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Research article

Smaller Formats of Volleyball Lead to Greater Improvements in Lower Limb Strength and Power, As Well As Reductions in Landing Forces: A Randomized Controlled Study in Girls

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Abstract
The purpose of this study was to compare the adaptations in muscular strength, power, and landing forces of young female volleyball players enrolled in two experimental programs: one using smaller formats of the game (SFG) and the other using larger formats of the game (LFG), with a third group serving as a control. This study employed a randomized controlled design, with an 8-week intervention period and pre- and post-intervention evaluations. Fifty-six trained/developmental participants (age: 14.7 ± 0.5 years) voluntarily participated in this study. Each experimental group received additional training twice a week. The SFG group participated in 2v2 and 3v3 formats on smaller courts (covering 2/6 of the court's available zones) with a regular net, while the LFG group played in 4v4 and 5v5 formats on larger courts (covering 4/6 of the court's available zones). Assessments were conducted using force platforms and included the following tests: (i) isometric mid-thigh pull test (IMTP), measuring peak force; (ii) squat jump test (SJ), measuring peak force; (iii) countermovement jump test (CMJ), measuring peak power and landing force; and (iv) drop jump test (DJT), measuring the reactive strength index. Significant differences emerged post-intervention across all outcomes ($p < 0.05$). The SFG exhibited significantly greater IMTP peak force compared to both the LFG ($p = 0.012$) and control groups ($p = 0.035$). Additionally, the SFG showed significantly greater SJ peak force than the LFG ($p = 0.036$) and control groups ($p = 0.023$). Regarding CMJ peak power, significantly higher values were observed in the SFG compared to the LFG ($p = 0.042$) and control groups ($p = 0.046$). Moreover, the SFG had significantly lower CMJ peak landing force than both the LFG ($p = 0.049$) and control groups ($p = 0.046$). Finally, RSI was significantly higher in the SFG than in the LFG ($p = 0.046$) and control groups ($p = 0.036$). This study highlights the significant benefits of incorporating 2v2 and 3v3 SFG formats to enhance muscular strength, power, and landing forces in young female volleyball players, contrasting with less effective outcomes observed with 4v4 and 5v5 LFG formats, suggesting potential neuromuscular advantages crucial for improving volleyball performance.

Key words: Volleyball, small-sided games, athletic training, muscular strength.

Introduction

Muscular strength and power are crucial for enhancing the performance and reducing the injury risk in women's volleyball (Augustsson et al., 2011). These physical characteristics are fundamental for executing high-intensity, explosive movements essential to the sport, such as spiking, blocking, and serving (Sattler et al., 2015). Increased muscular strength, particularly in the lower body, enhances jump height, contributing to more effective attacks and defensive actions (de Leeuw et al., 2022). Additionally, muscle power can play a vital role for quick directional changes and jumps on the court (Schons et al., 2019).

While muscular strength and power can be developed through effective training methods such as resistance training (Taha Idrees et al., 2022) or plyometric training (Ramirez-Campillo et al., 2021), these approaches are often associated with analytical-based exercises, excluding the ecological-based training context. Exploring alternative training methods that provide adequate stimulus for enhancing muscular strength and power, while incorporating more tactical and technical context, can be particularly beneficial (Gabbett, 2008). Small-sided games (SSG), among other methods, are especially promising (Halouani et al., 2023), because they promote enjoyment and commitment through their representativeness to the game (Ouertatani et al., 2022). These games can be understood as ecologically-based training, where the dynamics of the game are preserved, but modified by the coach to promote specific behaviors (Davids et al., 2013). Additionally, they provide a significant physiological and physical stimulus while maintaining the technical and tactical specificity of the sport (de Oliveira Castro et al., 2022). SSGs allow manipulation of different task conditions, impacting players by imposing various behaviors and physical demands (de Oliveira Castro et al., 2022). For instance, the smaller the game formats, the higher the physiological demands (Halouani et al., 2023), whereas a larger playing area during these games tends to enhance technical efficiency (Rocha et al., 2020). The frequency of exposure to these physical demands can ultimately promote adaptations in athletes' performance.

Some of the most common task conditions in SSGs involve adjusting the format of play (Halouani et al., 2023) and the court size (Jorge Rodrigues et al., 2022). However, other factors such as net height, types of blocking, and rule modifications also have a notable impact on how players adjust their behavior and experience different physical demands (Drikos et al., 2022; Palao et al., 2024). Modifying the format of play and court dimensions directly increases intensity, as smaller courts and fewer players necessitate more frequent high-intensity movements and individual participation (Halouani et al., 2023). Changes in net height

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may influence jumping dynamics, with taller nets requiring higher jumps, while different blocking rules affect defensive strategies and workload distribution.

While research SSG, especially in volleyball, has been growing, as evidenced by a recent systematic review (de Oliveira Castro et al., 2022), most studies are observational. The few experimental studies that exist compare SSG with other training approaches, often overlooking how varying task conditions, typically integrated into training programs, influence adaptations in muscle strength and power. This is particularly interesting in volleyball, as the game relies on jumping actions, which can naturally impact the level of neuromuscular stimulus, especially if the games influence the density of these actions (i.e., by manipulating the game design). For instance, a study (Gabbett, 2008) comparing skill-based conditioning games with instructional training highlighted that SSGs can effectively simulate the physiological demands of competition and enhance physical fitness parameters such as speed, vertical jump, spike jump, agility, upper-body muscular power, and maximal aerobic capacity. In another experimental study (Gjinovci et al., 2017) comparing SSG and plyometric training, researchers noted that the changes observed between pre- and post-testing were more closely correlated within the plyometric training group. While both training methods resulted in positive improvements in jumping and throwing capacities, plyometric training was found to be more effective than skill-based conditioning in enhancing conditioning capacities among female senior volleyball players (Gjinovci et al., 2017). Similarly, a study (Idrizovic et al., 2018) comparing SSG and plyometric training found that skill-based conditioning did not contribute to improvements in the studied physical fitness variables compared to regular volleyball training. However, the mechanical impact of SSGs can be adjusted by carefully managing the design of these games. By making specific modifications, the stimulus can be optimized to promote more favorable adaptations.

Understanding the impact of SSG requires conducting comparative experimental studies that systematically manipulate task conditions. The way in which these conditions are manipulated plays a crucial role in determining the physical demands of the exercise and, consequently, influencing the ultimate physical adaptation (Wang et al., 2024). This approach is essential for identifying optimal strategies to enhance athletic performance through SSG. Specifically, comparing how different playing formats affect adaptations is crucial. This comparison can guide coaches in adjusting training drills to enhance muscular adaptations. This innovative approach is particularly pertinent in volleyball and adds to the body of research on SSG, providing a basis for both the scientific community and methodological decisions made by strength and conditioning coaches.

Therefore, the aim of this study was to compare the adaptations in muscular strength, power, and landing forces of young female volleyball players enrolled in two experimental programs: one using smaller formats of the game (SFG) and the other using larger formats of the game (LFG), with a third group serving as a control. We hypothesize that SFG will more effectively enhance neuromuscular measures due to the smaller playing area and the greater number of individual actions these games promote, leading to higher mechanical demands during gameplay.

Methods

This section was written in accordance with the CONSORT guidelines for reporting experimental studies (Merkow et al., 2021).

Experimental approach to the problem

This study aimed to compare the effects of two experimental training interventions (SFG and LFG) with a control group, within the context of a randomized controlled trial. The experimental training interventions were incorporated into the regular court sessions, while the control group only participated in the regular court sessions. Players were recruited from regional teams using a convenience sampling strategy. Participants from five different volleyball teams were randomly allocated to one of the three experimental groups, ensuring that each team had players in each group to avoid biases related to specific training processes. Team A had 6 participants in SFG and 4 in the control group; Team B had 10 participants in LFG and 4 in the control group; Team C had 9 players in LFG and 3 in the control group; Team D had 7 players in SFG and 3 in the control group; and Team E had 6 players in SFG and 4 in the control group.

Randomization was conducted before the initial evaluation using the software Research Randomizer, with an allocation ratio of 1:1. The evaluators of the pre- and post-intervention assessments were blinded to the participants' group allocation. However, the players and coaches were not blinded. While regular on-court volleyball training was solely the responsibility of the coaching staff, the training intervention using SSGs was planned collaboratively, with input from both the research team and the coaching staff. These formats were then implemented by the coaching staff under the supervision of the research team.

The intervention study took place in the early phase of the season, before the competitive season began, and lasted a total of 10 weeks. This included 1 week of baseline assessments, 8 weeks of intervention, and 1 week of post-intervention evaluations. The participating teams competed at the same level and had 3 to 4 training sessions per week, with an average duration of 110 minutes per session. While three of the teams had three training sessions per week, two teams had four sessions per week. The interventions occurred twice a week, and as supplement to the regular in-court training which was exclusively responsibility of the coaching stuff. The researchers only interfered with the experimental training intervention, which was administered 20 minutes before the regular on-court sessions during the first and third training sessions of each week.

Participants

After recruiting fifty-nine potential volunteers for the study, three were excluded due to injuries at the time of the first evaluation (Figure 1). Fifty-six female youth volleyball players (age: 14.7 ± 0.5 years; height: 170.1 ± 4.8 cm; body mass: 61.1 ± 5.7 kg; body mass index: 21.1 ± 1.6 experience: 3.7 ± 0.8 years) competing in trained/developmental level (McKay et al., 2022) teams voluntarily enrolled in this study. Participants were included based on the following criteria: (i) being female players with a minimum of three years of experience; (ii) being active players with adherence rates of at least 85% in regular in-court training sessions; (iii) not having injuries or illnesses that interrupted the training intervention during the experimental phase; and (iv) not missing any of the evaluation tests or time points. The exclusion criteria were: (i) players missing more than 15% of the team's training sessions or the intervention program; (ii) being injured or ill during the experimental period; and (iii) missing any of the tests or evaluation time points.

The study protocol received approval from the Ethics Committee of the the Hefei Normal University (2024LLSP007). Furthermore, all participants and their legal guardians provided informed consent. The study followed the ethical principles laid out in the Declaration of Helsinki for research involving human subjects.

Evaluation procedures

The female volleyball players were assessed twice: once before the intervention and once after. These assessments took place in the week prior to the start of the training intervention and in the week immediately following the last intervention session. Both evaluations took place under similar circumstances, specifically during the first training session of the week following 48 hours of rest. The assessments occurred in the afternoon within a laboratory facility maintained at 22ºC with a relative humidity of 50%. The conditions and the order of participant analysis were identical for both evaluations. The evaluations were carried out by a team of six experienced evaluators in a blinded manner, meaning they were unaware of the participants' group assignments.

On the day of evaluation, participants first provided their demographic information and underwent anthropometric measurements (i.e., height and body mass). Following this, they engaged in a standardized warm-up protocol consisting of 5 minutes of moderate-intensity indoor cycling, followed by dynamic stretching exercises for the upper limbs (5 minutes) and lower limbs (7 minutes). After the dynamic stretching, participants performed three sets of 5 reactive jumps, followed by three sets of 5 unilateral drop jumps from a 10 cm box.

Upon completion of the standardized warm-up protocol, all participants followed the same sequence of evaluations: (i) isometric mid-thigh pull test (IMTP),

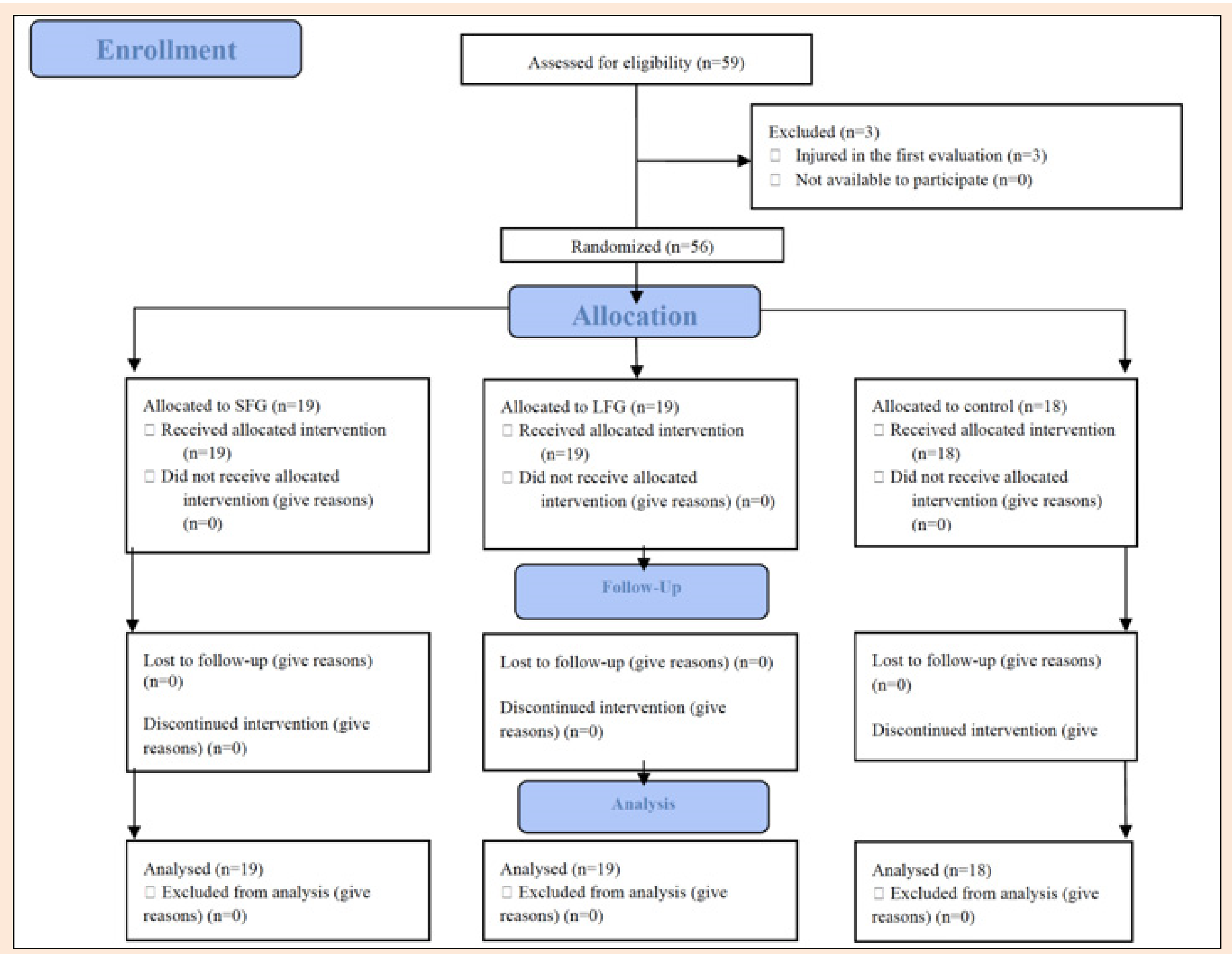

Figure 1. Flow of participants across enrollment, allocation, and analysis. SFG: smaller formats of the game; LFG: larger formats of the game.

(ii) squat jump test (SJT), (iii) countermovement jump test (CMJ), and (iv) drop jump test (DJ). Each test consisted of two trials separated by 3 minutes of rest. A 3-minute rest was also provided between tests. It is also important to report that before the recorded trials, all participants underwent a familiarization trial that was not counted, ensuring they understood the correct movement required for each test. There was a 5-minute rest period between each test.

Procedures for the Isometric Mid-Thigh Pull Test

During IMTP testing, athletes were positioned in a standardized power-pulling stance based on previous recommendations (130 - 140° for the knee angle and 145° for the hip angle) (Comfort et al., 2015). The bar height was adjusted to half the length between the greater trochanter and lateral epicondyle of the knee, using a goniometer to ensure precise alignment within acceptable ranges (Merrigan et al., 2020). The bar was securely fixed in place, eliminating slack. Athletes' hands were secured to the bar using wrist straps to standardize the gripping force, ensuring consistency in measurements during IMTP (Merrigan et al., 2020). Participants were instructed to exert maximal force on the bar for three seconds, emphasizing explosive upward movement. The tests were performed in a force platform (Quattro Jump, Kistler, Winterthur, Switzerland). The average peak vertical force (N) was calculated from the two trials conducted and served as the basis for subsequent data analysis. The average within-player coefficient of variation across the trials was 4.2%.

Procedures for the Squat Jump Test

Participants were instructed to perform an unloaded squat jump. While they were allowed to select their preferred foot position, the distance between their feet was measured to ensure consistency across all assessments. Participants began the test in a squat position, with their knees bent to approximately 90º, allowing them to find their comfortable depth, while keeping their hands on their hips. Upon instruction, they executed the jump with maximal effort, extending their knees powerfully and aiming to land smoothly on the force platform with both feet simultaneously. Peak force (N) was recorded during each trial and subsequently averaged for further data analysis. The average within-player coefficient of variation across the trials was 3.8%.

Procedures for the Countermovement Jump Test

The participants underwent the traditional CMJ test, starting by positioning themselves on the force platform in a standing posture. Following instructions, they initiated the movement by flexing their hips and knees, swiftly descending into a comfortable squat position, approximately at 90º. This was immediately followed by an explosive extension of their hips, knees, and ankles to jump vertically as high as possible, with hands positioned on their hips throughout. Participants were instructed to keep their knees extended during the air phase and to land smoothly on both feet simultaneously. Peak power (W/kg) and peak landing force (N) were recorded for each trial and then averaged for subsequent data analysis. The average within-player coefficient of variation across the trials was 5.6% for peak power and 6.8% for peak landing force.

Drop jump test

The evaluation of the player's reactive strength index (RSI) was conducted using a drop jump test, where participants descended from a platform elevated by 20 centimeters and immediately performed a maximal upward jump upon landing. Jump height was measured using the force platform. The RSI was calculated by dividing the flight time by the ground contact time. The average recorded RSI from the trials was selected for subsequent data analysis. The average within-player coefficient of variation across the trials was 4.7%.

Characteristics of the training intervention

As a supplement to their regular on-court volleyball training, the study introduced SSG interventions during extra-time sessions, conducted before the start of the regular training. Researchers exclusively implemented these experimental interventions, while the volleyball coaches of the teams managed all other in-court sessions. Over an eight-week period, players in the experimental groups participated in two additional SSG sessions per week. These sessions were strategically scheduled with a 48-hour gap between them, and the second session was conducted 48 hours after the first.

Each SSG session began before regular on-court training with a structured warm-up routine. This included 5 minutes of jogging, followed by dynamic stretching exercises for the upper limbs (7 minutes) and lower limbs (7 minutes). Following the dynamic stretching, participants engaged in three sets of 5 reactive jumps. Afterward, players spent 5 minutes working on individual technical elements in pairs, focusing on spiking, reception, and passing. Table 1 provides a comprehensive outline of the training plans for each session throughout the intervention period.

The assignment of teams in each SSG was exclusively the responsibility of the coaches. They aimed to achieve a balance in positions, skill levels, and physical capabilities. Teams were kept consistent to help players become familiar with their teammates and maintain a consistent style of play. However, opposing teams were varied to provide challenges for the players. During the training intervention, alterations were made intentionally to the training plan. After the initial 4 weeks, an additional exercise set was added to the training regimen. Within each 4-week block, variations in net height were also introduced to diversify movement patterns and playing dynamics. Both groups experienced identical variations in these modifications. The sole distinction between the groups lay in their playing formats: the SFG group used 2v2 and 3v3 formats, utilizing only one front and back row zones (e.g., 2 and 1), whereas the LFG group used 4v4 and 5v5 formats across two front and back row zones (e.g., 1, 2, 3, and 6).

Sample size

Using G*power software (version 3.1.9., Universität Düsseldorf, Germany), the study's sample size was calculated. This determination considered three groups and two measurement points, with an effect size of 0.25. To achieve a statistical power of 0.95 and a significance level of 0.05 for ANOVA repeated measures within-between interactions, a total sample size of 48 participants was recommended.

Table 1. Overview of SSG contents throughout the intervention duration.

	SFG – session1	SFG – session 2	LFG – session 1	LFG – session 2
Week 1	Five sets of 2-minute 2v2 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Four sets of 3-minute 3v3 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Five sets of 2-minute 4v4 matches were played on a standard net (2.24m). Each match took place with players occupying two front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.	Four sets of 3-minute 5v5 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.
Week 2	Five sets of 2-minute 2v2 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Four sets of 3-minute 3v3 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Five sets of 2-minute 4v4 matches were played on a standard net (2.24m). Each match took place with players occupying two front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.	Four sets of 3-minute 5v5 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.
Week 3	Five sets of 2-minute 2v2 matches were played on a shorter net (2.14m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Four sets of 3-minute 3v3 matches were played on a shorter net (2.34m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Five sets of 2-minute 4v4 matches were played on a shorter net (2.34m). Each match took place with players occupying two front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.	Four sets of 3-minute 5v5 matches were played on a shorter net (2.34m). Each match took place with players occupying only one front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.
Week 4	Five sets of 2-minute 2v2 matches were played on a shorter net (2.14m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Four sets of 3-minute 3v3 matches were played on a shorter net (2.34m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Five sets of 2-minute 4v4 matches were played on a shorter net (2.34m). Each match took place with players occupying two front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.	Four sets of 3-minute 5v5 matches were played on a shorter net (2.34m). Each match took place with players occupying only one front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.
Week 5	Six sets of 2-minute 2v2 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Five sets of 3-minute 3v3 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Six sets of 2-minute 4v4 matches were played on a standard net (2.24m). Each match took place with players occupying two front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.	Five sets of 3-minute 5v5 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.
Week 6	Six sets of 2-minute 2v2 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Five sets of 3-minute 3v3 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Six sets of 2-minute 4v4 matches were played on a standard net (2.24m). Each match took place with players occupying two front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.	Five sets of 3-minute 5v5 matches were played on a standard net (2.24m). Each match took place with players occupying only one front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.

SFG: smaller formats of the game; LFG: larger formats of the game

Table 1. Continue...

	SFG – session1	SFG – session 2	LFG – session 1	LFG – session 2
Week 7	Six sets of 2-minute 2v2 matches were played on a shorter net (2.14m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Five sets of 3-minute 3v3 matches were played on a shorter net (2.34m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Six sets of 2-minute 4v4 matches were played on a shorter net (2.34m). Each match took place with players occupying two front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.	Five sets of 3-minute 5v5 matches were played on a shorter net (2.34m). Each match took place with players occupying only one front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.
Week 8	Six sets of 2-minute 2v2 matches were played on a shorter net (2.14m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Five sets of 3-minute 3v3 matches were played on a shorter net (2.34m). Each match took place with players occupying only one front and back row zones of the court (example, 2 and 1). The rule required each team to make three touches before returning the ball.	Six sets of 2-minute 4v4 matches were played on a shorter net (2.34m). Each match took place with players occupying two front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.	Five sets of 3-minute 5v5 matches were played on a shorter net (2.34m). Each match took place with players occupying only one front and back row zones of the court (example, 1, 2, 3 and 6). The rule required each team to make three touches before returning the ball.

SFG: smaller formats of the game; LFG: larger formats of the game

Statistical procedures

After confirmation of normal distribution of the sample using the Kolmogorov-Smirnov test ($p > 0.05$) and homogeneity followed with Levene's test ($p > 0.05$), a mixed ANOVA considering the interaction of time (pre and post) and groups (SFG and LFG) was then applied, employing partial eta squared (η_p^2) to assess effect sizes categorized as > 0.01 (small), > 0.06 (moderate), and > 0.14 (large). Post-hoc comparisons utilized the Bonferroni test. Effect sizes for pairwise comparisons were calculated using Cohen's d, with classifications as follows (Hopkins et al., 2009): 0.0 - 0.2 for trivial effects, 0.2 - 0.6 for small, 0.6 - 1.2 for moderate, 1.2 - 2.0 for large, and values above 2.0 for very large effects. JASP software (version 0.18.3, University of Amsterdam, The Netherlands) conducted all statistical analyses, with significance set at $p < 0.05$.

Results

Table 2 presents the demographic and anthropometric descriptive statistics of the participants enrolled in the three experimental groups.

The Table 3 presents the descriptive statistics of strength, power and landing force variables in the three groups. Signification interactions were found between groups and time in the IMTP peak force ($F = 46.214$; $p < 0.001$; $\eta_p^2 = 0.636$), SJ peak force ($F = 89.634$; $p < 0.001$; $\eta_p^2 = 0.772$), CMJ peak power ($F = 18.217$; $p < 0.001$; $\eta_p^2 = 0.407$), CMJ peak landing force ($F = 49.356$; $p < 0.001$; $\eta_p^2 = 0.651$), and RSI ($F = 43.537$; $p < 0.001$; $\eta_p^2 = 0.622$).

No significant differences between groups were found at baseline for any of the measures (see Table 3). However, significant differences emerged post-intervention across all outcomes. Specifically, the SFG exhibited significantly greater IMTP peak force compared to both the LFG (p = 0.012; d = 0.957) and control groups (p = 0.035; d = 0.865). Additionally, the SFG showed significantly greater SJ peak force than the LFG (p = 0.036; d = 1.115) and control groups (p = 0.023; d = 0.824). Regarding CMJ peak power, significantly higher values were observed in the SFG compared to the LFG (p = 0.042; d = 0.763) and control groups (p = 0.046; d = 0.860). Moreover, the SFG had significantly lower CMJ peak landing force than both the LFG (p = 0.049; d = 0.733) and control groups (p = 0.046; d = 0.937). Finally, RSI was significantly higher in the SFG than in the LFG (p = 0.046; d = 0.240) and control groups (p = 0.036; d = 0.769).

It was also noted that the SFG significantly enhanced the following from pre- to post-intervention: IMTP peak force (mean difference: 134.6 N; p < 0.001; d = 0.756), SJ peak force (mean difference: 43.8 N; p < 0.001; d = 0.595), CMJ peak power (mean difference: 1.8 W/kg; p < 0.001; d = 0.360), CMJ peak landing force (mean difference: 149.6 N; p < 0.001; d = 0.438), and RSI (mean difference: 0.08; p < 0.001; d = 0.600).

Table 2. Descriptive statistics (mean ± standard deviation) of demographic and anthropometric variables in the three groups.

	SFG (n = 19)	LFG (n = 19)	Control (n = 18)
Age (years)	14.6 ± 0.6	14.7 ± 0.5	14.5 ± 0.9
Experience (years)	3.8 ± 0.8	3.5 ± 0.8	3.8 ± 0.9
Height (cm)	167.9 ± 4.6	171.4 ± 4.7	171.0 ± 4.5
Body mass (kg)	58.4 ± 4.4	61.9 ± 4.3	63.0 ± 7.2
Body mass index (kg/m²)	20.7 ± 1.2	21.1 ± 1.6	21.5 ± 1.8

SFG: smaller formats of the game; LFG: larger formats of the game

Table 3. Descriptive statistics (mean ± standard deviation) of strength, power and landing force variables in the three groups.

		SFG (n = 19)	LFG (n = 19)	Control (n = 18)	Between-group comparisons
IMTP peak force (N)	Pre	1995.8 ± 173.6	1936.1 ± 179.7	1961.3 ± 176.6	F = 0.542; p = 0.585; η_p^2 = 0.020
	Post	2130.4 ± 182.5 [b,c,*]	1956.3 ± 174.8 [a,*]	1975.9 ± 174.8 [a]	F = 5.337; p = 0.008; η_p^2 = 0.168
SJ peak force (N)	Pre	521.3 ± 74.0	495.0 ± 56.4	488.5 ± 119.9	F = 0.727; p = 0.488; η_p^2 = 0.027
	Post	565.0 ± 73.0 [b,c,*]	493.9 ± 54.5 [a]	487.3 ± 115.7 [a]	F = 4.791; p = 0.012; η_p^2 = 0.153
CMJ peak power (W/kg)	Pre	31.7 ± 4.7	29.3 ± 4.1	29.7 ± 3.5	F = 1.780; p = 0.179; η_p^2 = 0.063
	Post	33.5 ± 5.3 [b,c,*]	29.8 ± 4.4 [a,*]	29.8 ± 3.3 [a]	F = 4.222; p = 0.020; η_p^2 = 0.137
CMJ peak landing force (N)	Pre	1643.1 ± 388.5	1691.1 ± 323.3	1698.7 ± 216.9	F = 0.164; p = 0.849; η_p^2 = 0.006
	Post	1493.5 ± 294.7 [b,c,*]	1720.5 ± 324.6 [a,*]	1729.1 ± 208.3 [a,*]	F = 4.105; p = 0.022; η_p^2 = 0.134
RSI (A.U.)	Pre	1.09 ± 0.15	1.08 ± 0.6	1.07 ± 0.10	F = 0.147; p = 0.864; η_p^2 = 0.006
	Post	1.18 ± 0.15 [b,c,*]	1.09 ± 0.6 [a]	1.08 ± 0.11 [a]	F = 4.321; p = 0.018; η_p^2 = 0.140

IMTP: isometric mid-thigh pull test; SJ: squat jump test; CMJ: countermovement jump test; RSI: reactive strength index; a: significantly different from SFG (p < 0.05); b: significantly different from LFG (p < 0.05); c: significantly different from control (p < 0.05); *: significant within-group difference (post-pre) for a p < 0.05.

Discussion

The current experimental study revealed that SFG are effective in enhancing muscular strength, power, and landing forces in female volleyball players. SFG showed to be significantly better than LFG, which, in turn, did not show a significant difference compared to the control group. After 8 weeks of SFG, female volleyball athletes showed significant improvements in IMTP, SJ, CMJ, and RSI. However, a key finding is that SSG should be carefully implemented for targeting muscular variables in volleyball athletes, as larger formats are not effective in enhancing these main variables.

SFG, utilizing 2v2 and 3v3 formats, have been shown to significantly enhance SJ peak force and CMJ peak power in young female volleyball athletes. This improvement is likely due to the locomotor and mechanical demands imposed by these games during practice sessions (Sheppard and Newton, 2012). SFG formats require a higher frequency of jumps because of the increased individual actions, participation, and rapid movements per player (Rodríguez-Marroyo et al., 2014). This may lead to greater neuromuscular activation and muscular endurance compared to larger formats like 4v4 and 5v5. The intensified demand for quick transitions and explosive actions, such as jumping for blocks or spikes, in smaller team settings may have been promoted greater engagement of fast-twitch muscle fibers, which are essential for developing power and force (Suhadi et al., 2023). Moreover, the more frequent involvement in game actions possibly enhanced movement kinetic and kinematics (Beardt et al., 2018), thereby improving the efficiency of the kinetic chain used in jumping activities. However, measuring the intensity, biomechanical profile, and frequency/density of actions would add significant value to future studies aiming to establish a foundation for understanding whether accumulated load and adaptations are related.

The study also observed that the SFG significantly enhanced the peak landing forces measured during the CMJ, being better than both the LFG and control groups. The high repetition rate of jumps and landings in the smaller formats likely contributed to improved neuromuscular coordination, allowing athletes to better control and dissipate forces upon landing (Iida et al., 2013). This frequent, controlled exposure may help standardize landing mechanics, reducing variability and enhancing the ability to reinforce efficient movement patterns across different scenarios. Furthermore, the constant engagement in dynamic play may have enhanced proprioceptive feedback and joint stability, which are crucial for effective landing mechanics (Onate et al., 2001). These adaptations likely led to improved muscle stiffness and reactive strength (Barker et al., 2018), enabling athletes to manage landing forces more efficiently.

Indeed, the RSI measured in the DJ improved significantly and uniquely in the SFG, a result not observed in the LFG and the control groups. The use of smaller formats in confined spaces likely required athletes to perform more frequent reactive movements, such as jumps, quick directional changes, and rapid transitions to finalize plays. These actions may play a role for developing reactive strength, as they demand quick adaptations to dynamic game situations (McCormick et al., 2014). This increased demand may have stimulated greater neuromuscular adaptation, including enhanced motor unit recruitment and firing frequency, which are critical for improving RSI (Beattie et al., 2017). Additionally, the repetitive exposure to high-intensity stretch-shortening cycle activities in smaller formats may have optimized the efficiency of the elastic components of the musculotendinous unit (Turner and Jeffreys, 2010), leading to better storage and utilization of elastic energy. In contrast, larger formats (4v4 and 5v5) distribute physical demands among more players, resulting in fewer opportunities for each athlete to engage in high-intensity reactive actions.

The significant improvement in peak force during the IMTP, observed exclusively in the SFG, can be attributed to the higher intensity and frequency of powerful actions. The potential for greater individual participation in games, such as increased jumping for blocking and spiking, likely contributes to enhanced neuromuscular adaptations. These activities are expected to improve motor unit recruitment and synchronization, thereby enhancing the athletes' capacity to generate maximal force (Kavanaugh et al., 2018). Furthermore, the continuous demand for rapid force production and stabilization in smaller formats may foster the development of muscle strength and stiffness (Suchomel et al., 2018), particularly in the lower limbs and core, essential for generating high levels of isometric force. Possibly, more dedicated resistance training could provide significant advantages and potentially greater time efficiency (Cuthbert et al., 2023). However, SSGs, as an enjoyable training method (Toh et al., 2011), may complement this approach by addressing the specific demands of the game.

While the current experimental study shows interesting benefits of SFG in enhancing muscular strength, power, and landing forces among female volleyball players, several limitations warrant consideration for future research. Firstly, the study's duration of 8 weeks may not capture long-term effects or potential plateau in improvements beyond this timeframe. Moreover, the study did not monitor the external load demands during training sessions. Therefore, employing microelectromechanical systems would be essential to quantify movements and intensities accurately, thereby establishing a robust explanation that could potentially clarify the observed adaptations. Monitoring the number of jumps, jump power, and overall accelerations and decelerations along the three axes would ultimately help to understand how physical load relates to adaptation. Additionally, monitoring tactical behaviors and technical actions would help understand how the game's dynamics relate to physical efforts. The study's sample size and scope were also limited to a specific population (young female volleyball athletes), indicating a need for broader inclusion of diverse populations to generalize findings. The trainability of the participants may have been positively influenced by this training modality, and future studies with older players or those with higher fitness levels are recommended.

Despite its limitations, this study's findings offer practical implications for coaches working with young female volleyball athletes. Firstly, integrating SFG such as 2v2 and 3v3 formats can significantly enhance muscular strength, power, and landing forces in female volleyball players. Coaches can incorporate these formats as a complementary training approach to regular resistance training, aiming to promote essential neuromuscular adaptations. The emphasis on frequent jumps and rapid movements in SFG sessions appears sufficient for enhancing neuromuscular strength, power, and reactive strength in this population. However, coaches should be mindful of format size, as larger formats (e.g., 4v4, 5v5) do not seem to contribute to enhancing these outcomes and are therefore not recommended for targeting such adaptations.

Conclusion

In conclusion, this study shows the effectiveness of SFG such as 2v2 and 3v3 formats in significantly enhancing muscular strength, power, and landing forces among young female volleyball players over an 8-week period. SFG sessions resulted in significant improvements in peak force during IMTP and SJ, as well as peak power in CMJ, and enhancement of RSI, likely due to increased neuromuscular activation inherent in smaller formats. These formats also contributed to improved peak landing forces in CMJ. In contrast, LFG like 4v4 and 5v5 did not show significant benefits in these variables. Coaches and practitioners are encouraged to incorporate 2v2 and 3v3 SFG into the training routines of young female volleyball players to foster beneficial neuromuscular adaptations crucial for enhancing volleyball performance. Future research should explore the long-term effects and consider the impact of trainability in higher competitive populations on these adaptations.

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Key points

- Small-sided games (SFG) in 2v2 and 3v3 formats significantly improve muscular strength, power, and landing forces in young female volleyball players, likely due to increased neuromuscular activation.
- Larger SSG formats like 4v4 and 5v5 showed no significant advantages in these capacities.

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