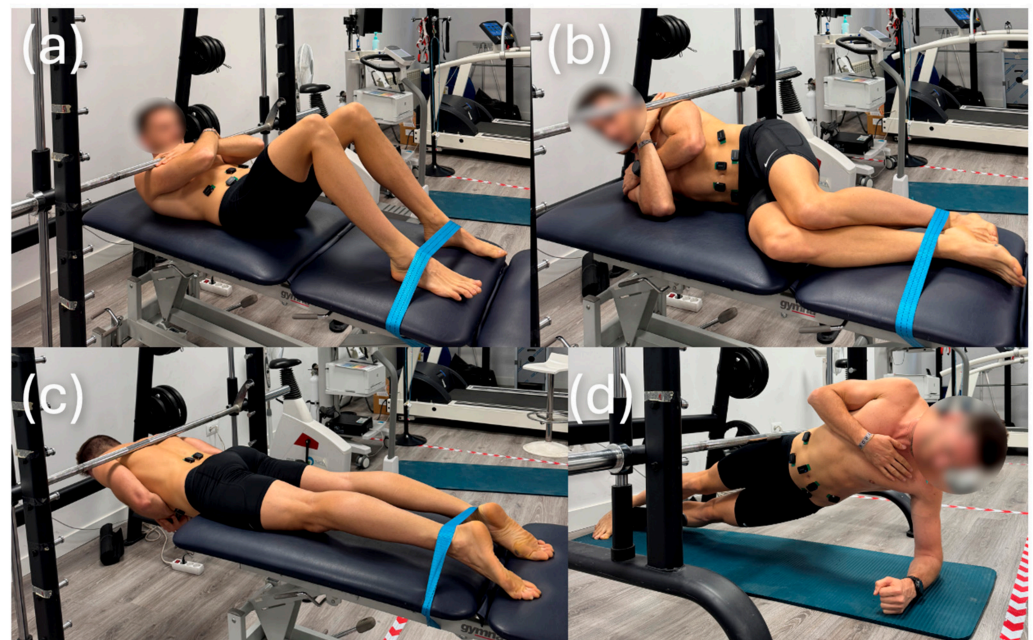


Figure 2. Maximal voluntary contraction (MVC) testing procedures used for sEMG signal normalization: (a) rectus abdominis; (b) external oblique; (c) multifidus; and (d) internal oblique.

Each participant performed two MVC trials, with at least 120 s of rest between attempts. If the difference between attempts exceeded 5%, a third trial was performed. For normalization, MVC signals were processed using the same 50 ms RMS procedure applied to the exercise trials, and the highest RMS value obtained across trials was retained for each muscle. Strong verbal encouragement was provided throughout each trial to ensure maximal effort.

2.5.3. Signal Processing and Data Analysis

Raw sEMG signals were processed using a standardized pipeline. Signals were first mean-centered and subsequently band-pass filtered between 20 and 450 Hz using an 801-tap finite impulse response (FIR) filter with a Hamming window. A 50 Hz notch filter based on an infinite impulse response design ($r = 0.99$) was then applied to attenuate power-line interference. The filtered signals were full-wave rectified and smoothed by calculating the root mean square (RMS) using a 50 ms moving window with 50% overlap (25 ms step).

Processed sEMG amplitudes were normalized to the highest maximal voluntary contraction (MVC) obtained for each muscle and expressed as a percentage of MVC (% MVC). For each dynamic steel club exercise, the peak RMS value was identified within each of the five repetitions, yielding five peak values per muscle per exercise; these five peaks were averaged to obtain the representative activation value for that exercise. For each isometric plank exercise (Figure 3), the peak (highest) RMS value recorded during the 15 s trial was used as the representative activation value (Figure 4). The peak, rather than the mean, RMS value was selected as the representative measure of activation because the two exercise categories fundamentally differ in their contraction profile: the plank imposes a sustained, continuous contraction, whereas the steel club exercises are inherently ballistic, with the functionally relevant neuromuscular demand concentrated into brief, recurring peaks of activation rather than distributed evenly across the movement. Averaging the signal under these ballistic conditions would dilute these peaks with the lower-amplitude phases between them, which would reduce the sensitivity of the analysis to the brief high-activation phases characteristic of these ballistic movements. This approach is consistent

with established practice in core and abdominal electromyography, where peak activation has been used as the primary index of muscular challenge [20].

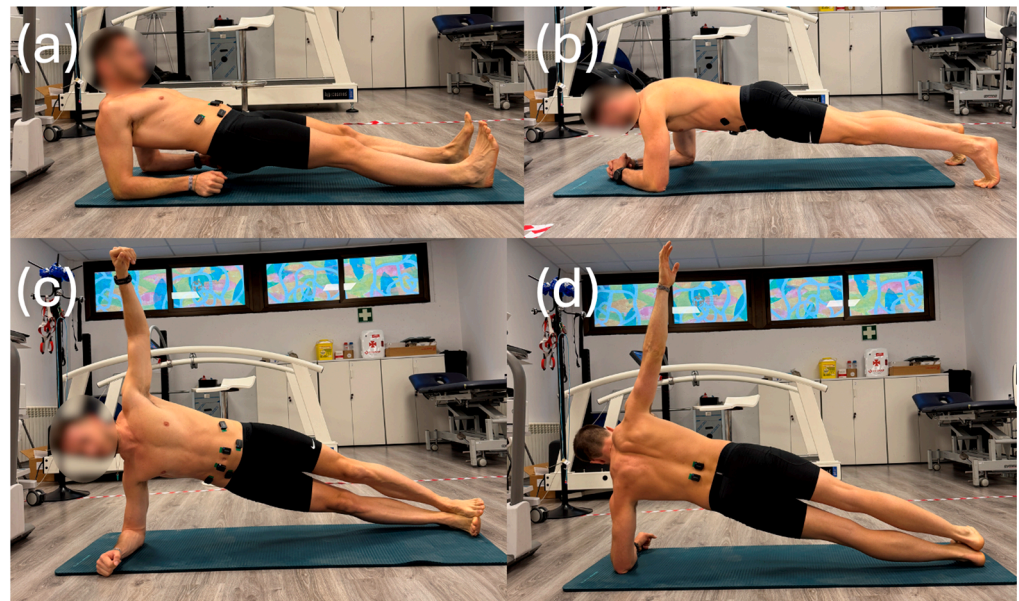


Figure 3. Conventional plank exercises performed during the experimental protocol: (a) Back Plank; (b) Front Plank; (c) Right Side Plank; and (d) Left Side Plank.

2.6. Steel Club and Plank Exercise Battery

Participants performed five consecutive repetitions of each steel club exercise, without interruption, at a standardized cadence of $55 \text{ beats} \cdot \text{min}^{-1}$ controlled by a metronome, and one 15 s isometric trial of each plank exercise; because the plank exercises were sustained isometric contractions, they were not performed to the metronome cadence. All fourteen exercise conditions were executed in an individually randomized order for each participant. A recovery period of 3 min was provided between exercise conditions; before proceeding to the next exercise, participants verbally confirmed that they felt fully recovered, and the rest period was extended whenever necessary.

The steel club exercise battery (Figure 5), performed using 8 kg and 16 kg implements (Clubbell World®, PRO model, Madrid, Spain; Figure 1c), included Shoulder Cast (8 kg, right and left arm; Figure 5a), Front Pendulum Double (8 kg; Figure 5b), Gamma Cast (16 kg; Figure 5c), Lateral Pendulum to Shoulder Cast (16 kg; Figure 5d), Mills (8 kg, right and left arm; Figure 5e), Reverse Mills (8 kg, right and left arm; Figure 5f), and Shield Cast (16 kg; Figure 5g). For all bilateral exercises performed using a single steel club, the right hand was consistently positioned on the lower grip to standardize exercise execution across participants. Load allocation followed a consistent criterion based on the number of hands controlling each implement: exercises performed with a single club gripped bilaterally, with both hands sharing control of the implement, used the 16 kg club, whereas exercises unilaterally performed with one arm, or bilaterally with one 8 kg club in each hand, used the 8 kg load per implement.

The isometric exercise battery (Figure 3) consisted of Back Plank (a), Front Plank (b), Right Side Plank (c) and Left Side Plank (d).

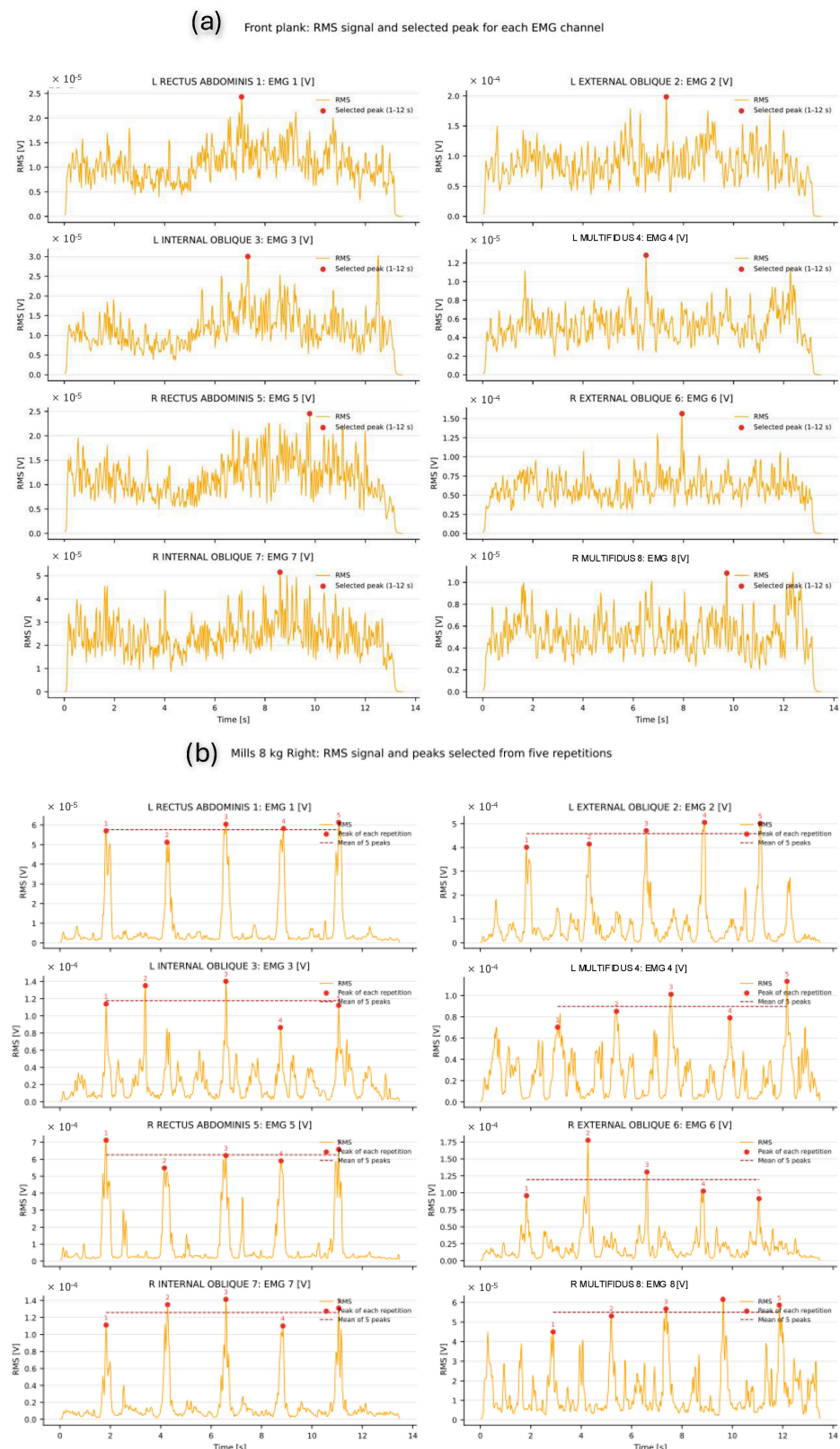


Figure 4. Representative root mean square (RMS) surface electromyographic signal and peak selection procedure: (a) Front Plank: RMS signal for each of the eight recorded channels during the 15 s isometric trial, with the selected peak (highest RMS value within the analysis window) marked for each channel. (b) Mills 8 kg Right: RMS signal across the five consecutive repetitions for each of the eight recorded channels, with the peak of each repetition identified (numbered 1–5) and the mean of the five peaks (dashed line) used as the representative activation value for that exercise. L = left; R = right.

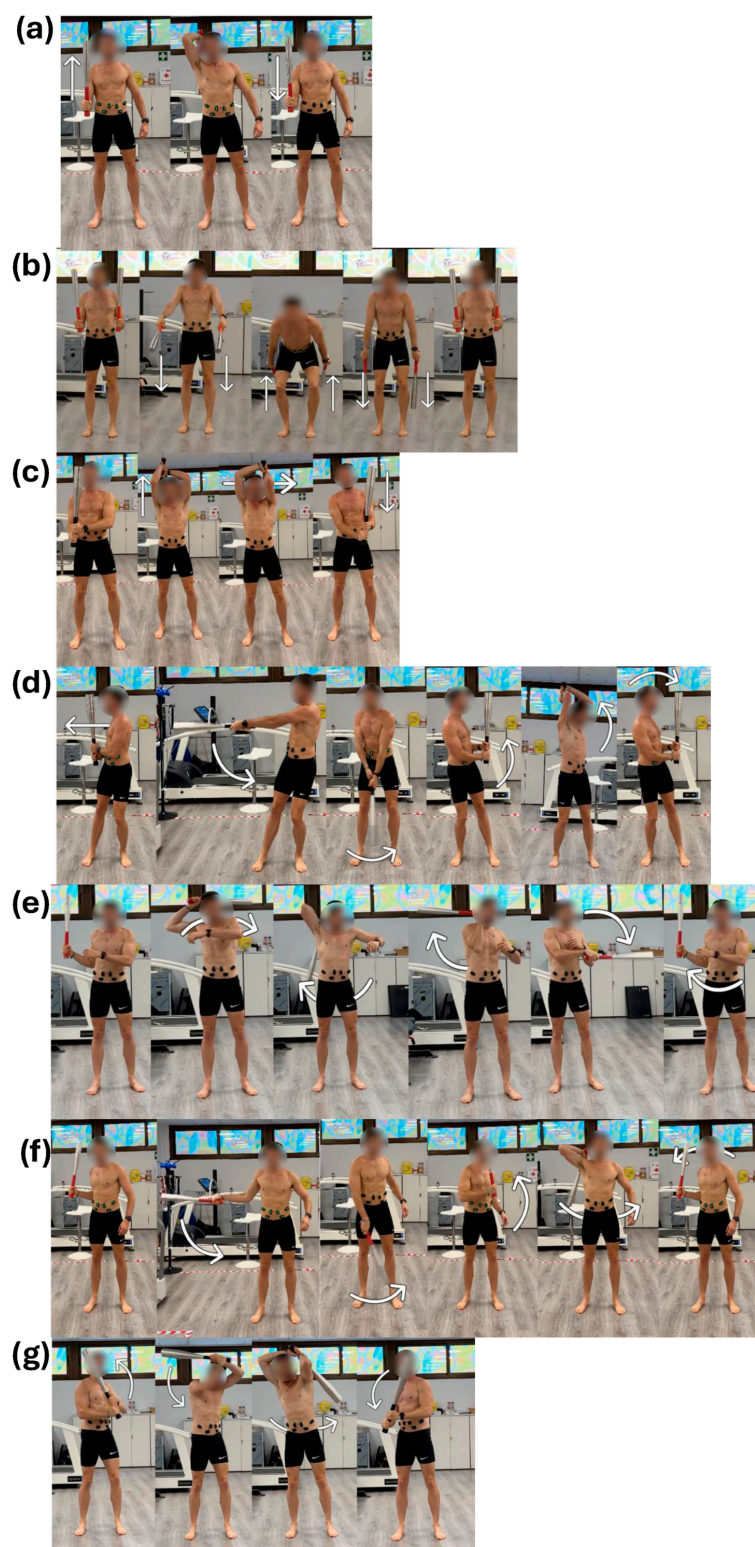


Figure 5. Steel club exercises included in the experimental protocol. Representative images illustrating the execution of the steel club exercises evaluated in this study: (a) Shoulder Cast; (b) Front Pendulum Double; (c) Gamma Cast; (d) Lateral Pendulum to Shoulder Cast; (e) Mills; (f) Reverse Mills; and (g) Shield Cast. White arrows indicate the primary direction of movement throughout each exercise. Unilateral exercises (Shoulder Cast, Mills, and Reverse Mills) were performed with both the right and left arms. Front Pendulum Double was bilaterally performed using one 8 kg club in each hand, whereas the Gamma Cast, Lateral Pendulum to Shoulder Cast, and Shield Cast were performed with both hands controlling a single 16 kg club.

2.7. Statistical Analysis

Descriptive statistics are presented as mean $\pm$ standard deviation (SD).

A priori sample size estimation was performed using G*Power (version 3.1; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany), based on effect size data obtained from a previous pilot study ($n = 10$) assessing core muscle activation during steel club exercises. The pilot data yielded an estimated effect size of $f = 0.25$ (medium, Cohen's convention). Assuming a correlation of 0.50 among repeated measures across the 14 exercise conditions and a significance level of $\alpha = 0.05$, a minimum of 12 participants was required to achieve 80% statistical power. To account for potential participant withdrawal or data loss during testing, the sample was expanded to 14 participants.

Prior to inferential analyses, the assumption of normality was assessed using the Shapiro–Wilk test applied to the paired differences for each pairwise comparison. For repeated-measures analyses, the assumption of sphericity was evaluated using Mauchly's test; sphericity was violated for the omnibus comparison of global core activation across the 14 exercise conditions (Mauchly's $W = 0.00$, $\chi^2 = 343.52$, $df = 90$, $p < 0.001$, $\epsilon = 0.320$), and Greenhouse–Geisser-corrected degrees of freedom were applied accordingly. Sphericity was separately evaluated for each muscle-group ANOVA and corrected in the same manner whenever violated.

Differences in global core activation among the 14 exercise conditions were examined using a one-way repeated-measures analysis of variance (ANOVA) with Greenhouse–Geisser correction applied due to the violation of sphericity, followed by Bonferroni-adjusted pairwise comparisons when appropriate. Because one participant lacked data for the Shield Cast 16 kg condition, this omnibus ANOVA was conducted using listwise deletion ($n = 13$); descriptive statistics for each exercise condition are based on all available data ($n = 14$, except Shield Cast 16 kg, $n = 13$). As a sensitivity analysis, a linear mixed-effects model with exercise condition as a fixed effect and participant as a random effect was fitted using all 195 available observations from the 14 participants. The effect of exercise condition remained significant ($p < 0.001$), confirming the robustness of the primary omnibus finding. Side-to-side differences in global muscle activation were independently assessed within each exercise using paired-samples *t*-tests. Each test addressed a separate within-exercise comparison of left- versus right-side activation, corresponding to a distinct biomechanical question rather than a common omnibus hypothesis across the exercise battery; accordingly, no across-exercise multiplicity adjustment was applied. Differences among the four muscle groups (rectus abdominis, external oblique, internal oblique, and multifidus) were separately examined for each exercise using one-way repeated-measures ANOVA, with Greenhouse–Geisser correction applied where sphericity was violated, followed by Bonferroni-adjusted pairwise comparisons.

For all ANOVA-derived pairwise comparisons, mean differences, 95% confidence intervals (95% CI), Bonferroni-adjusted *p* values, and Cohen's *d*z effect sizes were calculated. Cohen's *d*z values were interpreted according to Cohen's recommendations [21] as trivial (<0.20), small (0.20–0.49), medium (0.50–0.79), and large (≥ 0.80). Partial eta squared (η^2) was reported as the measure of effect size for repeated-measures ANOVA. η^2 values of approximately 0.01, 0.06, and 0.14 were interpreted as small, moderate, and large, respectively [21].

Statistical significance was set at $p < 0.05$. All statistical analyses were performed using IBM SPSS Statistics (Version 32.0; IBM Corp., Armonk, NY, USA), and descriptive summaries and graphical outputs were prepared using Microsoft Excel for Microsoft 365 (Version 16.111.2; Microsoft Corporation, Redmond, WA, USA).

2.8. Ethical Considerations

This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Universidad Francisco de Vitoria (protocol code 34/2025; 17 June 2025). All participants provided written informed consent before participation.

3. Results

3.1. Global Core Activation

Mean global core activation, calculated as the average activation of the eight recorded muscle sites, varied across the evaluated exercises (Figure 6). Among the plank variations, mean activation values were relatively homogeneous, ranging from $13.36 \pm 3.23\%$ MVC during the Left Side Plank to $16.76 \pm 8.02\%$ MVC during the Back Plank. The Front Plank and Right Side Plank showed intermediate values of $14.65 \pm 6.08\%$ MVC and $14.89 \pm 3.11\%$ MVC, respectively.

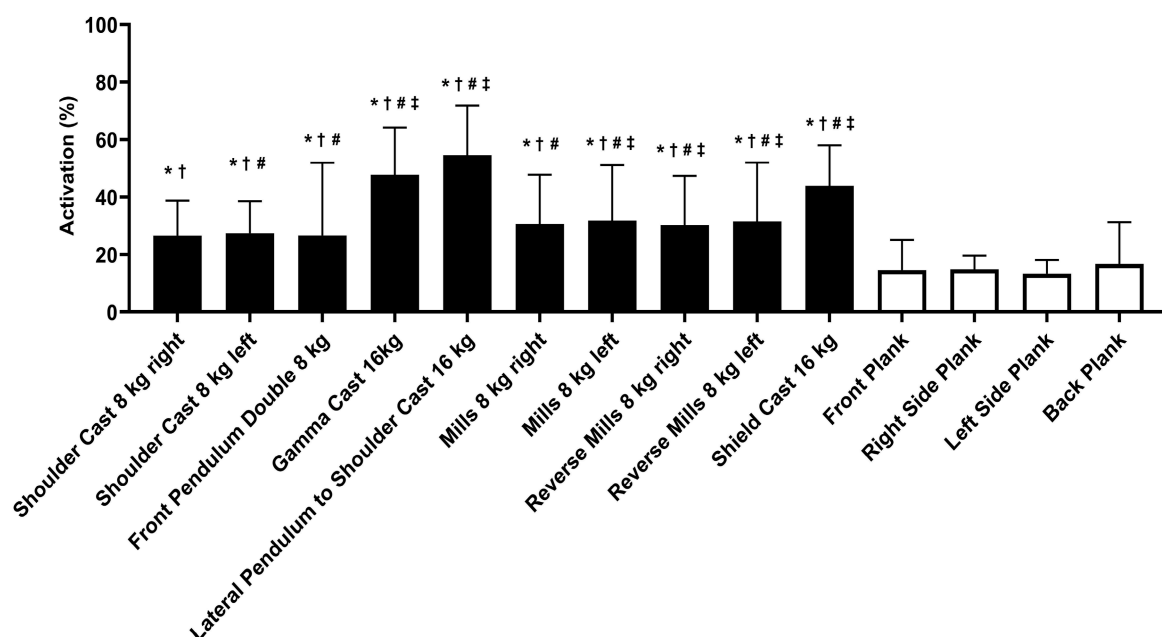


Figure 6. Global core muscle activation during steel club exercises and conventional plank variations. Mean global electromyographic activation expressed as a percentage of maximal voluntary contraction (% MVC) for each exercise. Global activation was calculated as the average normalized activity of the bilateral rectus abdominis, external oblique, internal oblique, and multifidus muscles. Values are presented as mean $\pm$ SD. Steel club exercises are shown in dark gray and plank variations in white. * = significant differences compared to Front Plank; # = significant differences compared to Right Side Plank; † = significant differences compared to Left Side Plank; ‡ = significant differences compared to Back Plank.

Mean activation values recorded during all steel club exercises were higher than those observed during the plank variations. The lowest mean activation values were recorded during the Shoulder Cast 8 kg Right ($26.61 \pm 9.08\%$ MVC), the Front Pendulum Double 8 kg ($26.71 \pm 7.12\%$ MVC), and the Shoulder Cast 8 kg Left ($27.50 \pm 8.00\%$ MVC). Intermediate values were recorded during the Mills 8 kg Right ($30.73 \pm 9.52\%$ MVC) and Mills 8 kg Left ($31.82 \pm 9.44\%$ MVC). Higher activation was observed during the Shield Cast 16 kg ($43.96 \pm 11.25\%$ MVC), whereas the highest mean activation values were recorded during the Gamma Cast 16 kg ($47.79 \pm 8.96\%$ MVC) and the Lateral Pendulum to Shoulder Cast 16 kg ($54.77 \pm 9.32\%$ MVC).

A one-way repeated-measures ANOVA revealed a significant main effect of exercise condition on global core activation, $F(4.16, 49.89) = 47.475$, $p < 0.001$, $\eta^2 = 0.798$ (Greenhouse–Geisser-corrected; Mauchly’s test indicated a violation of sphericity, $\epsilon = 0.320$).

Because the omnibus model used listwise deletion, pairwise mean differences are based on the 13 complete cases and may differ slightly from differences calculated from the descriptive means based on all available participants.

Bonferroni-adjusted pairwise comparisons showed that the Gamma Cast 16 kg, Lateral Pendulum to Shoulder Cast 16 kg, and Shield Cast 16 kg exercises elicited significantly greater global core activation than all four plank variations (all adjusted $p < 0.05$). The largest mean difference was observed between the Lateral Pendulum to Shoulder Cast 16 kg and the Front Plank (42.04% MVC, 95% CI, 37.01 to 47.07, Cohen’s $d_z = 5.05$, adjusted $p < 0.001$), whereas the smallest significant difference was observed between the Shoulder Cast 8 kg Right and the Left Side Plank (12.67% MVC, 95% CI, 6.70 to 18.64, Cohen’s $d_z = 1.28$, adjusted $p = 0.024$).

Among the 8 kg steel club exercises, significant differences relative to the plank conditions were observed for the Shoulder Cast 8 kg Left (except versus the Back Plank), Front Pendulum Double 8 kg (except versus the Back Plank), Mills 8 kg Left, Reverse Mills 8 kg Right, and Reverse Mills 8 kg Left, the last three significantly differing from all four plank variations. Shoulder Cast 8 kg Right significantly differed from the Front and Left Side Planks but not from the Right Side or Back Plank. Likewise, Mills 8 kg Right showed significantly greater activation than the Front, Right Side, and Left Side Planks, whereas the comparison with the Back Plank was not significant after Bonferroni adjustment.

3.2. Side-to-Side Activation

Figure 7 illustrates the side-to-side differences in global core activation across the evaluated exercises. Significant side-to-side differences were observed during the Right Side Plank, with substantially greater activation on the right side ($23.23 \pm 6.27\%$ MVC) than on the left side ($6.54 \pm 2.86\%$ MVC; mean difference = -16.69% MVC; 95% CI, -21.02 to -12.36 ; $p < 0.001$; Cohen’s $d_z = 2.225$). Conversely, the Left Side Plank elicited greater activation on the left side ($20.55 \pm 7.18\%$ MVC) than on the right side ($6.17 \pm 2.96\%$ MVC; mean difference = 14.38% MVC; 95% CI, 9.25 to 19.50 ; $p < 0.001$; Cohen’s $d_z = 1.620$).

Among the unilateral steel club exercises, significant side-to-side differences were observed during Shoulder Cast 8 kg Left, Mills 8 kg Right, Mills 8 kg Left, Reverse Mills 8 kg Right, and Reverse Mills 8 kg Left. Mills performed with the left arm produced the largest side-to-side difference, with higher activation on the right side ($38.70 \pm 11.24\%$ MVC) than on the left side ($24.94 \pm 9.54\%$ MVC; mean difference = -13.76% MVC; 95% CI, -18.86 to -8.66 ; $p < 0.001$; Cohen’s $d_z = 1.558$). Similarly, Reverse Mills 8 kg Left resulted in greater activation on the right side ($35.72 \pm 8.06\%$ MVC) than on the left side ($27.40 \pm 10.00\%$ MVC; mean difference = -8.32% MVC; 95% CI, -13.43 to -3.21 ; $p = 0.004$; Cohen’s $d_z = 0.940$), whereas Mills 8 kg Right elicited greater activation on the left side ($35.16 \pm 11.75\%$ MVC) than on the right side ($26.29 \pm 10.80\%$ MVC; mean difference = 8.87% MVC; 95% CI, 1.88 to 15.86 ; $p = 0.017$; Cohen’s $d_z = 0.733$). Shoulder Cast 8 kg Left and Reverse Mills 8 kg Right also showed significant side-to-side differences, although with smaller effect sizes (both $d_z \approx 0.7$).

No significant side-to-side differences were observed during the Front Plank ($p = 0.071$), Back Plank ($p = 0.199$), Shoulder Cast 8 kg Right ($p = 0.110$), Front Pendulum Double 8 kg ($p = 0.561$), Gamma Cast 16 kg ($p = 0.266$), Lateral Pendulum to Shoulder Cast 16 kg ($p = 0.555$), or Shield Cast 16 kg ($p > 0.05$).

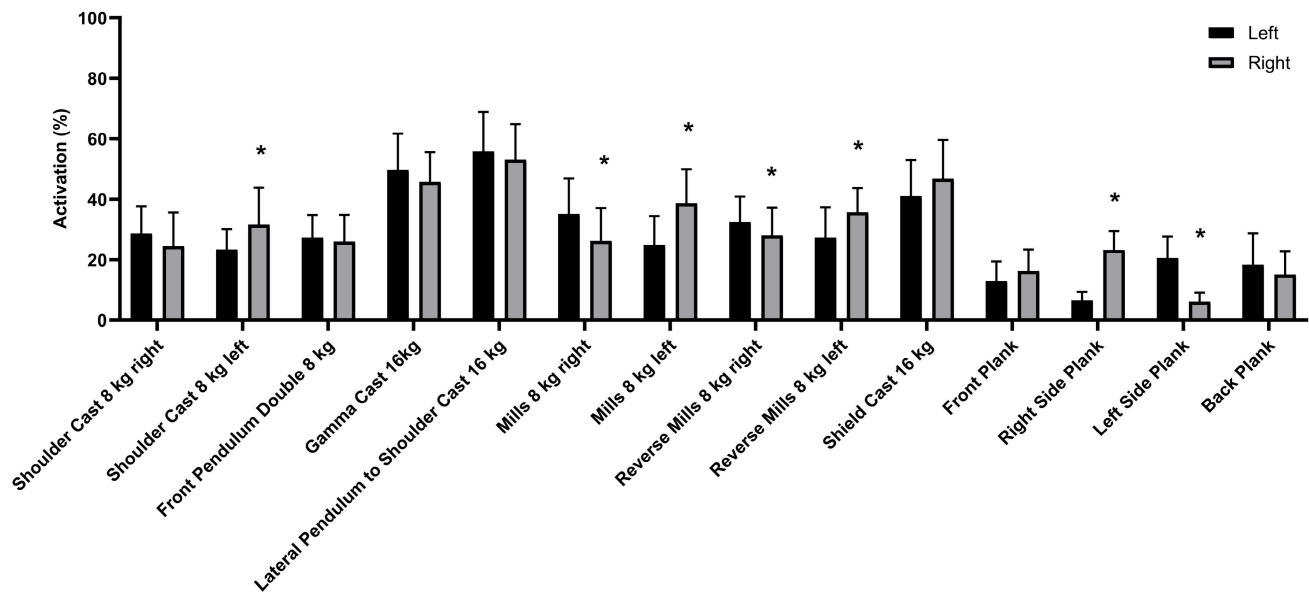


Figure 7. Side-to-side global core muscle activation during steel club exercises and conventional plank variations. Mean global electromyographic activation expressed as a percentage of maximal voluntary contraction (% MVC) for the left and right sides during each exercise. Global activation was calculated as the average normalized activity of the rectus abdominis, external oblique, internal oblique, and multifidus recorded on each body side. Values are presented as mean $\pm$ SD. Black bars represent the left side, and gray bars represent the right side. % MVC = percentage of maximal voluntary contraction. * = significant side-to-side difference within the exercise.

3.3. Mean Activation per Muscle Group

When bilateral muscles were averaged, different activation profiles were observed across the evaluated exercises (Figure 8). The rectus abdominis generally showed the lowest activation values, reaching its highest levels during the Gamma Cast 16 kg ($43.84 \pm 20.36\%$ MVC) and the Lateral Pendulum to Shoulder Cast 16 kg ($43.67 \pm 13.79\%$ MVC). The external oblique exhibited its highest activation during the Lateral Pendulum to Shoulder Cast 16 kg ($53.91 \pm 16.72\%$ MVC), followed by the Gamma Cast 16 kg ($48.93 \pm 16.71\%$ MVC). The internal oblique exhibited the highest mean activation values across most steel club exercises, reaching $69.40 \pm 12.18\%$ MVC during the Lateral Pendulum to Shoulder Cast 16 kg and $61.42 \pm 14.79\%$ MVC during the Gamma Cast 16 kg. In contrast, the multifidus exhibited a distinct activation profile, with the highest values observed during the Lateral Pendulum to Shoulder Cast 16 kg ($51.19 \pm 11.52\%$ MVC) and the Front Pendulum Double 8 kg ($43.29 \pm 14.79\%$ MVC).

Repeated-measures ANOVA independently performed for each exercise showed significant differences among the four muscle groups in all steel club exercises and in the Front Plank, Left Side Plank, and Back Plank conditions (all $p \leq 0.033$; $\eta^2 = 0.218$ – 0.626). Where Mauchly's test indicated a violation of sphericity, Greenhouse–Geisser-corrected degrees of freedom were applied (Front Plank, $F(1.91, 24.81) = 6.218$, $p = 0.007$; Back Plank, $F(1.78, 23.14) = 10.130$, $p < 0.001$; Shoulder Cast 8 kg Left, $F(1.71, 22.26) = 4.207$, $p = 0.033$). The only condition without significant between-muscle differences was the Right Side Plank, $F(3, 39) = 2.500$, $p = 0.074$, $\eta^2 = 0.161$.

The largest muscle-group effect was observed during the Front Pendulum Double 8 kg, $F(3, 39) = 21.736$, $p < 0.001$, $\eta^2 = 0.626$. Bonferroni-adjusted comparisons showed that the internal oblique and multifidus were significantly more activated than both the rectus abdominis and external oblique. The multifidus exceeded the rectus abdominis by 28.47% MVC (95% CI, 18.38 to 38.57; Cohen's $d_z = 1.629$) and the external oblique by 31.68% MVC (95% CI, 22.12 to 41.25; Cohen's $d_z = 1.912$). The internal oblique exceeded the rectus

abdominis by 22.31% MVC (95% CI, 11.56 to 33.06; Cohen's $d_z = 1.199$) and the external oblique by 25.53% MVC (95% CI, 14.80 to 36.26; Cohen's $d_z = 1.374$).

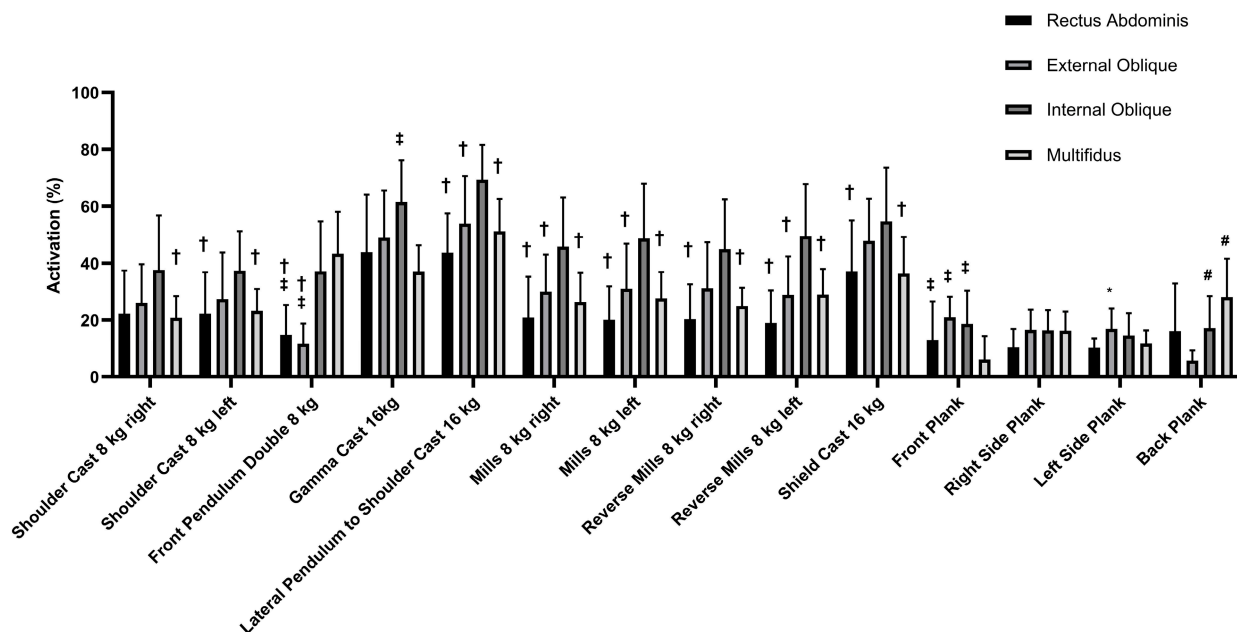


Figure 8. Mean activation of individual core muscles during steel club exercises and conventional plank variations. Mean electromyographic activation of the rectus abdominis, external oblique, internal oblique, and multifidus expressed as a percentage of maximal voluntary contraction (% MVC) during each exercise. Muscle activation values were calculated by averaging the normalized electromyographic activity recorded from the left and right sides of each muscle. Values are presented as mean $\pm$ SD. % MVC = percentage of maximal voluntary contraction. * = significant differences compared to rectus abdominis; # = significant differences compared to external oblique; † = significant differences compared to internal oblique; ‡ = significant differences compared to multifidus.

During the Lateral Pendulum to Shoulder Cast 16 kg, muscle activation also significantly differed among groups, $F(3, 39) = 12.263$, $p < 0.001$, $\eta^2 = 0.485$. The internal oblique was significantly more activated than the rectus abdominis (mean difference = 25.73% MVC; 95% CI, 18.88 to 32.57; Cohen's $d_z = 2.170$), external oblique (mean difference = 15.48% MVC; 95% CI, 4.73 to 26.24; Cohen's $d_z = 0.831$), and multifidus (mean difference = 18.21% MVC; 95% CI, 11.16 to 25.26; Cohen's $d_z = 1.491$).

A comparable pattern was observed during the Mills and Reverse Mills exercises. During Mills 8 kg Right and Mills 8 kg Left, the internal oblique was significantly more activated than the rectus abdominis, external oblique, and multifidus, with mean differences ranging from 15.81 to 28.58% MVC and large effect sizes (Cohen's $d_z = 0.833$ – 1.645). During Reverse Mills 8 kg Right, the internal oblique exceeded the rectus abdominis (mean difference = 24.61% MVC; 95% CI, 14.14 to 35.08; Cohen's $d_z = 1.357$) and multifidus (mean difference = 20.03% MVC; 95% CI, 10.01 to 30.06; Cohen's $d_z = 1.154$). During Reverse Mills 8 kg Left, the internal oblique was significantly more activated than the rectus abdominis, external oblique, and multifidus, with mean differences ranging from 20.57 to 30.52% MVC and large effect sizes (Cohen's $d_z = 0.883$ – 1.497).

During Shield Cast 16 kg, analyzed with $n = 13$ because of one missing value, muscle activation significantly differed among groups, $F(1.75, 21.05) = 5.385$, $p = 0.016$, $\eta^2 = 0.310$ (Greenhouse–Geisser-corrected; Mauchly's test indicated a violation of sphericity, $\epsilon = 0.585$). The internal oblique was significantly more activated than the rectus abdominis (mean difference = 17.54% MVC; 95% CI, 11.03 to 24.06; Cohen's $d_z = 1.628$) and multifidus (mean difference = 18.36% MVC; 95% CI, 8.19 to 28.53; Cohen's $d_z = 1.091$).

3.4. Exercise-Specific Dominant Muscle Activation

Each steel club exercise was characterized by a distinct muscle activation profile, although the internal oblique consistently exhibited the highest mean activation values across most of the exercise battery (Figures 9–11). Specifically, the internal oblique showed the highest mean activation during the Shoulder Cast 8 kg performed with both the right ($37.59 \pm 19.18\%$ MVC) and left arm ($37.36 \pm 13.86\%$ MVC) (Figure 10), the Mills 8 kg performed with the right ($45.77 \pm 17.40\%$ MVC) and left arm ($48.66 \pm 19.32\%$ MVC) (Figure 9), the Reverse Mills 8 kg performed with the right ($44.91 \pm 17.61\%$ MVC) and left arm ($49.51 \pm 18.37\%$ MVC) (Figure 9), the Gamma Cast 16 kg ($61.42 \pm 14.79\%$ MVC) (Figure 10), the Lateral Pendulum to Shoulder Cast 16 kg ($69.40 \pm 12.18\%$ MVC) (Figure 11), and the Shield Cast 16 kg ($54.66 \pm 18.98\%$ MVC) (Figure 10).

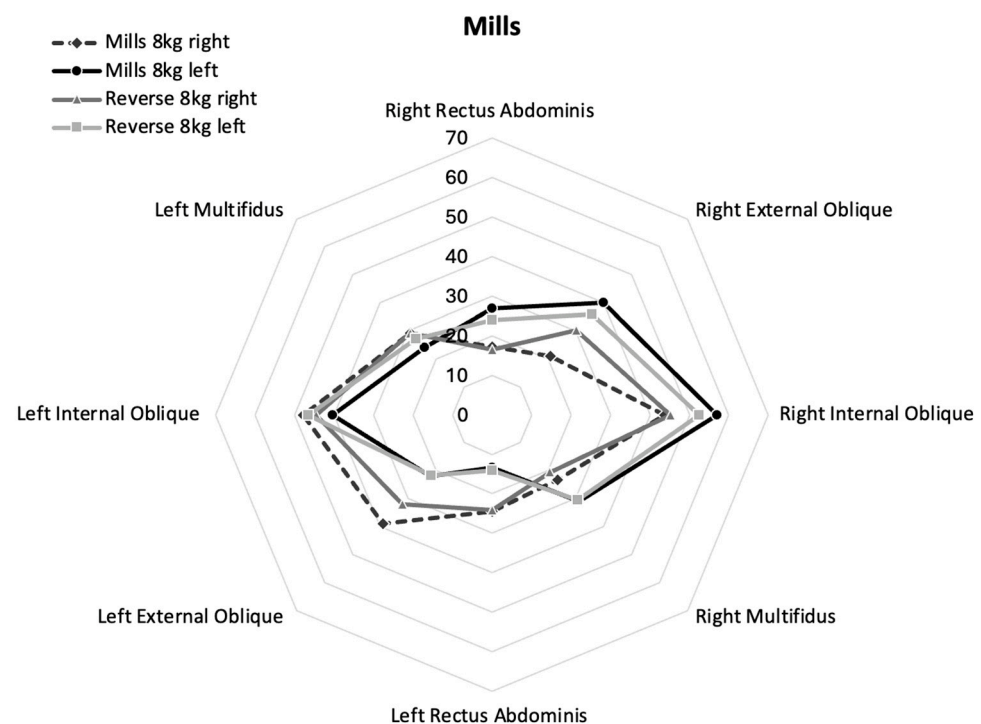


Figure 9. Muscle activation profile during Mills exercises. Radar plot showing the normalized electromyographic activation (% MVC) of the eight recorded muscle sites (left/right rectus abdominis, external oblique, internal oblique, and multifidus) during the Mills and Reverse Mills exercises (8 kg, right and left arm). Values represent the mean activation of all available participants ($n = 14$). % MVC = percentage of maximal voluntary contraction.

The Front Pendulum Double 8 kg was the only exercise in which the multifidus exhibited the highest mean activation value, reaching $43.29 \pm 14.79\%$ MVC (Figure 11), whereas the activation values recorded for the abdominal muscles were comparatively lower.

In contrast, the plank variations displayed lower dominant muscle activation values and different activation profiles (Figure 12). The Front Plank and Left Side Plank showed the highest activation of the external oblique ($20.95 \pm 7.26\%$ MVC and $16.89 \pm 7.15\%$ MVC, respectively), and the Back Plank showed the highest activation of the multifidus ($28.05 \pm 13.54\%$ MVC). The Right Side Plank showed the highest activation of the external oblique ($16.49 \pm 7.09\%$ MVC).

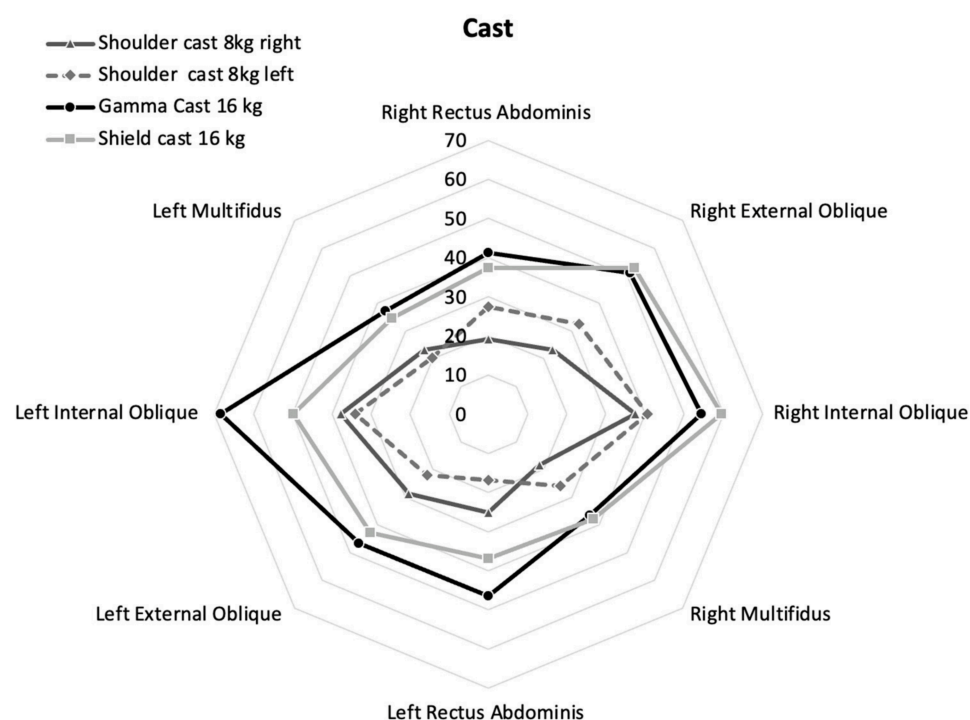


Figure 10. Muscle activation profile during Cast exercises. Radar plot showing the normalized electromyographic activation (% MVC) of the eight recorded muscle sites during the Shoulder Cast (8 kg, right and left arm), Gamma Cast (16 kg), and Shield Cast (16 kg) exercises. Values represent the mean activation of all available participants ($n = 14$, except for Shield Cast 16 kg, $n = 13$). % MVC = percentage of maximal voluntary contraction.

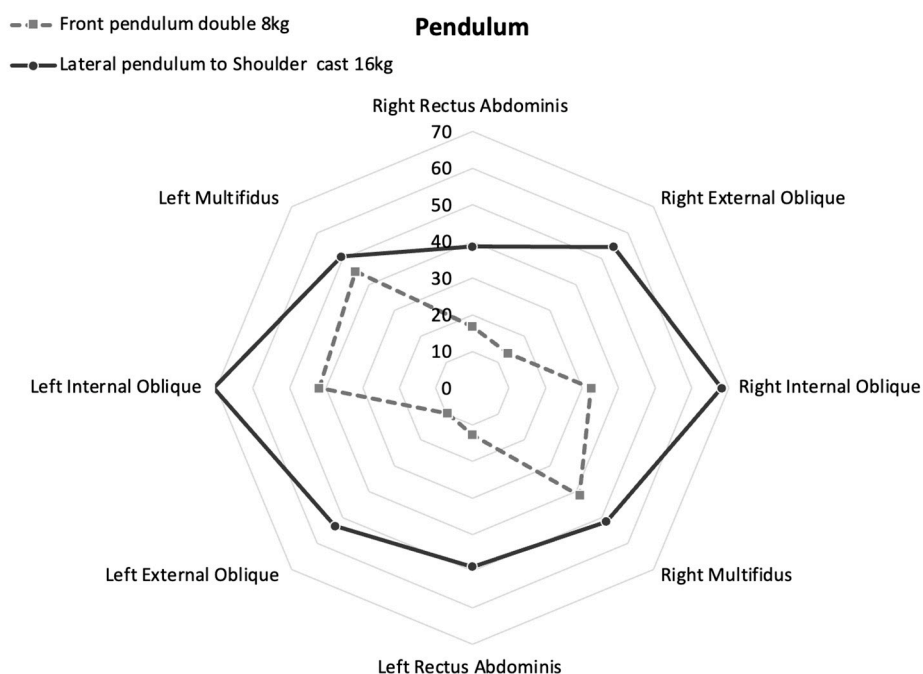


Figure 11. Muscle activation profile during Pendulum exercises. Radar plot showing the normalized electromyographic activation (% MVC) of the eight recorded muscle sites during the Front Pendulum Double (8 kg) and Lateral Pendulum to Shoulder Cast (16 kg) exercises. Values represent the mean activation of all available participants ($n = 14$). % MVC = percentage of maximal voluntary contraction.

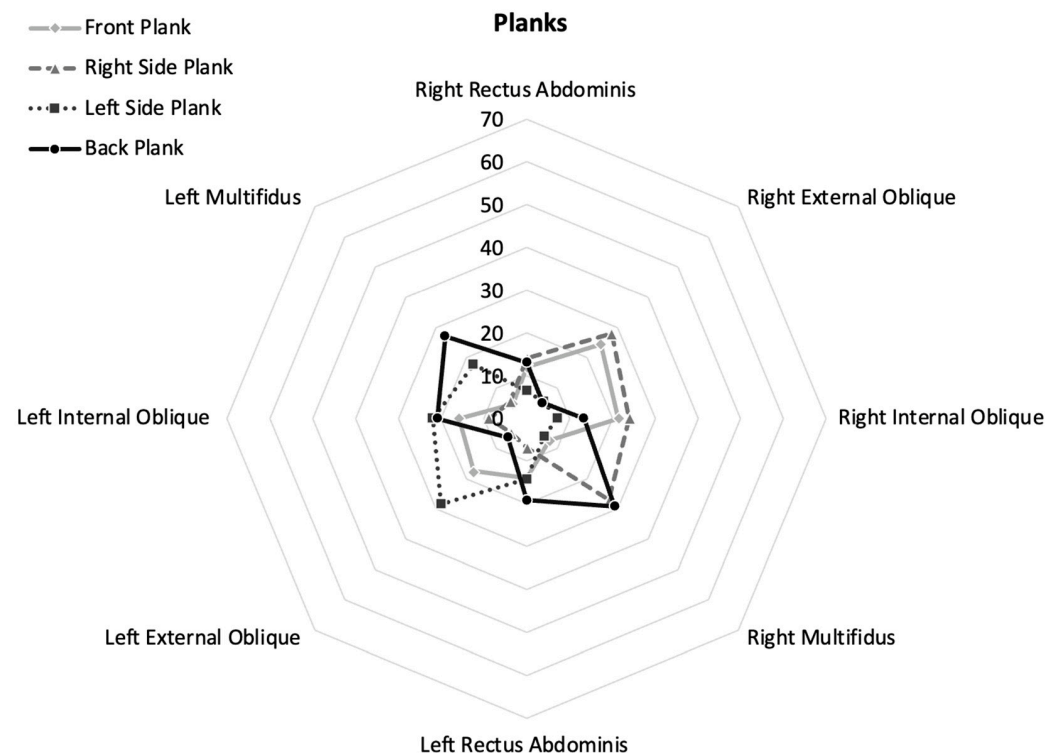


Figure 12. Muscle activation profile during Plank exercises. Radar plot showing the normalized electromyographic activation (% MVC) of the eight recorded muscle sites during the Front Plank, Right Side Plank, Left Side Plank, and Back Plank exercises. Values represent the mean activation of all available participants ($n = 14$). % MVC = percentage of maximal voluntary contraction.

4. Discussion

The present study provides the first comprehensive surface electromyographic characterization of core muscle activation during steel club exercises and yields three principal findings. First, steel club exercises elicited greater global core activation than conventional plank variations, with the largest responses observed during the 16 kg Lateral Pendulum to Shoulder Cast, Gamma Cast, and Shield Cast. This advantage was not uniform across exercises: the 16 kg exercises significantly differed from all four plank variations, whereas some 8 kg exercises (e.g., Shoulder Cast 8 kg Right) did not differ from every plank condition, indicating that the advantage over the plank was clearest and most consistent for the 16 kg exercises. Second, this greater activation was not uniformly distributed across the trunk musculature but followed exercise-specific recruitment patterns, with the internal oblique emerging as the dominant muscle across most of the exercise battery. Third, exercise-specific side-to-side differences were observed in selected unilateral conditions, particularly Mills and Reverse Mills. Taken together, these findings indicate that the neuromuscular demands of steel club training extend beyond a generalized increase in trunk activity and are consistent with the rotational loading, long lever arm, and displaced center of mass that characterize the implement. This interpretation is consistent with broader models of core function and sports conditioning [1,2,22].

The greater activation observed during the steel club exercises is consistent with their mechanical characteristics. Whereas a plank requires the trunk to resist gravity from a largely static position, steel club movements involve the continuous acceleration, deceleration, and redirection of an external load whose mass is displaced from the grip axis. The combination of a long lever arm and displaced center of mass generates substantial and continuously varying external moments as the implement is accelerated, decelerated, and redirected along circular and pendular trajectories. Consequently, changes in implement

orientation continuously alter the magnitude and direction of the mechanical demands acting on the trunk. This mechanism is consistent with prior observations that manipulating the external lever markedly increases core demand: Schoenfeld et al. [7] reported that lengthening the lever arm of a standard plank substantially raised activation of the rectus abdominis and external oblique, and Snarr and Esco [8] attributed the elevated trunk activation seen when the center of mass is displaced from the base of support to the increased demand for spinal stabilization. A comparable mechanism has been documented for other displaced-mass implements: kettlebell exercises, in which the load is likewise offset from the hand, have been shown to impose substantial trunk muscle activation and spinal loading [23]. Controlling these varying moments requires ongoing neuromuscular regulation, with the trunk musculature contributing not only to spinal stabilization but also to the transmission of force between the upper and lower extremities while resisting rotational perturbations [1,3]. This mechanical environment resembles the demands of many sport-specific skills, including throwing, striking, and rapid changes in direction, and is consistent with contemporary perspectives arguing that trunk training should extend beyond isolated stabilization to incorporate dynamic, multiplanar tasks [2].

A central finding was the presence of exercise-specific activation patterns. Rather than a uniform increase across all trunk muscles, significant between-muscle differences were observed within most steel club exercises. The internal oblique consistently exhibited the highest activation, the rectus abdominis generally the lowest, and the multifidus reached its peak during the Front Pendulum Double 8 kg. This distribution suggests that the demands of steel club exercises relate more to the control of rotational and anti-rotational moments than to sagittal-plane trunk flexion. Given its anatomical orientation and established role in trunk rotation and lumbopelvic stabilization, the internal oblique is well suited to multiplanar trunk control and force transmission, whereas the multifidus profile is consistent with its role in segmental spinal stability under rapidly changing inertial loads [3,24]. Exercise-specific recruitment has also been reported during advanced Swiss ball tasks: Marshall and Desai [15] observed that rectus abdominis activation was greatest during a bridge exercise, whereas the Swiss ball roll produced a distinct whole-body activation profile. Although that study did not assess the internal oblique, it similarly demonstrated that trunk recruitment depends on the mechanical characteristics of the exercise. The present results extend this principle to loaded, implement-based rotational movements, in which the internal oblique emerged as the primary contributor across most steel club exercises. Collectively, these observations reinforce the view that effective core function depends on coordinated intermuscular activity rather than the isolated activation of individual muscles [1,2].

Beyond the magnitude and distribution of activation, the unilateral steel club exercises revealed a further feature that distinguishes this modality from bilateral isometric tasks: exercise-specific side-to-side differences. During the Mills and Reverse Mills variations, as well as the Shoulder Cast performed with the left arm, activation significantly differed between the left and right sides of the trunk, with the largest side-to-side difference observed during Mills performed with the left arm. This lateralized response is mechanically consistent with the offset loading imposed when the implement is predominantly driven by one arm, which generates asymmetric rotational moments that the contralateral trunk musculature must counteract. A comparable pattern of trunk and shoulder asymmetry has been reported during two-armed kettlebell swings, another displaced-mass implement, supporting the mechanical basis of this lateralized response [25]. From an applied standpoint, this property may be relevant for training contexts in which lateralized trunk control is a specific objective, such as the development of anti-rotational capacity or the targeted loading of one side of the trunk; equally, it implies that unilateral steel club exercises should

be programmed on both sides to avoid inducing or reinforcing activation asymmetries. The plank variations, by contrast, produced the expected pattern, with the side-lying planks strongly loading the down-side musculature and the bilateral planks showing no significant side-to-side difference.

These findings should be read as an extension of the existing core-training literature rather than a challenge to it. Previous electromyographic work has shown that conventional plank and rehabilitation exercises effectively recruit the trunk musculature and remain valuable tools for developing endurance and motor control [4,5]. Within these tasks, the external oblique is typically the most active anterior muscle, while the posterior extensors contribute little; Snarr and Esco [8], for instance, found that during a traditional plank, the external oblique (42.0% MVC) exceeded the rectus abdominis (36.1% MVC), and the lumbar erector spinae remained low (10.0% MVC). A broadly similar profile was evident in most plank conditions of the present study, although recruitment differed across plank variations, with the Back Plank showing a greater posterior contribution, supporting the interpretation of the standard plank as an anti-extension task with limited posterior-chain demand. Such exercises, however, are performed under stable mechanical conditions in which the direction of the external load changes little, whereas the steel club exercises examined here imposed continuously varying external moments and did not all elicit the same response: activation varied with the movement pattern and mechanical characteristics of each exercise. This reinforces the principle that exercise selection influences both the magnitude and the distribution of trunk activation [2], and it positions multiplanar rotational loading with a displaced-mass implement as a distinct complement to, rather than a replacement for, established isometric approaches.

Relatively large interindividual variability was observed for several exercise conditions, as reflected by the standard deviations. This variability likely reflects differences in participants' movement strategies, technical proficiency with steel club exercises, anthropometric characteristics, and neuromuscular coordination. Future research should examine the determinants of this variability and whether distinct execution strategies influence core muscle activation.

Several interpretive cautions temper these conclusions. First, surface electromyography quantifies muscle activation, not force production or transmission; the mechanical language used here should therefore be understood as a plausible interpretation of the underlying demands rather than a direct measurement of trunk kinetics. Second, surface recordings over the internal oblique may include signal contributions from adjacent abdominal wall musculature, including the transversus abdominis and external oblique, particularly during dynamic movements [12,26,27]. Accordingly, these recordings should be interpreted as regional surface electromyographic activity rather than completely isolated internal oblique activation. Although the internal oblique MVC procedure was based on a previously evaluated normalization protocol [19], interindividual differences in the task eliciting maximal activation cannot be excluded and may have influenced the normalized % MVC values; future studies may therefore benefit from using a battery of candidate MVC tasks (e.g., resisted side bending, rotation, and/or diagonal flexion) and retaining the highest muscle-specific activation for normalization. Third, comparisons of absolute activation magnitudes across studies must be made with caution, as differences in maximal voluntary contraction protocols substantially affect normalized values; the comparisons drawn here are therefore based on the relative pattern of muscle recruitment rather than on absolute percentages. Finally, greater muscle activation does not by itself establish superior training value. Marshall and Desai [15] likewise cautioned that high activation during technically complex Swiss ball exercises does not necessarily imply superior practical value.

The applied benefits of steel club training will require confirmation through longitudinal intervention studies rather than acute electromyographic measurement alone.

Two further considerations warrant mention. First, the sample comprised only experienced male practitioners, and the extent to which these activation patterns generalize to women or to individuals with less technical proficiency remains unknown. Second, given the external loads and rotational demands involved, safe implementation of steel club training likely requires adequate technical instruction and progressive loading, particularly for less experienced individuals. More broadly, because all participants were experienced steel club practitioners, the present activation patterns should not be generalized to novice or untrained individuals, whose movement strategies are likely to differ; future research should examine whether training experience influences core muscle activation during steel club exercises.

Overall, the value of a core exercise is determined not only by the activation it elicits but also by its capacity to reproduce the neuromechanical demands of functional movement [1,2,22,28]. In athletic tasks, the trunk rarely operates under static, predictable conditions; it continuously regulates force transmission while adapting to changing directions, velocities, and external moments across multiple planes. The activation profiles observed here indicate that steel club exercises expose the core to precisely this kind of dynamic environment—rotational loading, inertial perturbation, and continuously changing force vectors—while modulating the distribution of recruitment according to the demands of each movement. Viewed in this light, the core is better conceived not merely as a stabilizing structure but as a dynamic force-transmission system, and movement-specific neuromechanical challenges of the type provided by steel club training may represent a useful addition to comprehensive core-conditioning programs.

Limitations

The cross-sectional design was appropriate for characterizing acute electromyographic responses but does not permit conclusions regarding chronic adaptations. Standardized absolute loads ensured consistent testing conditions across participants; however, because body mass ranged from 69.0 to 100.5 kg, the same 8 and 16 kg loads represented different relative external demands among individuals. This may have contributed to interindividual variability in normalized muscle activation and limits interpretation of the responses as being solely attributable to exercise biomechanics. Accordingly, the 8 and 16 kg conditions used here should not be interpreted as independent levels of a loading factor. Future studies should scale external loads according to individual characteristics, such as body mass and/or maximal dynamic strength, and examine the same exercises across progressively increased relative loads to better characterize dose–response relationships. Exercise order was randomized, and participants rested for at least 3 min and confirmed recovery before each condition; nevertheless, residual fatigue cannot be entirely excluded. The number of repetitions per steel club exercise (five) was selected to limit fatigue accumulation across the 14 exercise conditions completed within a single session, although this relatively low count may have contributed to variability in the peak value. The different temporal approach used to summarize dynamic and isometric conditions may influence direct comparisons between exercise modalities. In particular, the use of a single peak during the continuous plank condition may overestimate the activation typically sustained throughout the task. Future studies should directly compare peak- and time-averaged RMS approaches across dynamic and isometric exercise modalities to determine the influence of temporal signal processing on between-exercise comparisons. Surface electromyography characterizes regional muscle activation but does not directly quantify muscle force or spinal loading. Finally, although the sample size was supported by an a priori power analysis for the

primary outcome, secondary analyses may be less precise. The sample was exclusively male to increase sample homogeneity; consequently, the present findings should not be generalized to female practitioners. A dedicated study in women is planned as a direct extension of this work. Future studies should examine chronic adaptations and combine electromyography with kinetic and kinematic measurements.

5. Conclusions

The present study provides the first comprehensive electromyographic characterization of core muscle activation during a battery of steel club exercises and demonstrates that, among experienced steel club practitioners, several steel club conditions—particularly the 16 kg variations—elicit greater global core activation than conventional plank variations. These differences were statistically significant across exercise conditions. Distinct exercise-specific recruitment patterns were also identified, with the internal oblique consistently exhibiting the greatest activation across most steel club exercises and the multifidus showing a particular contribution during pendular movements. Collectively, these findings indicate that steel club exercises provide a dynamic, rotational, and multiplanar neuromuscular stimulus that differs from the activation profile observed during conventional isometric core exercises. Steel club training may therefore represent a valuable complement to conventional plank-based approaches, particularly for athletes and physically active individuals seeking to develop multiplanar trunk control under movement-specific conditions. Given that the present findings are based on acute electromyographic activation, they should not be interpreted as evidence of superior long-term hypertrophic or functional adaptations. Longitudinal studies are required to determine whether these activation profiles translate into meaningful improvements in trunk function and athletic performance. From a practical standpoint, steel club exercises provide a dynamic and multiplanar neuromuscular activation profile that contrasts with the sustained isometric nature of conventional planks, positioning them as a rotational, dynamic complement rather than a replacement for isometric core training, with unilateral variations preferably performed on both sides to ensure balanced exposure.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Universidad Francisco de Vitoria (protocol code 34/2025; approved 17 June 2025).

Informed Consent Statement: Informed consent was obtained from all subjects involved in this study. This includes explicit written consent from the participant depicted in photographs for the publication of images showing his torso.

Data Availability Statement: The data presented in this study are not available due to privacy and ethical restrictions associated with the biometric and physical-performance information collected from participants.

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