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Research article

Impact of Small-Sided Game Formats on Electromyographic Responses in College Students

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Abstract

This study examined the effects of three small-sided game (SSGs) formats -1v1, 3 3v3, and 6v6- on muscle activation and fatigue during balance and jump performance tasks in collegiate athletes. Sixty healthy university students were randomly assigned to three groups (n = 20 each) for a 5-day SSG training program on standardized artificial turf. Training duration and recovery intervals were controlled, with player number and pitch size as independent variables. Muscle activity was measured using surface electromyography (sEMG) from the rectus femoris (RF) and biceps femoris (BF) during both the double-leg stance (DLS) balance task and the countermovement vertical jump (CMJ) task. Muscle activation and neuromuscular fatigue were quantified using the root mean square (RMS) and median frequency (MF) of the sEMG signal. Across all formats, CMJ elicited greater activation and fatigue than DLS ($p < 0.001$). The 6v6 format produced the highest activation (CMJ-RMS: 0.055 ± 0.012) and greatest fatigue (CMJ-MF: 62.5 ± 5.3 Hz), significantly exceeding 1v1 ($p < 0.01$). The 3v3 format showed peak DLS-MF (78.2 ± 6.7 Hz), higher than 1v1 ($p=0.003$), indicating optimal activation–fatigue balance. Temporally, 1v1 maintained higher DLS-MF on Days 1 - 3 ($p < 0.05$), reflecting short-term neuromuscular efficiency. RF activation was highest in 6v6 ($p < 0.01$), while BF fatigue resistance was greatest in 3v3 ($p < 0.05$). In conclusion, 6v6 maximizes activation and fatigue, 3v3 provides balanced activation–fatigue, and 1v1 yields early neural efficiency but greater long-term fatigue. Future research should investigate longitudinal adaptations, sport-specific applications, and the influence of SSG formats on injury risk.

Key words: Football; conditioned games; electromyography; countermovement jump; neuromuscular activation; muscle fatigue; formats.

Introduction

Small-sided games (SSGs) are increasingly recognized as an essential component of soccer training due to their ability to develop physical, technical, and tactical attributes simultaneously (Clemente et al., 2021; Kekelekis et al., 2024). These games replicate match-specific scenarios while allowing coaches to manipulate task constraints such as pitch size and the number of players to achieve specific training responses in soccer players (Fernández-Espínola et al., 2020). There is consistent evidence supporting the effectiveness of SSGs in improving VO_2max and aerobic performance in field-based tests, with smaller formats typically inducing higher physiological demands compared to larger-sided games, although they generally result in lower distances covered at high intensity (Bujalance-Moreno et al., 2019). Additionally, SSGs enhance the development of soccer-specific technical and tactical skills, with smaller-sided formats (e.g., three-a-side) promoting more frequency of short passes, dribbles, and goals scored (Clemente and Sarmento, 2020). Moreover, coaches value SSGs for their ability to develop tactical principles and inter-player coordination within and between team sectors (Ometto et al., 2018).

To achieve the desired training adaptations, coaches frequently manipulate various task constraints within SSGs to modulate players' responses. Common manipulations include altering the number of players, pitch dimensions, and specific game rules, such as end mechanism or bout duration (Ometto et al., 2018; Machado et al., 2022). Changing the number of players directly influences the intensity of play, the frequency of individual interventions, interpersonal distances, and opportunities for ball possession, shooting, and passing (Vilar et al., 2014). In general, formats with fewer players, such as 2 vs 2, are associated with higher physiological demands, including elevated heart rate and blood lactate concentrations (Brandes et al., 2012). These formats also promote a greater number of technical actions, such as touches and passes, without necessarily imposing excessive physical stress(Joo et al., 2016). Similarly, modifying pitch size significantly impacts both the physical demands and the technical and tactical behaviors elicited during play (Machado et al., 2022). Larger playing areas tend to increase physical demands, including total distance covered and distance covered at higher running velocities (Castillo et al., 2021).

While SSGs are effective for eliciting a range of physical and technical adaptations, the intensity, particularly in smaller formats, can lead to acute reductions in neuromuscular performance. For instance, formats such as 2v2 or 4v4 have been shown to decrease peak power output and jump height immediately following exercise, although these values typically return to baseline within two hours (Sparkes et al., 2018). Moreover, smaller formats (e.g., 4v4) appear to be more demanding in terms of repetition frequency and the development of fatigue reflected by decline in sprint performance over short distances (5 m and 15 m) compared to larger formats (e.g, 8v8) (Rebelo et al., 2016). Additionally, using larger relative pitch areas within

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SSGs has been associated with higher internal and external loads, leading to a decrease in hamstring force (Madison et al., 2019). The number of accelerations performed during a session, a common outcome in SSGs, was linked with an increased risk of hamstring fatigue, which may be mitigated through appropriate adjustment of the relative pitch size (Madison et al., 2019).

Although declines in muscular power following SSGs have been well documented (Sparkes et al., 2018), the underlying neuromuscular mechanisms remain unclear. Surface electromyography (EMG) provides a direct method of assessing muscle activation and fatigue by quantifying both the magnitude (root mean square, RMS) and spectral characteristics (median frequency, MF) of the signal (Cifrek et al., 2009). RMS reflects the intensity of muscle activation (Burden and Bartlett, 1999), while MF is sensitive to fatigue-related shifts in muscle fiber conduction velocity (Bilodeau et al., 2003). By standardizing RMS values to maximal voluntary contraction (MVC), it is possible to compare activation levels across tasks and conditions, independent of inter-individual variability. However, studies using EMG to investigate SSGs are limited, representing a meaningful gap in the current understanding of how different SSG formats affect players' muscular activity. This is likely due to the technical complexity and high levels of noise when recording EMG during dynamic SSG activities. In contrast, laboratory-based tests such as the countermovement jump (CMJ) provide a more controlled setting for EMG implementation (Padulo et al., 2013). For example, previous research (McNeal, Sands and Stone, 2010) has shown that repeated maximal jumps reduce muscle activation, as measured by surface EMG, alongside force production, potentially explaining fatigue-related declines in performance.

The absence of research on the impact of different small-sided games (SSGs) on muscular activity represents an important gap in the literature, particularly given that varying external demands—such as the density of accelerations and decelerations or the number of high-speed runs—can differently affect key lower-limb muscles like the rectus femoris and biceps femoris. This issue is especially relevant because, despite the widespread use of SSGs in soccer training, the specific neuromuscular demands associated with different formats remain largely unexplored. Assessing muscle activation patterns via EMG may provide a valuable means of determining how variations in player numbers can influence muscular engagement and fatigue, which may, in turn, result in distinct impairments depending on the game format. Such knowledge can inform more effective recovery strategies and individualized load management approaches (Madison et al., 2019).

Understanding these neuromuscular responses is crucial for coaches and practitioners aiming to design training sessions that specifically target muscle groups and movement patterns aligned with the tactical and physical demands of different SSG formats. EMG-based analyses can also provide insights into the mechanisms of fatigue and their effects on muscle function, which are essential for developing injury prevention strategies and optimizing training programs to minimize fatigue-related performance decrements. Building on this rationale, the present study aims to assess the effects of three SSG formats—1v1, 3v3, and 6v6—on muscle activation responses measured via EMG during Double-Leg Stance (DLS) and countermovement jump (CMJ) tests in college athletes. In the absence of prior related research, we hypothesize that smaller-sided games (e.g., 1v1) will elicit higher activation of lower-limb muscles (rectus femoris, biceps femoris) due to increased intensity and involvement in accelerations and decelerations, whereas larger-sided games (e.g., 6v6) will produce lower peak muscle activation but may result in greater overall fatigue due to longer durations of play and running demands.

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Methods

Participants

This study followed the CONSORT 2025 guidelines for experimental research. The sample size was calculated using G*Power software (version 3.1.9.7; Kiel University, Germany) with parameters set at $\eta^2 = 0.04$, $\alpha = 0.05$, and a statistical power (1-β) of 0.95, indicating a minimum requirement of 16 participants per group. To account for potential attrition, 63 physical education students, classified as Tier 1 (recreationally active) in the Participants Classification Framework (McKay et al., 2022), were initially recruited, of whom 3 were subsequently excluded due to lower limb injuries sustained in the two weeks prior to the study. The remaining 60 participants were randomly assigned to 1v1 group. The inclusion criteria were i) absence of major health conditions such as heart disease or diabetes; ii) non-professional soccer players; iii) absence of injuries in the three previous months; iv) voluntary participation with signed informed consent; and v) complete all training and testing procedures. The study protocol was approved by the Research Ethics Committee of Wuhan Sports University (approval number: 2024045) and registered with the Chinese Clinical Trial Registry (registration number: ChiCTR2400089504, registration date: September 11, 2024). All procedures adhered to the principles of the Declaration of Helsinki.

Experimental design

A five-day period of data collection was conducted for each group, with each group starting under different formats: 1v1, 3v3, and 6v6, respectively. Figure 1 illustrates the study design.

Due to the nature of the intervention, an open-label design was adopted. To minimize potential expectancy effects and observer bias, standardized operating procedures (SOPs) and objective surface electromyography (sEMG) analysis methods were implemented. All sEMG data were processed using standardized codes to ensure the objectivity of data analysis. Participants were kept unaware of the intervention's purpose or expected effects.

Randomization was performed by personnel not involved in the experimental procedures. Participants were randomly divided into three groups (n = 20 per group) based on their individual characteristics. Data collection and intervention implementation were carried out by different researchers. A team meeting was held prior to the study to ensure procedural consistency.

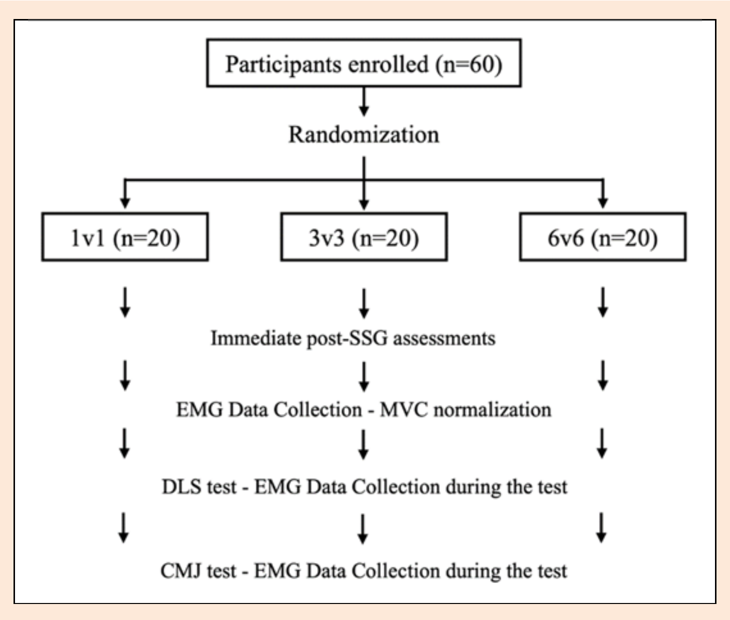

Figure 1. Overview of the study design. EMG: electromyography; DLS: Double-Leg Stance; CMJ: countermovement jump; MVC: maximum voluntary contraction.

The initial testing period lasted from 8:00 October 27, 2024, to November 23, 2024. After exercise, participants in each group underwent immediate measurements of sEMG for DLS and CMJ assessments in a random order. All experimental procedures were completed in the Sports Science Laboratory of Chaohu University, China, and no protocol deviations were reported. Figure 2 shows the flowchart of the experimental procedure.

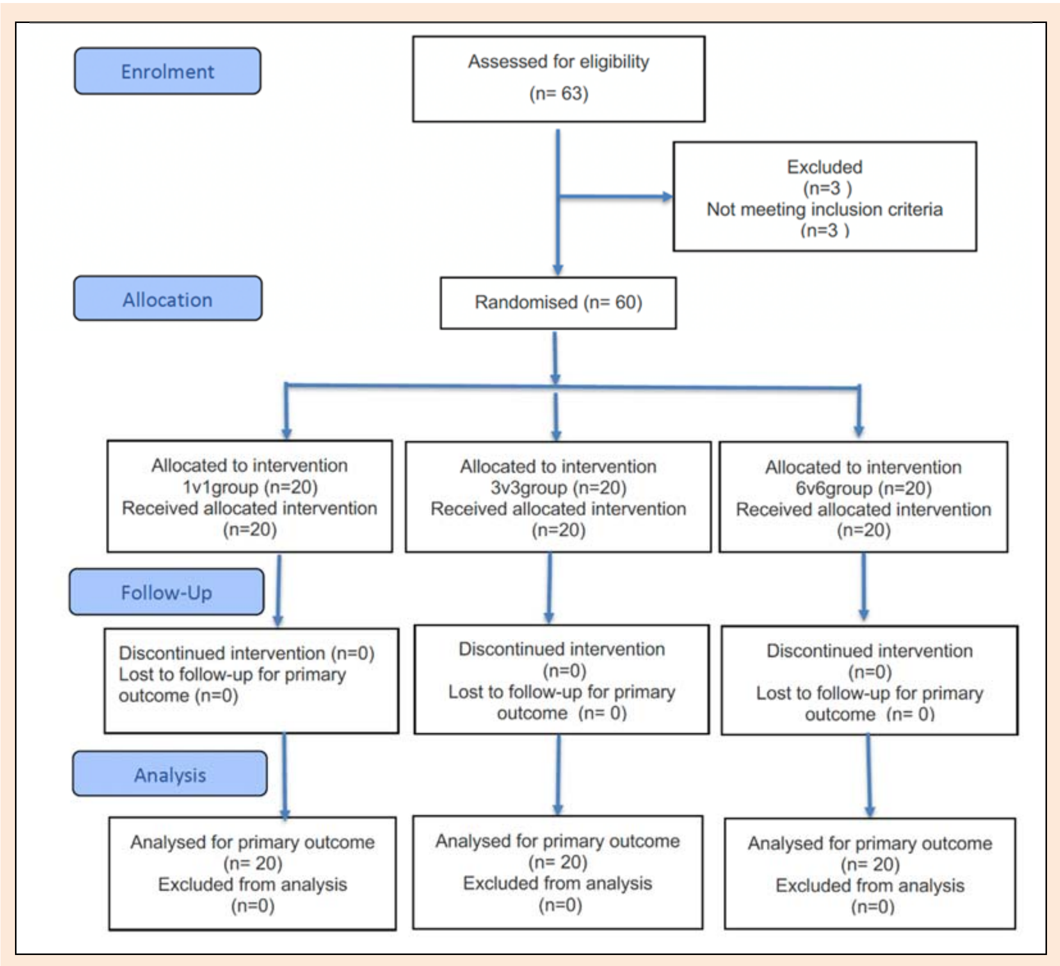

Figure 2. Flowchart of participants.

Small-sided games

All SSGs were conducted on a standardized outdoor artificial turf field without goalkeepers under the following environmental conditions: 1v1 (mean temperature: 17.7°C, humidity: 52%), 3v3 (18.27°C, 50%), and 6v6 (16.9°C, 56%). Each SSGs plan was designed to the size of the group: 1v1 includes 8 one-minute rounds, with a 1-minute passive recovery time (10×20m; IIE = 100m²), 3v3 includes 3 rounds of 4 minutes each, with a 3-minute passive recovery interval (30×15 m; IIE = 75 m², 6v6 consists of two 6-minute matches with a 3-minute halftime break (40×20 m; IIE = 67 m². The rules are as follows: Contestants are free to touch the ball. Coaches will only intervene when safety issues arise. There is no goalkeeper. When the ball went out of bounds, the coach passed it to the opponent. The offside rule has been cancelled.

Internal load was assessed using heart rate (HR) and estimated oxygen uptake (VO_2) measures derived from the Firstbeat Sensor (Firstbeat Technologies, Finland) (Carneiro et al., 2023). These measures were collected as secondary outcomes to monitor training load associated with participants' engagement during the games and to control for variations in effort across different formats. This approach enables a better understanding and characterization of participants' exertion during the games, as well as its potential impact on fatigue analysis.

Instruments and data collection protocols

Neuromuscular function was assessed using two instruments: The Double-Leg Stance (DLS) and the Countermovement Jump (CMJ). In the DLS, participants stood naturally with feet shoulder-width apart and arms relaxed at their sides. Postural stability was monitored via computer, recording the time until loss of balance, defined as lifting or shifting a foot, moving the arms for stabilization, or exhibiting excessive body sway. In the CMJ, vertical jump performance was measured using a Kistler force platform (validity: $r = 0.98$ with motion sensor, $p < 0.001$; reliability: ICC = 0.84, $p < 0.01$) (Pasquale et al., 2024). Before data collection, participants practiced the CMJ twice until familiar with the movement pattern.

DLS and CMJ were used to assess participants' muscular activity. Surface EMG activity was recorded using a wireless Delsys Trigno Avanti system (Delsys Inc., USA) with bipolar differential silver/silver-chloride electrodes (10 mm diameter, 20 mm inter-electrode distance) at 2000 Hz. Skin was prepared by removing hair and cleaning with alcohol. Electrode placement followed SENIAM guidelines (Hermens et al., 2000): rectus femoris (RF), Midpoint of the muscle belly along the line from anterior inferior iliac spine to superior patella border; and biceps femoris (BF) Long Head: Midpoint between ischial tuberosity and fibular head.

EMG signals were preprocessed by removing the DC component, applying Butterworth bandpass filters (10–500 Hz for MVC and DLS; 20–500 Hz for CMJ), and a 50 Hz adaptive notch filter. Key EMG parameters included: root mean square (RMS) which reflects overall muscle activation intensity; and median frequency (MF), obtained via FFT to identify spectral shifts indicative of muscle fatigue. EMG values during maximum voluntary contraction (MVC) were set as 100% MVC, and all other EMG data were normalized relative to these values (RMSMVC).

Procedures

Prior to data collection, participants were prepared for electromyographic assessment by having hair removed from the target muscle areas and the skin cleaned with alcohol. Electrodes were then placed on the bilateral RF and BF long head. Data collection involved tests conducted in the following order:

Maximum Voluntary Contraction (MVC): During this test, a stable 1-second contraction period was extracted from a 3-second time window for subsequent analysis. The electromyographic RMS values from this test were used to normalize data from the other tests.

Double-Leg Stance (DLS): Participants adopted a natural stance with feet shoulder-width apart and arms relaxed at their sides. They were instructed to maintain this position for 30 seconds. The test was terminated if they lost balance (e.g., lifting a foot, excessive body sway), and the time until this occurred was recorded.

Countermovement Jump (CMJ): After a 1-minute rest interval following the DLS test, participants performed the CMJ. They were instructed to place their hands on their hips, stand for 1–2 seconds, descend to a 90° knee angle, jump vertically with maximal effort, and land in a controlled manner. Jump height was measured by the force platform.

Statistical analysis

Statistical analyses were performed using R software (Version 4.4.5), and figures were generated using ["ggplot2 package in R", "OriginPro 2023"]. Data are presented as mean ± standard deviation (M ± SD) or median (interquartile range, Q1-Q3) as appropriate. The Shapiro-Wilk test was used to assess the normality of distribution for all variables across groups. The Shapiro-Wilk normality test indicated that variables such as age, height, body mass, and exercise volume in most groups did not follow a normal distribution ($p \leq 0.05$). Therefore, nonparametric Kruskal-Wallis tests were used for intergroup comparisons.

For covariates (age, body mass, height, athletic experience) and baseline surface sEMG parameters (baseline root mean square [RMS] and median frequency [MF]), non-normally distributed data were analyzed using the Kruskal-Wallis test to compare differences between experimental groups.

To evaluate the effects of training interventions on RMS and MF, two Generalized Linear Mixed Models (GLMMs) were constructed:

RMS Model: Employed a gamma distribution with a log link function. The dependent variable was RMS, with fixed effects including condition, training day (day), muscle group (muscle), test type (test), and baseline RMS (baseline). Multiple interaction terms (condition: day, condition: test, day: test) were incorporated, along with a random effect structure of (1|muscle:subjectID) to account for within-subject correlations in repeated measurements.

MF Model: Utilized a Tweedie distribution with a log link function. The dependent variable was MF, with fixed effects analogous to the RMS model (condition, day, muscle, test, baseline MF) and corresponding interaction terms (condition: day, condition: test, muscle: test, day: test). The random effect structure was specified as (1|subjectID).

Following model fitting, residual diagnostics were conducted using the DHARMa package to detect model deviations, including overdispersion, zero inflation, and nonlinearity. Estimated marginal means (EMMs) were calculated using the emmeans package, and Holm's method was applied for multiple comparison adjustments.

Effect sizes were calculated and interpreted according to Cohen's conventions: small (d = 0.2), medium (d = 0.5), and large (d = 0.8) (Lakens, 2013). Statistical significance was set at α = 0.05 for all analyses.

Results

Baseline characteristics and intergroup comparisons

The internal load during the SSGs reflected a mean heart rate of 163±14.9, 151±10.1, and 146±16.1bpm for the 1v1, 3v3, and 6v6 formats, respectively. Mean oxygen uptake was 42±5.45. $ml \cdot kg^{-1} \cdot min^{-1}$, 37±4.3$ml \cdot kg^{-1} \cdot min^{-1}$, and 34±6.2$ml \cdot kg^{-1} \cdot min^{-1}$across the same formats, with no significant differences observed between them. Regarding external load, the Results showed no significant differences among the three groups (e.g., 1v1, 3v3, and 6v6) in age, height, body mass, exercise volume, baseline RMS (root mean square), or baseline MF (all $p > 0.05$), indicating balanced baseline characteristics across groups (Table 1).

Muscle fatigue levels during DLS and CMJ tests across conditions

Figure 3 shows EMG indices, RMS amplitude (RMS; panel A) and median frequency (MF; panel B), obtained during the DLS and CMJ tests in each SSGs format. RMS was significantly higher in CMJ than in DLS across all formats ($p < 0.001$), with significantly greater CMJ-RMS in 3v3 and 6v6 compared to 1v1 ($p < 0.05$). All formats showed MF decreases from DLS to CMJ, with DLS–MF in 1v1 significantly lower than in 3v3 and 6v6 ($p < 0.001$). CMJ-MF increasing progressively from 1v1 to 6v6, with significantly greater CMJ-MF in 3v3 compared to 1v1 ($p < 0.05$) and 6v6 compared to 1v1 ($p < 0.001$).

The differences in muscle RMS and MF during DLS and CMJ tests across different muscles in various small-sided games (SSGs)

Figure 4 presents the RMS and MF electromyographic indices recorded from RF and BF during DLS and CMJ tests across the three SSGs formats. RMS values during the DLS did not show significant differences among groups ($p > 0.05$). However, during the CMJ, RMS values in all muscles were significantly in the 3v3 and 6v6 groups compared to the 1v1 group ($p < 0.05$). Regarding MF, significant differences were observed during the DLS, with the 1v1 displaying markedly lower values than both 3v3 and 6v6 ($p < 0.001$). A similar pattern was observed in the CMJ, where MF values were significantly lower in the 1v1 format compared to the 3v3 ($p < 0.05$) and 6v6 ($p < 0.01$) formats. The significance and degree of significance of RMS and MF in the left leg muscles appear consistent with those in the right leg, without conducting a statistical analysis between the two sides.

Table 1. Anthropometric and demographic characteristics (mean ± standard deviation, and lower and upper 95% confidence intervals).

Parameters	1v1 (n=20)	3v3 (n=20)	6v6 (n=20)	*p-value*
Age (years)	19.00 ± 0.50 (18.00; 19.50)	19.00 ± 0.45 (18.20; 19.80)	18.50 ± 0.55 (17.90; 19.10)	0.4427
Height (cm)	178.50 ± 6.51 (174.51; 182.49)	180.75 ± 5.15 (177.60; 183.90)	178.30 ± 4.75 (175.21; 181.39)	0.2499
Body mass (kg)	70.95 ± 8.02 (65.92; 76.00)	70.15 ± 8.52 (64.96; 75.34)	70.95 ± 6.87 (66.52; 75.38)	0.9372
Experience (years)	3.00 ± 0.35 (2.70; 3.30)	3.00 ± 0.00 (3.00; 3.00)	3.00 ± 0.00 (3.00; 3.00)	0.2732
Baseline-RMSmvc	0.03 ± 0.01 (0.02; 0.04)	0.02 ± 0.01 (0.01; 0.03)	0.03 ± 0.01 (0.02; 0.04)	0.0693
Baseline-MF (Hz)	74.22 ± 12.00 (70.16; 78.28)	83.98 ± 10.00 (80.04; 87.92)	76.17 ± 11.50 (71.77; 80.57)	0.4068

RMSmvc: root mean square amplitude; MF: median frequency; Hz: hertz.

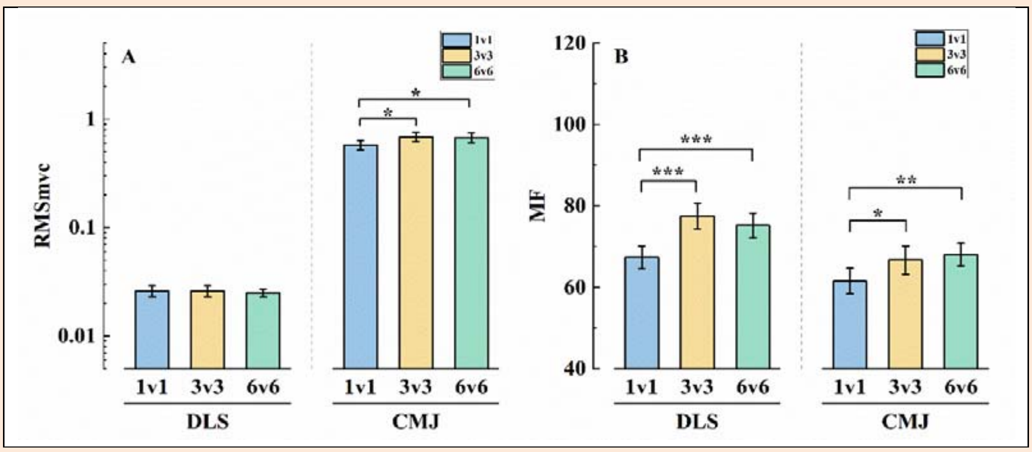

Figure 3. Global RMS (root mean square) and MF (median frequency) electromyographic responses during DLS (Double-Leg Stance) and CMJ (countermovement jump) tests under different SSG formats. Global RMS and MF electromyographic responses during DLS and CMJ tests under different SSG formats. * significantly different at $p < 0.05$; **: significantly different at $p < 0.01$; ***: significantly different at $p < 0.001$

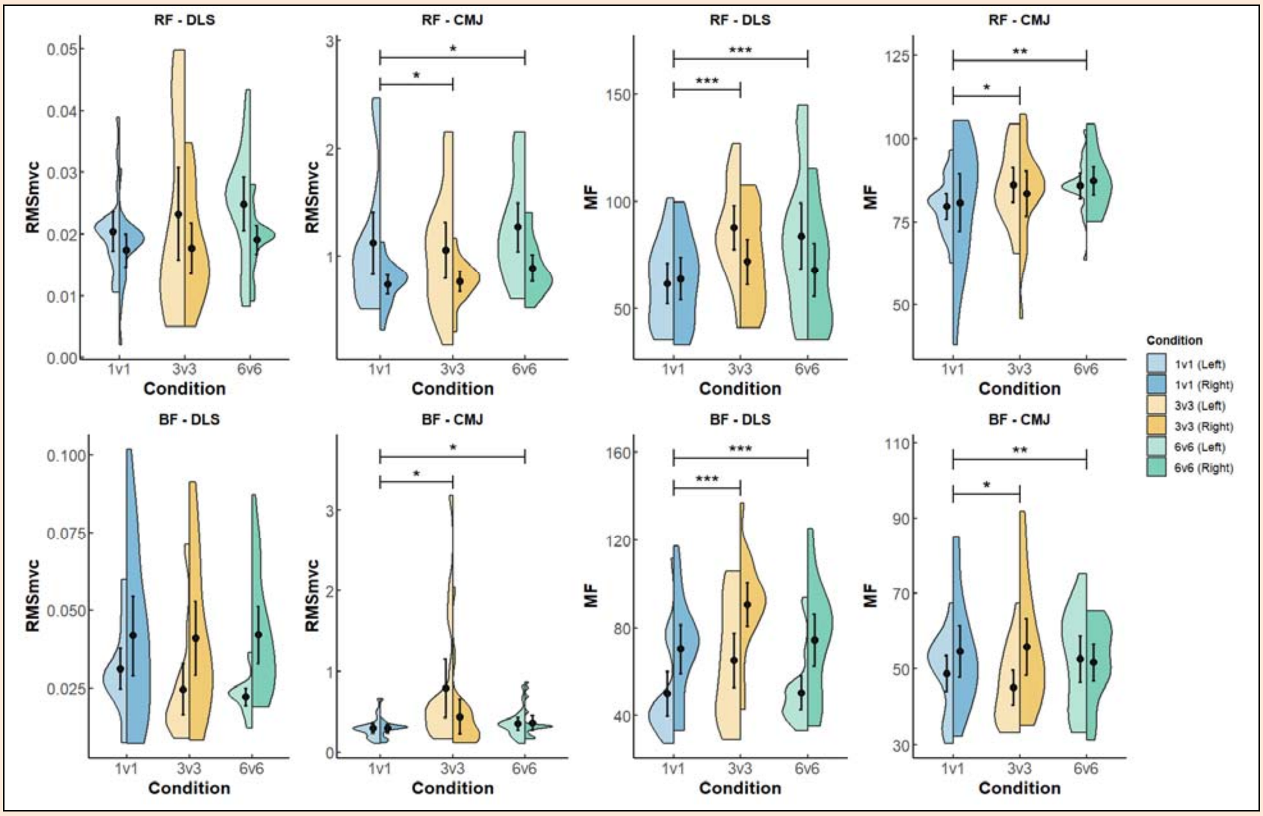

Figure 4. Electromyographic RMS (root mean square) and MF (median frequency) values of rectus femoris and biceps femoris muscles during DLS (Double-Leg Stance) and CMJ (countermovement jump) tests in each leg across different SSG formats (1v1, 3v3, 6v6). * significantly different at $p < 0.05$; **: significantly different at $p < 0.01$; ***: significantly different at $p < 0.001$.

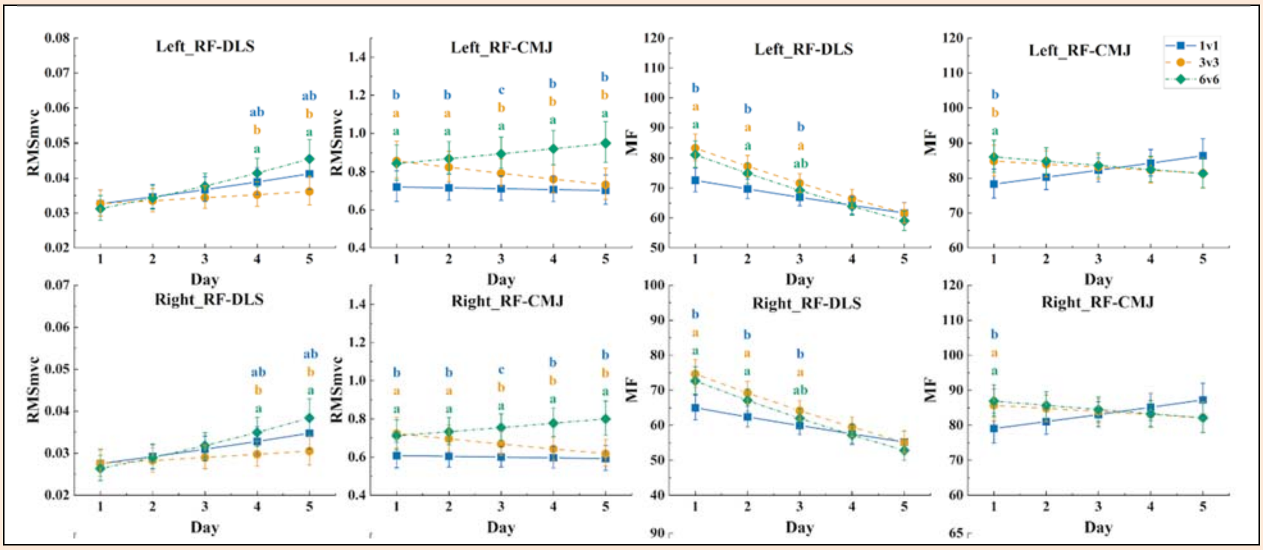

Figure 5. Time-course evolution of RMS (root mean square) and MF (median frequency) electromyographic indices across five days in each small-sided game format during DLS (Double-Leg Stance) and CMJ (countermovement jump) tests in rectus femoris (RF) muscles. a) indicates a significant difference from 6v6 ($p < 0.05$); b) indicates a significant difference from 3v3 ($p < 0.05$); and c) indicates a significant difference from 1v1 ($p < 0.05$).

Temporal Trends in RMS and MF across different SSGs formats

Figure 5 illustrates the time-course evolution of RMS and MF values across five days of SSGs exposure, differentiating between muscle groups (RF and BF bilaterally) and test conditions (DLS and CMJ). In DLS, RMS values showed a progressive increase over time across all groups, with significant differences emerging between 3v3 and 6v6 on Days 4 and 5. Conversely, MF values declined significantly from day 1 to day 5, with day 1 to day 2 differences (1v1 vs 3v3/6v6), 3th differences (1v1 vs 3v3) diminishing after day 3. In the CMJ test, RMS values remained stable over time, although 1v1 consistently differed from both 3v3 and 6v6 across all days, with further distinctions between 3v3 and 6v6 arising from 3th onward. MF values during CMJ were stable throughout the intervention, with significant intergroup differences only observed on 1st (1v1 vs 3v3/6v6).

Discussion

Our study suggested that SSGs of varying formats (1v1, 3v3, 6v6) elicited significantly different electromyographic responses during DLS and CMJ tasks, as measured by muscle activation (RMS) and neuromuscular fatigue (MF). Across all formats, CMJ tasks induced greater RMS values than DLS, reflecting the increased muscular demands of dynamic, explosive movements. RMS during CMJ was significantly higher in the 3v3 and 6v6 formats compared to 1v1, suggesting that moderate-to-large group games may generate greater residual muscle activation.

Interestingly, despite the intense nature of 1v1 formats, which theoretically involve maximal individual effort due to continuous engagement (Owen et al., 2004), participants exhibited significantly lower CMJ-RMS values post-task. This suggests that acute neuromuscular fatigue may impair post-SSGs muscle recruitment, rather than indicating lower physical load. Supporting this interpretation, MF values were significantly lower in 1v1 across both CMJ and DLS, indicating a fatigue-induced shift toward lower EMG frequencies, associated with slowed motor unit conduction velocity and altered firing rates. This aligns with a previous study (Madison et al., 2019) suggesting that the number of accelerations—often occurring in 1v1 formats—leads to significant decreases in parameters such as hamstring strength, contributing to increased fatigue and performance decline.

The observed decline in MF from DLS to CMJ across all formats supports a fatigue response, but the persistently lower MF values in the 1v1 group further highlight the high neuromuscular strain imposed by this format. Unlike 6v6, which allows for intermittent rest due to role rotation and larger team structure, the 1v1 format involves sustained, high-intensity actions without shared load (Beato et al., 2023), likely leading to greater accumulation of peripheral fatigue. This is consistent with prior reports suggesting that formats with minimal passive recovery time are more fatiguing (Zouhal et al., 2020).

Muscle-specific analyses further show the differentiated response patterns of the RF and BF. The RF, as a biarticular muscle involved in both hip flexion and knee extension, plays a major role during concentric force production during take-off in CMJ, exhibited the highest activation (RMS) in the 6v6 format (Kakehata et al., 2021). Its higher activation suggesting that larger-sided games may potentiate quadriceps recruitment due to increased running speed, and sprinting (Rumpf et al., 2025). In contrast, the BF showed more activation patterns in the 3v3 format, evidenced by higher CMJ-RMS and moderate MF declines—implying effective engagement with controlled fatigue. Given the BF's role in deceleration and eccentric control, this may reflect appropriate demands in moderate-sided games (Clemente et al., 2025). The MF reduction in BF during DLS in 1v1 further suggests that eccentric fatigue was greatest in this format, possibly due to the high braking demands of one-on-one duels, where rapid directional changes are frequent (Fraga et al., 2025). These findings underline the need for format-specific recovery, especially for the hamstrings in high-intensity formats like 1v1, which may elevate the risk of fatigue-related efforts. The contrasting behavior of RF and BF underscores the importance of task-specific monitoring. Practitioners should be aware that hamstring-dominant fatigue may be underestimated if relying only on global load indicators. This level of specificity is especially important in return-to-play protocols (Huygaerts et al., 2020).

The temporal evolution of RMS and MF across five days adds an important perspective on adaptation and fatigue accumulation. RMS values during DLS progressively increased over time, particularly in the 3v3 and 6v6 groups, possibly reflecting neuromuscular adaptation and improved motor unit recruitment with repeated exposure. This aligns with previous findings from 4v4 formats, which reported only short-term impairments in neuromuscular function and transient perturbations (Sparkes et al., 2018). Conversely, MF declined progressively across days, with the most pronounced decrease in the 1v1 format, suggesting cumulative fatigue and potentially insufficient recovery. This reinforces the idea that, despite its smaller format, 1v1 requires careful load monitoring due to its high neuromuscular demands.

Interestingly, CMJ-RMS values remained relatively stable across days, indicating a plateau in muscle activation. However, persistent intergroup differences in MF suggest that fatigue dynamics—not activation capacity—drive the variability in recovery. The mismatch between activation stability and progressive fatigue in some formats suggests the importance of incorporating both RMS and MF in neuromuscular monitoring to monitor training and recovery balance. The findings of this study suggest that, to stimulate explosive strength and maximizing muscle activation, larger formats such as 6v6 are recommended due to their higher post-SSGs RMS responses, particularly in the RF. Moderate formats like 3v3 appear to offer an optimal balance between activation and controlled fatigue, especially beneficial for enhancing hamstring function while minimizing injury risk. In contrast, 1v1 formats, despite their simplicity, impose the highest neuromuscular fatigue—as evidenced by consistently lower MF values—and therefore should be used sparingly or with adjusted recovery protocols. Moreover, the distinct fatigue and activation patterns observed between CMJ and DLS tasks suggests the importance of task-specific assessments when monitoring training load. Practitioners can use this information to individualize recovery strategies, and design SSGs-based microcycles that align with targeted performance outcomes, whether aiming to improve concentric power, postural control, or fatigue resilience.

An interesting finding from this study is that muscle fatigue appears to be present and varies across different game formats, despite the absence of major differences in internal load (HR and VO_2). While HR and VO_2 are commonly used indicators of physiological strain and are consistently reported to be higher in smaller formats (Clemente et al., 2025), they primarily reflect the cardiorespiratory response to exercise and may not fully capture localized muscular fatigue. The secondary results suggest that, although the overall physiological demand was relatively similar, the neuromuscular system experienced differing levels of fatigue. This should be considered by coaches, as it indicates a potential dissociation between overall physiological load and localized neuromuscular fatigue, highlighting the importance of using multiple assessment tools to evaluate training effects and physiological responses in athletes.

Despite the findings, this study has some limitations. Firstly, the research only focused on the four main muscles of the lower limbs. Future research can expand to include more relevant muscle groups, such as the triceps surae and gluteus maximus, which are key muscles involved in lower limb movements. Secondly, this study only adopted two test tasks (DLS and CMJ). In the future, more functional tasks specific to ball sports can be considered, such as sudden stops and direction changes, lateral movements, etc. Thirdly, the research cycle of this study was five days, making it difficult to reflect the long-term training effects. Future research can extend the observation period to investigate the chronic adaptation process. In addition, this study did not measure biochemical indicators and subjective fatigue feelings, and was designed to observe the combined training of several SSGs.

Despite the current limitations of our study, these findings provide a basis for coaches, fitness trainers, and sports scientists to consider when designing training programs. For example, coaches aiming to enhance concentric power might prioritize larger formats like 6v6, given that they elicited higher muscle activation (RMS), particularly in the RF. Conversely, the 3v3 format could be an interesting drill for developing hamstring function and eccentric control, as it appears to offer a good balance between muscle activation and a manageable level of fatigue. For high-intensity conditioning, the 1v1 format is effective, but the significant neuromuscular fatigue it induces—evidenced by the meaningful drop in median frequency (MF)—suggests that coaches should consider implementing specific recovery protocols to help mitigate injury risk, especially for the hamstrings.

Conclusion

This study suggests that SSGs formats elicit distinct neuromuscular responses depending on format of play, and targeted muscle groups. Specifically, larger formats (3v3 and 6v6) were associated with greater post-SSGs muscle activation, particularly during CMJ tasks, while smaller formats like 1v1 induced significantly higher levels of neuromuscular fatigue, as evidenced by decreased EMG median frequency (MF). These effects were also muscle-specific, with the rectus femoris showing peak activation in 6v6 and the biceps femoris responding most favorably in 3v3, highlighting different mechanical demands across formats. Temporal trends further revealed that repeated exposure to SSGs led to adaptive increases in muscle activation but also cumulative fatigue—especially in 1v1—indicating the need for load management. Future studies should investigate how different SSGs formats drive long-term neuromuscular adaptations, evaluate their effects on performance in specific competitive contexts, and determine their potential impact on injury risk. Moreover, examining how SSG intensity, session frequency, and individual player characteristics interact could help establish more precise guidelines for designing training drills and recovery protocols.

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Key points

- 6v6 SSG format induced the highest muscle activation and fatigue, particularly in the rectus femoris suggesting to be suitable for strength-focused stimulus.
- 3v3 SSG format produced a balance between muscle activation and fatigue, especially in the biceps femoris, indicating its potential for enhancing fatigue resistance and control during balance tasks like DLS.
- 1v1 SSG format showed superior initial neuromuscular efficiency (higher DLS median frequency) in early sessions, but greater fatigue accumulation over time, suggesting it may be effective for short-term neural stimulus but less sustainable for prolonged performance.

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