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Research article

Scoring and Possession Small-Sided Games Elicit Distinct 48-Hour Muscle Damage and Neuromuscular Responses in Basketball Athletes

DongMing Zhu✉
College of Sports and Health, Nanchang Institute of Science & Technology, 330100 Nanchang, China

Abstract

Small-sided games (SSGs) are widely used in basketball, yet the specific recovery demands imposed by different SSG formats remain unclear. Therefore, the aim of this study was to compare acute and short-term physiological and neuromuscular responses following scoring-oriented SSG using baskets (SSGbasket), possession-oriented (SSGpossession), and a control condition with no SSGs conducted (CON). Thirty-six trained basketball players completed all three conditions in a randomized crossover repeated-measures design. Salivary creatine kinase (CK), pressure pain threshold (PPT), visual analogue scale (VAS) soreness, and reactive strength index (RSI) were assessed at baseline, post, 24 h, and 48 h. There were significant condition × time interactions for CK ($p < 0.001$), PPT ($p < 0.001$), VAS ($p < 0.001$), and RSI ($p < 0.001$). CK increased most in SSGbasket, exceeding SSGpossession and CON at 24 h and 48 h (all $p < 0.001$). PPT decreased significantly at all post-exercise time points in SSGbasket and SSGpossession compared with CON (all $p < 0.01$), with SSGbasket showing the lowest values at 24 h ($p < 0.001$). VAS soreness was substantially higher in SSGbasket vs. the other conditions immediately post, at 24 h, and at 48 h (all $p < 0.001$). RSI decreased significantly from baseline in all formats ($p < 0.001$), but impairments were largest and most prolonged after SSGbasket compared with SSGpossession and CON (all $p < 0.001$). In conclusion, scoring-oriented SSGbasket elicits larger changes in salivary CK, soreness, and neuromuscular function than possession-oriented SSGbasket or the control training day used in this protocol, requiring careful scheduling within the basketball microcycle.

Key words: Basketball, team sports, recovery, neuromuscular impact, fatigue.

Introduction

Basketball coaches have increasingly adopted games-based drills and small-sided games (SSGs) as a core component of training, because they integrate decision-making, skill execution, and high-intensity locomotor and contact actions that closely resemble the competitive context (Montgomery et al., 2010; O'Grady et al., 2020). A key strength of SSGs lies in the coach's ability to manipulate task constraints to produce specific internal and external load profiles (Clemente, 2016). The number of players, relative playing area per athlete, work-to-rest ratio, tactical rules and objectives, and defensive strategies can substantially modify heart rate responses, running demands, and technical-tactical behaviors (Jose Figueiredo de Souza et al., 2024).

In basketball, fewer players (e.g., 2v2 vs 4v4) and full-court formats clearly increase high-intensity movements, heart rate, and ratings of perceived exertion, highlighting the sensitivity of internal and external load to structural modifications of the drill (Klusemann et al., 2012). Recently, a more nuanced body of work in youth soccer has focused on "scoring method" and "bout-ending mechanism" as task constraints, demonstrating that goal-oriented vs ball-possession formats, and the presence or absence of scoring targets, substantially alter psychophysiological intensity and tactical behavior in SSGs (Qiao et al., 2025).

The manipulation of scoring rules appears especially relevant when contrasting finishing-oriented versus possession-oriented tasks. In these soccer SSGs ball-possession formats and larger playing areas are associated with higher heart rate intensities but impaired technical accuracy and tactical decision-making, suggesting a trade-off between physiological overload and execution quality under fatigue (Qiao et al., 2025). However, in basketball SSGs, the specific consequences of manipulating tactical objectives (e.g., scoring- vs possession-oriented rules) for neuromuscular fatigue and indirect markers of muscle damage, particularly over the subsequent 24 - 48 h, have not been examined.

Within basketball, SSGs and games-based drills are now a dominant mode of practice across levels of play. A systematic review of external and internal workloads in basketball games-based drills demonstrated that reducing player numbers, increasing space, and using continuous formats generally increase internal load (heart rate, perceived exertion) and high-intensity accelerations and decelerations (O'Grady et al., 2020). Experimental studies in male basketball players show that 2v2 and 3v3 SSGs elicit very high heart rate responses (~85 - 90% HRmax) and substantial sprinting and shuffling demands, often comparable to or exceeding those observed in full 5v5 practice drills (Klusemann et al., 2012). In 3v3 basketball SSGs, varying tactical tasks (offensive vs defensive emphasis) and work–rest regimes also modulates external load, internal load, and acute hormonal responses, with offensive-oriented tasks and longer work intervals producing higher physical and physiological strain and elevations in cortisol (Sansone et al., 2019). These findings indicate that basketball SSGs are potent stimuli not only for technical-tactical development but also for inducing substantial metabolic and neuromuscular stress.

The acute fatigue and recovery profile following such game-based tasks has become a growing focus in team sports, due to its relevance for weekly periodization, injury risk, and return-to-play management. In soccer, con-

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trolled SSG protocols have been associated with pronounced exercise-induced muscle damage (EIMD), evidenced by delayed-onset muscle soreness (DOMS), elevations in creatine kinase (CK), and transient decrements in jump, sprint, and strength performance for up to 48–72 hours (Papanikolaou et al., 2021; Bekris et al., 2022). For instance, competitive players exposed to 4v4 and 8v8 SSG formats showed prolonged increases in CK and DOMS and slow recovery kinetics of strength and countermovement jump performance, with lower-density formats (i.e., greater relative area per player) inducing longer-lasting decrements (Papanikolaou et al., 2021). Similarly, 3v3 SSGs in semi-professional soccer players have been shown to perturb inflammatory markers, CK, and hormonal indicators, supporting the notion that SSGs can generate a muscle damage and systemic stress profile comparable in some respects to match play (Bekris et al., 2022).

In basketball, the time course of fatigue and muscle damage has been more frequently described in relation to matches or tournaments than to SSGs per se. A simulated basketball game in college-level players produced substantial increases in CK at 24 h (>200%) and 48 h (>30%) post-game, indicative of significant muscle damage, despite players maintaining sprint and jump performance during the match itself (Pliauga et al., 2015). Tournament-based research has reported small-to-moderate increases in markers of muscle damage and inflammation across 3-day competitions, with only modest benefits of different recovery interventions, emphasizing the cumulative stress of repeated basketball exposures (Montgomery et al., 2008).

A recent systematic review on recovery in basketball synthesized the evidence for sleep, nutrition, cold-water immersion, compression garments, and other modalities, and explicitly highlighted the importance of monitoring physiological and biochemical markers such as CK to individualize recovery strategies (Mihajlovic et al., 2023). Within this literature, the temporal profile of fatigue and muscle damage has been characterized predominantly in able-bodied players during simulated or competitive match play, whereas recovery after training sessions built specifically around small-sided games is much less documented. Existing SSG-based research in basketball has largely involved wheelchair athletes and has focused on acute internal load and neuromuscular responses within the session or immediately pre- to post-SSG, with minimal information on 24 - 48 h recovery trajectories in able-bodied players (Iturricastillo et al., 2018).

Evidence from other contact and invasion sports suggests that not only the global load, but also the qualitative nature of the task (e.g., level of contact, tackling, or collision) can substantially modulate neuromuscular fatigue and muscle damage responses. In rugby league (Johnston et al., 2014), adding physical contact to SSGs markedly increased upper-body neuromuscular fatigue and blood CK compared with non-contact SSGs, leading the authors to recommend that highly contact-intensive training be scheduled well in advance of competition. Likewise, in handball, contact SSGs induced greater inflammatory responses and larger upper- and lower-body neuromuscular impairments than no-contact versions, underscoring the impact of task-specific constraints on fatigue profiles (Dello Iacono et al., 2017). When viewed alongside work in soccer on scoring methods and field size, which shows that ball-possession formats and larger areas can simultaneously increase internal load and impair technical decision-making (Qiao et al., 2025), these findings suggest that "how" an SSG is structured (e.g., scoring vs possession emphasis) may substantially influence the depth and duration of fatigue and muscle perturbation.

Despite the rapid growth of SSG research, the recent scoping review (Clemente et al., 2025) on fatigue and recovery after SSGs emphasized several important gaps. Most work has been conducted in soccer, with limited sport-specific data in basketball, particularly in able-bodied players; existing basketball SSG studies emphasize acute internal/external load or hormonal responses, but rarely extend follow-up beyond the immediate post-exercise period (Sansone et al., 2019; O'Grady et al., 2020). Moreover, few studies directly compare SSG formats that differ only in their tactical objective or scoring rule (e.g., ball possession vs goal/basket scoring) while holding other variables (number of players, court area, work–rest ratio) constant, and almost none report neuromuscular and muscle damage markers at 24 and 48 h post-exercise in such a design. Creatine kinase and related biochemical markers are widely used as practical indicators of mechanical damage and recovery–fatigue status in team sport athletes, and elevated CK concentrations have been associated with decrements in neuromuscular performance and potentially increased injury risk when recovery is not enough (Baird et al., 2012). Studies in soccer report that CK peaks between 24 and 48 h after intense match or SSG exposure in many athletes, coinciding with peak DOMS and reduced jumping and sprinting capacity (Papanikolaou et al., 2021). Yet the temporal profile and magnitude of CK and neuromuscular changes after basketball SSGs with different tactical objectives (baskets vs ball possession) remain undefined, and it is unclear whether the additional technical pressure and continuous involvement typical of ball-possession formats produce a different fatigue and muscle-damage signature than scoring-oriented SSGs that emphasize finishing actions around the basket.

To our knowledge, no previous study in able-bodied basketball players has directly compared scoring- versus possession-oriented SSGs while tracking muscle damage and neuromuscular markers over 48 hours. In this context, there is a clear need for controlled, sport-specific studies that examine how different basketball SSG formats, embedded in regular training, influence acute and residual fatigue and muscle damage. A randomized three-period crossover design, in which the same athletes experience (i) regular basketball training plus SSGs with baskets (i.e., scoring-focused games), (ii) the same regular training plus ball-possession SSGs without baskets as the primary objective, and (iii) regular training alone (control), allows within-subject comparisons that markedly reduce inter-individual variability in fitness, playing position, and recovery capacity. However, when such conditions are implemented across consecutive in-season weeks with official matches, potential order and carryover effects, as well as week-to-week differences in competitive demands and background training load, cannot be completely eliminated. In the present protocol, we sought to mitigate these influences by randomizing the sequence of conditions, embedding each experimental session at the same point of the weekly microcycle, and standardizing the surrounding training structure. By assessing neuromuscular performance and indirect muscle-damage markers immediately post, 24 h, and 48 h after each condition, this design still provides a robust within-player comparison of the acute load and short-term recovery trajectory associated with each SSG format and the control training day.

Therefore, the primary aim of the present study is to compare the acute and short-term (24 and 48 h) effects of basketball SSGs with baskets (SSGbasket), basketball small-sided ball-possession games (SSGpossession), and regular training without SSGs (CON) on markers of fatigue and muscle damage in trained basketball players. Specifically, we seek to examine differences between conditions in neuromuscular performance (e.g., jump test), delayed onset muscle soreness (DOMS), pressure pain threshold (PPT) and CK across the 48-hour recovery period. By isolating the influence of the SSG tactical objective (scoring vs ball possession) while controlling for the underlying training session, this study aims to provide applied, evidence-based guidance on how to integrate different SSG formats into basketball microcycles without compromising recovery or increasing the risk of maladaptive fatigue.

Methods

Study design and setting

This investigation was designed as a three-period, three-condition randomized crossover trial with repeated measures at baseline, immediately post-session, 24 h, and 48 h. All data were collected in the early phase of the competitive season, when players had already completed the pre-season period and were engaged in a regular weekly match schedule. Participants were recruited from three competitive regional-level basketball teams that followed a comparable in-season microcycle. Participants were allocated in a 1:1:1 ratio to one of three intervention sequences (Figure 1), each comprising the three experimental conditions (SSGbasket, SSGpossession, CON) in a different order. The randomization sequence was generated a priori by an investigator who was not involved in data collection or outcome assessment using a computer-based random number generator. Allocation was stratified by team so that all three sequences were represented within each squad. To maintain allocation concealment, the sequence list was implemented using sequentially numbered, opaque envelopes prepared by the same investigator. Envelopes corresponding to each player were opened only after completion of baseline assessments and immediately before the first experimental week, when players and coaching staff were

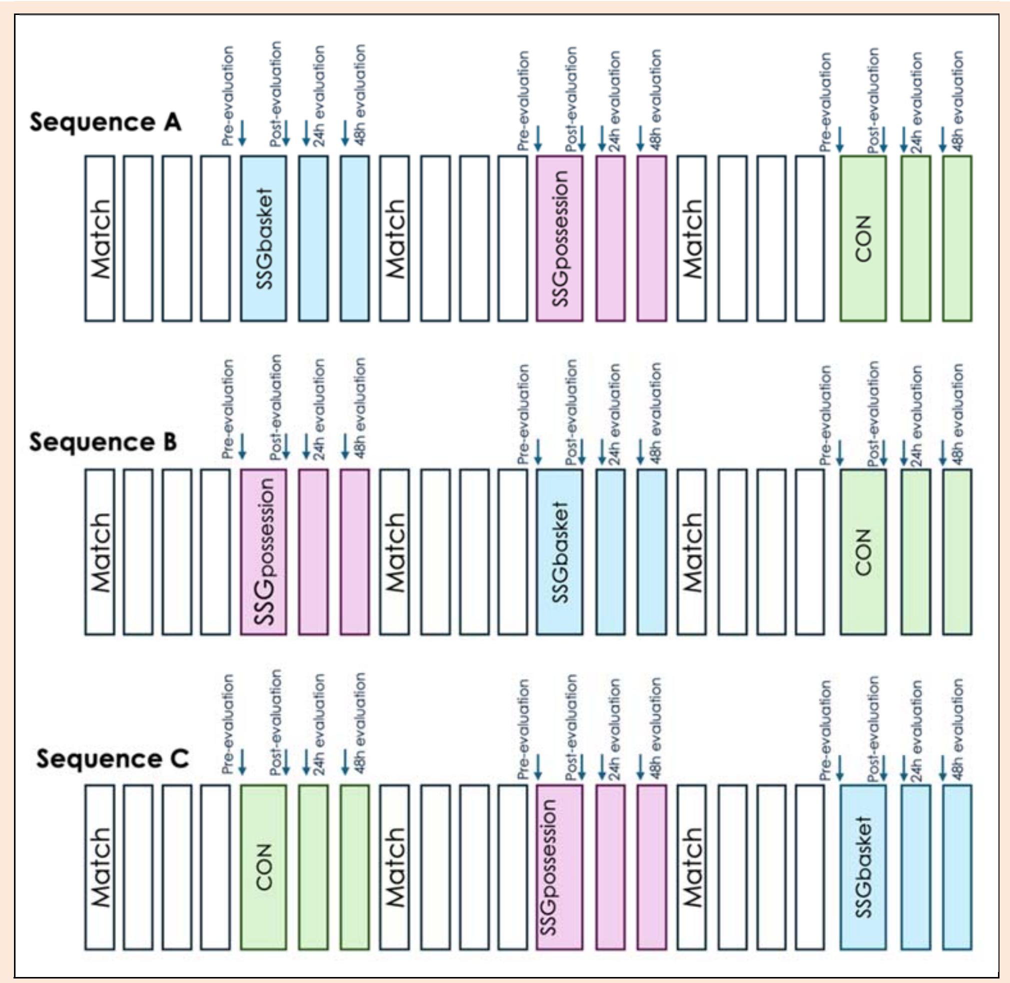

Figure 1. Three-week study design and the three different randomized sequences. SSGbasket: small-sided games with baskets; SSGpossession: small-sided games with ball possession; COM: control (no small-sided games). The arrows illustrate the time points of evaluation.

informed of the assigned sequence. The three experimental weeks were scheduled consecutively, and in each week every player completed exactly one experimental condition, such that all participants were exposed to each condition once over the three-week period. The weekly structure was standardized to minimize confounding effects of variations in competition and training load. Each experimental condition was implemented on the Wednesday of the microcycle, approximately 72 h after the official weekend match, when players had returned to a relatively recovered state but were still within the same competitive rhythm. On each of these Wednesdays, the regular team practice was conducted as usual, and the specific experimental condition was embedded into the main training content: (i) SSGbasket, in which players performed SSGs oriented toward scoring on regulation baskets; (ii) SSGpossession, in which players performed structurally similar small-sided games but with ball possession, rather than basket scoring, as the primary objective; or (iii) CON, in which players completed only the standard team training content without any additional SSGs component. The overall pattern of training volume, session timing, and rest days across the three weeks was kept as consistent as possible for each team to reduce between-week variability in background load. Given this standardized microcycle structure and the placement of each experimental session 72 h after the preceding official match and one week apart from the next experimental condition, the interval between conditions was considered sufficient to allow dissipation of residual fatigue from the prior experimental exposure (Pliauga et al., 2015; Edwards et al., 2018).

All sessions and measurements were conducted on the teams' usual indoor basketball courts during their habitual training time in the late afternoon or early evening, under stable environmental conditions. On the day of each experimental session (Wednesday), players underwent baseline (pre-session) assessment followed by the assigned training condition, after which immediate post-session measurements were collected. Follow-up assessments were then performed 24 h and 48 h after each experimental session, at the same time of day as the baseline assessment to control for diurnal variation. At all four time points (pre, post, 24 h, 48 h) during each of the three weeks, the following outcomes were recorded: salivary creatine kinase (CK) concentration as a biochemical index of muscle impact, pressure pain threshold (PPT) in the hamstrings as an objective marker of muscle tenderness, delayed-onset muscle soreness (DOMS), and reactive strength index (RSI) derived from a drop jump test as a neuromuscular performance indicator.

To characterize the internal load imposed by each condition and to provide a control measure of perceived demands, players also reported their session rating of perceived exertion using the Borg CR-10 scale after each experimental training session. These ratings were collected consistently across all three conditions and weeks, allowing comparison of perceived intensity between SSGbasket, SSGpossession, and CON. The combination of a randomized crossover design, tightly controlled weekly structure, and repeated measurements over 48 h was chosen to facilitate within-player comparisons of the time course of fatigue and muscle impact associated with each type of SSG and with regular training alone.

Participants

For this crossover design, an a priori sample size estimation was performed using G*Power 3.1 for F-tests, ANOVA: repeated measures, within factors. The calculation was based on detecting a condition × time interaction in salivary CK, which we considered the primary outcome for this trial. We based the expected magnitude of this interaction on previous work showing moderate-to-large changes in CK, neuromuscular performance and delayed-onset muscle soreness (DOMS) over 24 - 48 h after small-sided games and basketball-specific training, with typical partial η^2 values in the range 0.08 - 0.15 (Johnston et al., 2014; Pliauga et al., 2015; Mascarin et al., 2018; Doma et al., 2018; Bekris et al., 2022). These η^2 values correspond to Cohen's f of approximately 0.29 - 0.42 when converted using f = √(η^2/(1-η^2)). To avoid overestimating the expected effect and to adopt a conservative assumption within this range, we specified a medium effect size of $f = 0.30$ for the condition × time interaction. The remaining parameters were $\alpha = 0.05$, desired power $(1-\beta) = 0.80$, one group (within-subjects), and 12 repeated measurements (3 conditions × 4 time points), assuming an average correlation among repeated measures of $r = 0.60$ and a conservative nonsphericity correction $\varepsilon = 0.75$. Under these assumptions, the computed minimum sample size was $N = 24$ players to detect the prespecified medium condition × time interaction with 80% power. To account for potential attrition and missing data (estimated at 20 - 25%), we planned to recruit at least 30 athletes.

A total of 43 males under-21 (20.1 ± 0.8 years old; 187.2 ± 5.3 cm; 74.6 ± 4.1 kg; 6.8 ± 3.2 years of experience) provincial basketball players from three teams competing in the same regional amateur league were initially screened for eligibility. Recruitment occurred through convenience sampling, with entire teams invited to participate as part of their early-season training period. Of the 43 players approached, 36 met the inclusion criteria and agreed to participate in the study. The remaining seven players were excluded because they were either injured at the time of data collection or unavailable to attend all scheduled measurement sessions across the three experimental weeks.

Inclusion criteria required that athletes (i) were registered under-21 players competing in the provencial regional amateur competition, (ii) had completed the pre-season training period, (iii) were free from musculoskeletal injury for at least four weeks prior to the start of the study, (iv) were able to participate fully in all scheduled training sessions, and (v) were available for all four measurement time points (pre, post, 24 h, 48 h) during each of the three intervention weeks. Exclusion criteria included (i) current injury or medical condition limiting full basketball participation, (ii) use of medications or recovery treatments known to affect muscle damage or neuromuscular performance markers, (iii) and absence from any of the scheduled data collection sessions.

All participating teams followed a typical training structure for Chinese under-21 amateur regional-level basketball players. This consisted of four team-based training sessions per week, each lasting approximately 90 - 120 minutes, including warm-up, technical and tactical work, physical conditioning, and small-sided or full-court play segments. Matches occured once per week on weekends. Training sessions during the study period were conducted in accordance with the teams' habitual seasonal structure, and no changes were made to the surrounding microcycle aside from the implementation of the experimental SSG conditions.

Ethical approval for the study was obtained from the Nanchang Institute of Science & Technology ethics committee (code number NIST20250427), which reviewed the study protocol in accordance with the Declaration of Helsinki (2013 revision) and standards for research involving human participants. All players provided written informed consent prior to participation. The consent procedures included a clear explanation of the study aims, testing schedule, potential risks, voluntary nature of participation, and the right to withdraw at any time without penalty. All data were anonymized and treated confidentially, with coded identifiers used during data processing to protect participant privacy.

Small-sided games

All experimental conditions were carried out within a standardized SSG format designed to provide a consistent, repeatable stimulus across the three intervention weeks. The SSG format was identical for both experimental conditions except for the tactical objective (scoring on baskets vs maintaining ball possession). Each drill was performed as a 2 vs 2 game, using teams and opponents that remained constant throughout the three-week protocol to reduce variability arising from unfamiliar team dynamics or changing opposition profiles.

The games were played on a reduced playing area corresponding to one-third of a regulation basketball court length, positioned laterally so that players used the full court width. The playing area for each SSG was approximately 9.3 m in length and 15 m in width, totaling 140 m².

All SSGs followed rules derived from standard basketball regulations, with minor adjustments to suit the reduced space and to encourage continuous play. Usual violations such as double dribbling, traveling, or excessive contact were enforced. However, modifications were applied to the restricted-area rules and shooting constraints to better fit the reduced court dimensions. Players were not allowed to remain statically inside a designated area for prolonged periods, ensuring movement fluidity and preventing defensive congestion. A technical staff member acted as referee for each game to ensure consistency in rule application, maintain competitive integrity, and minimize variability in stoppages or enforcement. An official size basketball (Men's size 7) was used during all SSGs.

The intervention differed only in the tactical objective assigned to the SSGs. In the SSGbasket condition, the court was equipped with regulation baskets, and players aimed to score as many points as possible within each set. Standard scoring values were applied. Defensive actions, tactical spacing, and transitions were thus oriented toward creating or preventing scoring opportunities. In the SSGpossession condition, the same playing area, number of players, and temporal structure were maintained, but no baskets were used, and scoring was removed entirely. The objective of the drill was to maximize ball possession time, encouraging teams to maintain control under pressure, execute passes efficiently, and create movement structures to retain the ball. Turnovers or defensive deflections resulted in immediate possession changes. This condition was designed to stimulate sustained technical involvement, reduced stoppages, and high-intensity repeated actions, without the burst demands associated with scoring attempts.

The temporal structure of the intervention was standardized across both SSG conditions. Athletes completed six sets of 2 minutes of play, each followed by 2 minutes of passive recovery to allow partial physiological restoration while maintaining the accumulated high-intensity profile typical of basketball SSGs. Players were instructed to compete at full intensity in every bout, and coaches reinforced the importance of maximal tactical, technical, and physical engagement.

In the control (CON) condition, players performed the same full team training session as their teammates but did not participate in the SSG component. While the other two conditions included the SSGs before the regular training session content, the control group proceeded directly from warm-up to the standard technical–tactical team practice. This allowed the CON condition to serve as a representative training-day comparator while isolating the effects of SSGbasket and SSGpossession on subsequent fatigue and muscle-impact outcomes. All sessions were conducted indoors on the teams' habitual training courts, at the same time of day each week, and using the same equipment and warm-up procedures to maintain environmental and procedural consistency across conditions.

Evaluations

All physiological, neuromuscular, and perceptual evaluations were conducted under standardized conditions to ensure methodological consistency and replicability. On the day of each experimental condition (SSGbasket, SSGpossession, or CON), participants were assessed before the SSGs, immediately after the SSGs, and again at 24 h and 48 h post-intervention. At each time point, the following outcomes were measured in the same fixed order: salivary creatine kinase (CK), pressure pain threshold (PPT) of the hamstrings, delayed-onset muscle soreness (DOMS), and reactive strength index (RSI) obtained from a standardized drop jump protocol. Immediately after completing SSG bouts (only in SSGbasket and SSGpossession), players also reported their perceived internal load using the Borg CR-10 scale, serving as a reference for session-related exertion.

All evaluations took place in a dedicated assessment room located adjacent to the indoor training court. The room was environmentally controlled at 22°C with 55% relative humidity to minimize external influences on physiological or neuromuscular outcomes. Testing was conducted by the same team of trained evaluators throughout the study to reduce inter-rater variability. All assessments were scheduled at the same time of day (afternoon) for each participant across the three weeks to mitigate circadian fluctuations in performance and biological markers.

A consistent testing sequence was applied at every data collection point to standardize the order of physiological and neuromuscular stress. First, athletes were seated comfortably for salivary CK collection, ensuring at least 10 minutes without food or drink intake beforehand. Second, PPT was assessed on the dominant-limb hamstring using a calibrated algometer, following three consecutive measures with standardized application rate. Third, DOMS ratings were obtained using a validated visual analog scale, with athletes performing a controlled squat movement to reproduce muscle tension. Fourth, athletes performed the drop jump test from a fixed height to determine RSI, completing three attempts separated by brief rest periods, with the best performance retained for analysis. In SSGbasket and SSGpossession, the Borg CR-10 rating was obtained immediately after the final SSG bout before the in-court regular training occur.

On SSG days, the pre-session evaluation was performed immediately before the warm-up and SSG intervention, while the post-session evaluation occurred within 5 minutes of the final bout to capture acute fatigue effects. At 24 h and 48 h, evaluations were conducted before the team's regular training session, representing the athletes' recovery status upon re-entering their normal training environment.

Participants were instructed not to engage in any additional recovery modalities outside of their normal lifestyle and team training routines. They were asked to refrain from massage, cold-water immersion, sauna, compression garments, or any structured recovery treatments during the entire three-week protocol. Athletes were also instructed to maintain their typical daily habits (including sleep schedules, school or work activities, and nutrition patterns) to preserve ecological validity and ensure that observed changes reflected the training conditions rather than external recovery interventions.

Salivary creatine kinase

Salivary CK was selected as a non-invasive surrogate of exercise-induced muscle damage and muscle membrane disruption. Several studies in athletes show that CK activity in saliva increases after strenuous exercise or match play in team sports such as futsal (Barranco et al., 2017) and rugby sevens (González Fernández et al., 2020), suggesting that salivary CK is responsive to muscle-damaging loads. Moreover, concurrent blood–saliva sampling in athletes indicates that salivary CK closely tracks plasmatic CK both at rest and following high-intensity exercise, with strong correlations and acceptable agreement between measures (Ovchinnikov et al., 2022).

Saliva samples were collected using the passive drool method, which minimizes stimulation-related variability and is widely recommended for endocrinological and biochemical saliva analyses. Before sampling, athletes refrained from eating, drinking (other than water), or using oral hygiene products for at least 10 minutes to avoid contamination or dilution effects. Participants sat comfortably with their head slightly inclined forward and allowed saliva to naturally pool before passively drooling into a sterile polypropylene collection tube.

Immediately after collection, samples were sealed, labeled with coded identifiers, and placed in a portable refrigerated container at approximately 4°C. All samples were transported to the laboratory within one hour. Upon arrival, they were centrifuged at 3000 rpm for 10 minutes to remove mucins and insoluble material. CK activity was then quantified using the EnzyChrom Creatine Kinase Assay Kit (ECPK-100, BioAssay Systems, USA), an analytically robust colorimetric assay. The EnzyChrom™ CK method shows strong analytical validity, with a sensitivity threshold of <10 U/L, and exhibits excellent reliability, with reported intra-assay coefficients of variation typically below 5% and inter-assay variability below 10%, making it suitable for repeated-measures monitoring in athletic populations. Assays were completed according to the manufacturer's instructions, and absorbance readings were obtained using a calibrated microplate reader (BioTek, ELx800). All samples were analyzed in duplicate, with mean values used for subsequent analysis to enhance precision.

Pressure pain threshold

The measurement site was the midpoint of the dominant limb's hamstring muscle belly (approximately halfway between the ischial tuberosity and the medial tibial tuberosity), which was marked with a skin-safe pen to ensure consistency across sessions. A calibrated digital algometer (Wagner FDX10 Algometer, Wagner Instruments Inc., Greenwich CT, USA) was used for all PPT assessments. The device employs a 1 cm^2 probe tip and allows measurement in kg/cm^2. The examiner placed the probe tip perpendicular to the skin surface and applied increasing pressure at a constant rate. Participants were instructed to say "stop" as soon as the sensation of deep pressure changed into the sensation of pain (i.e., the pain-threshold moment). Three consecutive trials were performed, separated by 30 seconds, and the mean value of the three readings was used for that time point. The same trained examiner performed all measurements throughout the study to minimize inter-rater variability.

PPT and DOMS were assessed over the dominant hamstring because this muscle group is loaded eccentrically during high-intensity basketball actions such as sprinting, braking and jump-landing, and has been shown to exhibit prominent post-match soreness and biochemical signs of muscle damage in basketball players (Moreira et al., 2013; Pliauga et al., 2015).

Delayed onset muscle soreness

DOMS was quantified using a 100-mm Visual Analog Scale (VAS), which is considered the gold-standard method for subjective pain assessment due to its high sensitivity, ease of use, and excellent reliability in both clinical and sports-science contexts. The VAS for exercise-induced muscle pain has demonstrated excellent test–retest reliability, with intraclass correlation coefficients between 0.98 and 0.99, small coefficients of variation (2.2 - 4.5%), and a standard error of measurement around 2.6 mm in experimental DOMS models (Tenberg et al., 2022). The VAS consisted of a 100-mm horizontal line anchored at the left end with "no soreness" (0 mm) and at the right end with "extreme soreness" (100 mm). Participants were asked to rate the level of soreness specifically in their dominant-leg hamstring muscles.

Reactive strength index

RSI was calculated as the ratio of jump height (m) to ground contact time (s) during a single drop jump. All RSI assessments were conducted using the MyJump2 mobile application (MyJump Lab, Spain), a validated tool that analyzes high-speed video recordings to determine jump height and contact time (Haynes et al., 2019).

For the drop jump test, participants stepped off a 30-cm plyometric box keeping hands on their hips to minimize arm swing. Upon ground contact, athletes were instructed to "jump as fast and as high as possible", emphasizing minimal ground contact time and maximal rebound height. Each athlete performed three trials, separated by 45 - 60 seconds of passive rest to avoid fatigue accumulation. The best (highest RSI) of the three attempts was retained for analysis.

Video recordings were captured using an iPhone with a high-speed camera operating at 240 frames per second, positioned on a tripod at approximately 1.5 m distance and perpendicular to the sagittal plane of the movement. The same device, app version, and rater were used for all measurements to minimize procedural variability. The analyst selected the frames corresponding to initial ground contact and takeoff within the MyJump2 interface, following the app's recommended workflow. The software then automatically computed jump height and contact time, from which RSI was derived.

Statistical methods

Normality of residuals was assessed using the Shapiro–Wilk test, while sphericity was examined using Mauchly's test; violations of sphericity were corrected using the Greenhouse–Geisser adjustment. For all repeated-measures models, residual diagnostics were examined to verify model assumptions. In particular, we inspected Q–Q plots and residual-versus-fitted value plots to assess the normality and homoscedasticity of residuals, and no substantial violations of these assumptions were observed. Descriptive statistics are presented as mean ± standard deviation (SD), together with 95% confidence intervals where appropriate. Given the repeated-measures, fully within-subject structure (same athletes completing all three conditions and all four time points), the primary analyses for each dependent variable (salivary CK, PPT, DOMS, and RSI) were conducted using a two-way repeated-measures analysis of variance (ANOVA) with factors: (i) Condition (3 levels: SSGbasket, SSGpossession, CON); and (ii) Time (4 levels: pre, post, 24 h, 48 h). The condition × time interaction was the primary effect of interest, as it reflects whether the recovery pattern differed between SSG types and control. Where significant main or interaction effects were detected, we conducted planned post hoc pairwise comparisons with Bonferroni correction. For each dependent variable (salivary CK, PPT, DOMS, RSI), two families of pairwise tests were examined: (i) between-condition comparisons (SSGbasket vs SSGpossession, SSGbasket vs CON, SSGpossession vs CON) at each time point (4 time points × 3 comparisons); and (ii) within-condition comparisons between time points (pre vs post, pre vs 24 h, pre vs 48 h, post vs 24 h, post vs 48 h, 24 h vs 48 h) performed separately for each condition (3 conditions × 6 comparisons). Bonferroni adjustment was applied within each family of tests (i.e., between-condition contrasts at a given outcome and time, and within-condition time contrasts for a given outcome), and results were interpreted using the Bonferroni-adjusted p-values ($p < 0.05$). Session perceived exertion (CR-10) was analyzed using a t-paired test (comparing the SSGs conditions). Effect sizes for ANOVA components were reported using partial eta squared (η^2p), classified as small (0.01), moderate (0.06), or large (0.14). Pairwise comparisons additionally included Cohen's d effect sizes with the following interpretation (Cohen, 1988): trivial (<0.20), small (0.20 - 0.49), moderate (0.50 - 0.79), and large (≥0.80). Session perceived exertion (CR-10) was analyzed using a one-way repeated-measures ANOVA across the conditions, since it was measured only once per session. Post hoc tests with Bonferroni adjustment were again applied when necessary. All analyses were conducted using IBM SPSS Statistics (Version 27). Significance was set at $p < 0.05$.

Results

For salivary CK, Mauchly's test indicated that the sphericity assumption was met for the factor Condition ($W = 0.918$, $p = 0.232$), but violated for Time and for the Condition × Time interaction (both $p < 0.001$). The two-way repeated-measures ANOVA revealed a large Condition × Time interaction for CK activity ($F(2.96, 103.65) = 26.68$, $p < 0.001$, $\eta^2p = 0.433$). Across the entire protocol there were also large main effects of Condition ($F(2,70) = 71.36$, $p < 0.001$, $\eta^2p = 0.671$) and Time ($F(1.20, 42.00) = 678.70$, $p < 0.001$, $\eta^2p = 0.951$). Between-condition comparisons at each time point showed that CK concentrations were comparable at baseline ($p > 0.05$) but differed significantly at all subsequent time points ($p < 0.001$). This is illustrated in Figure 2.

Within-condition analyses confirmed distinct recovery trajectories across the 48-hour period. In SSGbasket, CK rose progressively at each time point relative to baseline: values were higher immediately post-session (mean difference 8.58 U/L, 95% CI 3.61 to 13.56, $p < 0.001$), further elevated at 24 h (17.64 U/L, 95% CI 11.78 to 23.50, $p < 0.001$), and peaked at 48 h (85.72 U/L, 95% CI 77.57 to 93.87, $p < 0.001$). Each later time point also exceeded the preceding one (post vs 24 h, 9.06 U/L, 95% CI 6.55 to 11.56, $p < 0.001$; post vs 48 h, 77.14 U/L, 95% CI 67.71 to 86.57, $p < 0.001$; 24 h vs 48 h, 68.08 U/L, 95% CI 57.20 to 78.97, $p < 0.001$), consistent with a large and continuously accumulating muscle-damage response. In SSGpossession, CK also increased significantly over time, but with a smaller overall magnitude: compared with baseline, levels were higher immediately post-session (4.50 U/L, 95% CI 0.43 to 8.57, $p = 0.023$), at 24 h (11.94 U/L, 95% CI 6.30 to 17.59, $p < 0.001$), and at 48 h (59.64 U/L, 95% CI 52.67 to 66.61, $p < 0.001$). In this condition, CK at 24 h exceeded post-session values (7.44 U/L, 95% CI 0.30 to 14.59, $p = 0.037$), and 48 h concentrations remained substantially highe r than both post and 24 h (55.14 -

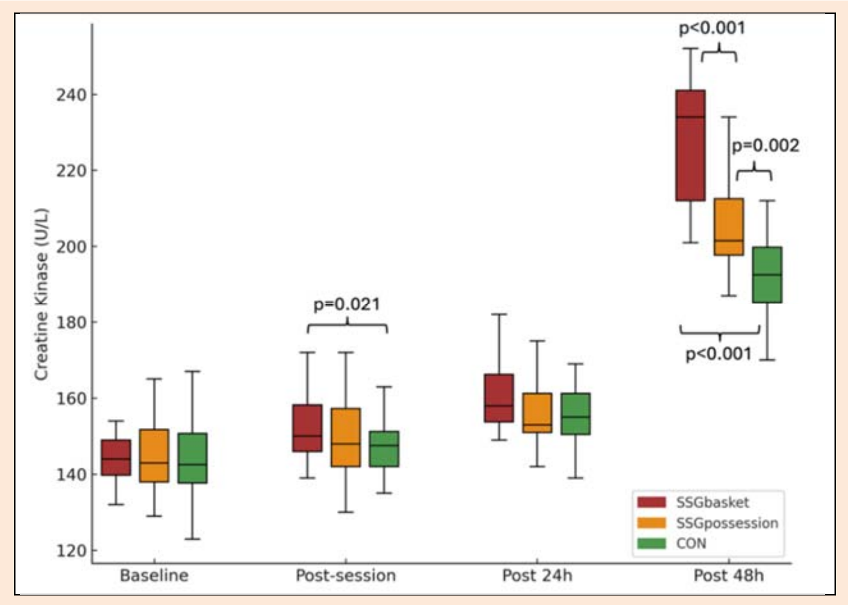

Figure 2. **Creatine kinase levels over the four different time points considering the conditions of small-sided with baskets (SSGbasket), in ball possession (SSGpossession) and control (CON). Higher values indicate greater muscle damage (higher CK activity).**

47.69 U/L, all $p < 0.001$), indicating a delayed but clearly elevated muscle-damage profile. Even in the CON condition, CK increased above baseline at 24 h (11.83 U/L, 95% CI 9.51 to 14.15, $p < 0.001$) and 48 h (49.44 U/L, 95% CI 40.25 to 58.64, $p < 0.001$), with both follow-up points also exceeding the immediate post-session measurement (9.31 - 46.92 U/L, all $p < 0.001$), though the absolute values remained lower than in the SSG conditions, particularly compared with SSGbasket.

For PPT, Mauchly's test indicated that the sphericity assumption was violated for the factor condition ($W = 0.397$, $p < 0.001$) and for the condition × time interaction ($W = 0.008$, $p < 0.001$), but not for time ($W = 0.800$, $p = 0.186$). The two-way repeated-measures ANOVA revealed a significant condition × time interaction for PPT ($F(2.97, 103.76) = 7.11$, $p < 0.001$, $\eta^2p = 0.169$). There was a main effect of condition ($F(1.25, 43.67) = 3.92$, $p = 0.045$, $\eta^2p = 0.101$), indicating modest overall differences in PPT between formats, and a robust main effect of time ($F(3, 105) = 24.01$, $p < 0.001$, $\eta^2p = 0.407$). Between-condition comparisons at each time point indicated that players started the sessions with comparable PPT, with no significant differences between SSGbasket, SSGpossession, and CON at baseline. Immediately post-session and at 48 h, no pairwise comparison between conditions reached significance after Bonferroni correction (all $p \geq 0.059$). In contrast, clear between-condition differences emerged at 24 h post-session (Figure 3).

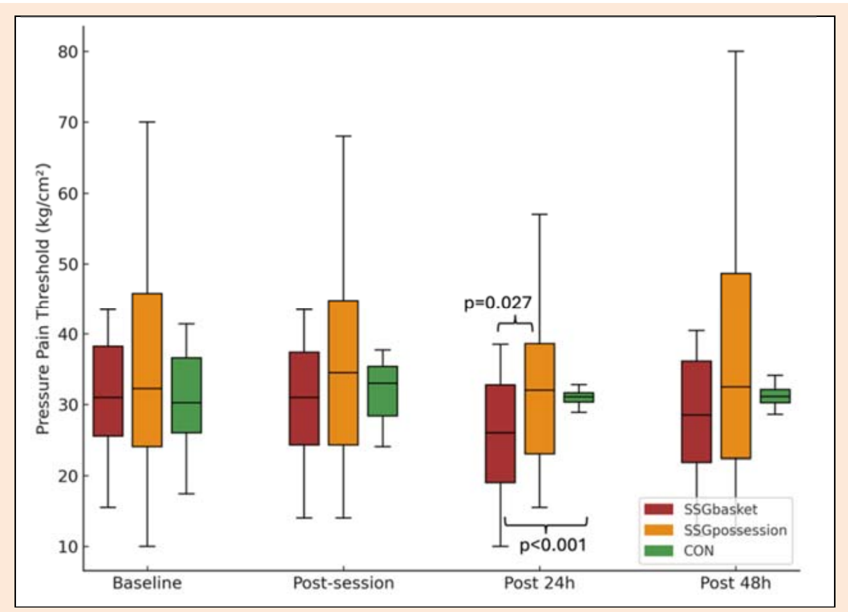

Figure 3. **Pressure pain threshold (PPT) levels over the four different time points considering the conditions of small-sided with baskets (SSGbasket), in ball possession (SSGpossession) and control (CON). Lower PPT values indicate greater mechanical sensitivity and muscle soreness.**

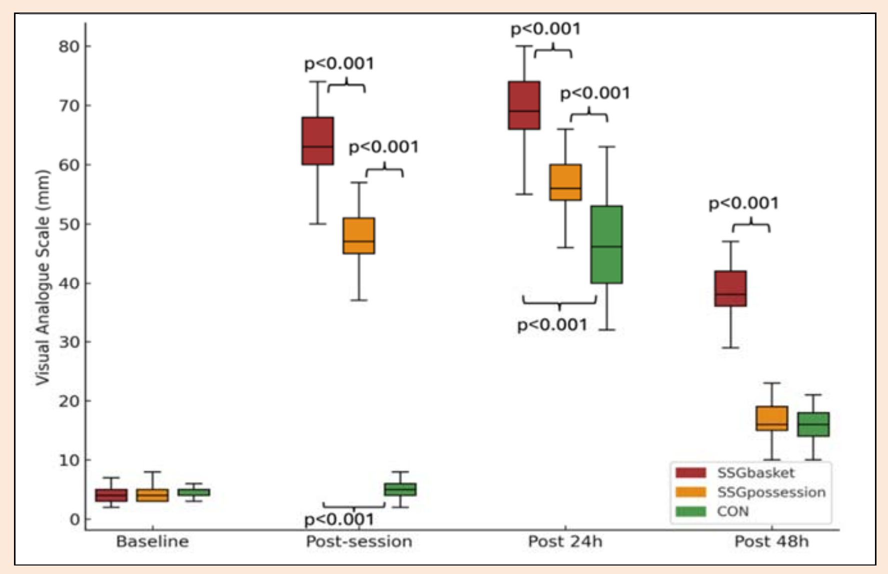

Figure 4. Visual analogue scale (VAS) levels over the four different time points considering the conditions of small-sided with baskets (SSGbasket), in ball possession (SSGpossession) and control (CON). Higher VAS scores indicate greater perceived muscle soreness.

In SSGbasket, PPT showed a consistent decline from pre- to post-session and into the recovery period. Relative to baseline, PPT was already slightly but significantly reduced immediately post-session (mean difference 0.78, 95% CI 0.16 to 1.40, $p = 0.008$), with a much larger reduction at 24 h (5.83, 95% CI 5.33 to 6.34, $p < 0.001$) and a persistent deficit at 48 h (2.75, 95% CI 2.19 to 3.31, $p < 0.001$). All pairwise comparisons between time points in SSGbasket were significant (all $p < 0.001$), with 24 h representing the lowest PPT and 48 h indicating partial, but incomplete, recovery toward baseline. In SSGpossession, changes were more moderate. PPT did not differ significantly between baseline and the immediate post-session measurement ($p = 0.525$), and baseline values were also similar to those at 48 h ($p = 1.000$). However, PPT at 24 h was lower than at post-session (mean difference 4.00, 95% CI 1.73 to 6.27, $p < 0.001$) and lower than at 48 h (4.33, 95% CI 0.97 to 7.69, $p = 0.006$), indicating a temporary dip in PPT at 24 h with recovery by 48 h. In the CON condition, PPT remained highly stable across all time points, with no significant pairwise differences observed between baseline, post-session, 24 h, or 48 h (all $p = 1.000$), consistent with minimal changes in mechanical sensitivity under regular training.

For VAS muscle soreness, Mauchly's test indicated that the sphericity assumption was violated for Condition ($W = 0.063$, $p < 0.001$), Time ($W = 0.252$, $p < 0.001$), and the Condition × Time interaction ($W \approx 0.000$, $p < 0.001$). The two-way repeated-measures ANOVA revealed a very large Condition × Time interaction for VAS ($F(1.57, 55.05) = 603.82$, $p < 0.001$, $\eta^2p = 0.945$). Across the full protocol there were also very large main effects of Condition ($F(1.03, 36.14) = 805.20$, $p < 0.001$, $\eta^2p = 0.958$) and Time ($F(1.88, 65.82) = 3723.87$, $p < 0.001$, $\eta^2p = 0.991$). Between-condition comparisons at each time point showed that players started with similar pre-session soreness, with no significant differences between SSGbasket, SSGpossession, and CON (all $p = 1.000$; mean VAS ≈ 4 - 5 in all conditions). Immediately post-session, VAS scores diverged (Figure 4).

In SSGbasket, VAS scores rose extremely sharply from pre to post, remained very high at 24 h, and only partially recovered by 48 h. Relative to baseline, soreness was markedly higher immediately post-session (mean difference 59.19, 95% CI 56.67 to 61.72, $p < 0.001$), further increased at 24 h (64.92, 95% CI 62.32 to 67.51, $p < 0.001$), and remained substantially elevated at 48 h (34.17, 95% CI 32.23 to 36.10, $p < 0.001$). All pairwise comparisons between time points in SSGbasket were significant (all $p < 0.001$): VAS increased from post to 24 h (-5.72, 95% CI -6.07 to -5.38, $p < 0.001$, indicating higher soreness at 24 h), and decreased from 24 h to 48 h (-30.75, 95% CI -31.56 to -29.94, $p < 0.001$) while remaining well above baseline. In SSGpossession, soreness also increased markedly but with slightly lower magnitude. Compared with baseline, VAS was significantly higher immediately post-session (42.83, 95% CI 40.71 to 44.96, $p < 0.001$), at 24 h (52.47, 95% CI 50.22 to 54.72, $p < 0.001$), and at 48 h (12.67, 95% CI 11.33 to 14.01, $p < 0.001$). Within this condition, VAS increased from post to 24 h (9.64, 95% CI 9.22 to 10.06, $p < 0.001$), then declined by 48 h, with 48 h values lower than both post (-30.17, 95% CI -31.06 to -29.28, $p < 0.001$) and 24 h (-39.81, 95% CI -40.79 to -38.82, $p < 0.001$), yet still above baseline. In the CON condition, soreness remained stable from pre to immediately post (mean difference -0.39, 95% CI -1.15 to 0.37, $p = 0.961$), indicating that the control training did not acutely increase perceived muscle pain. However, VAS rose substantially at 24 h and remained elevated at 48 h relative to baseline. Compared with pre-session, soreness was much higher at 24 h (41.58, 95% CI 37.29 to 45.88, $p < 0.001$) and still elevated at 48 h (11.25, 95% CI 10.01 to 12.49, $p < 0.001$), and 24 h values exceeded both post (41.19, 95% CI 36.89 to 45.50, $p < 0.001$) and 48 h (30.33, 95% CI 25.83 to 34.83, $p < 0.001$).

For the RSI, Mauchly's test indicated that the sphericity assumption was violated for Condition ($W = 0.620$, $p < 0.001$), Time moments ($W = 0.321$, $p < 0.001$), and the Condition × Time moments interaction ($W = 0.088$, $p <$

0.001). The two-way repeated-measures ANOVA revealed a large Condition × Time moments interaction for RSI ($F(3.04, 106.21) = 33.86$, $p < 0.001$, $\eta^2p = 0.492$). Across the full protocol there were also very large main effects of Condition ($F(1.45, 50.71) = 89.31$, $p < 0.001$, $\eta^2p = 0.718$) and Timemoments ($F(1.79, 62.72) = 2828.58$, $p < 0.001$, $\eta^2p = 0.988$). Between-condition comparisons at each time point indicated that players began with identical reactive strength. Although all formats induced an acute decline in RSI, the scoring-oriented SSGbasket condition produced the largest and most persistent reactive-strength impairment, with SSGpossession showing an intermediate deficit and CON the smallest (Figure 5).

In SSGbasket, RSI decreased sharply from pre- to post-session (mean difference 0.645, 95% CI 0.614 to 0.676, $p < 0.001$), remained substantially lower than baseline at 24 h (0.495, 95% CI 0.464 to 0.526, $p < 0.001$), and was still depressed at 48 h (0.377, 95% CI 0.342 to 0.412, $p < 0.001$). Comparisons between post-session and follow-up time points showed progressive recovery: RSI at 24 h was higher than immediately post-session (-0.150, 95% CI -0.182 to -0.117, $p < 0.001$), and 48 h values exceeded both post (-0.267, 95% CI -0.304 to -0.231, $p < 0.001$) and 24 h (-0.118, 95% CI -0.138 to -0.097, $p < 0.001$), although they remained clearly below baseline. In SSGpossession, a similar pattern emerged but with a smaller overall deficit. Relative to baseline, RSI was significantly reduced immediately post-session (0.614, 95% CI 0.572 to 0.656, $p < 0.001$), remained lower at 24 h (0.404, 95% CI 0.357 to 0.451, $p < 0.001$), and was still below baseline at 48 h (0.235, 95% CI 0.180 to 0.290, $p < 0.001$). Within-condition comparisons showed that RSI improved from post to 24 h (-0.210, 95% CI -0.254 to -0.166, $p < 0.001$) and further from post to 48 h (-0.379, 95% CI -0.431 to -0.327, $p < 0.001$), with 48 h values also higher than at 24 h (-0.169, 95% CI -0.194 to -0.144, $p < 0.001$), although not fully back to pre-session levels. In the CON condition, RSI also decreased significantly following the session, but the extent of impairment and the residual deficit at 48 h were again smaller than in the SSG formats. Relative to baseline, RSI was markedly lower immediately post-session (0.626, 95% CI 0.597 to 0.656, $p < 0.001$), still reduced at 24 h (0.343, 95% CI 0.308 to 0.378, $p < 0.001$), and remained slightly below baseline at 48 h (0.158, 95% CI 0.126 to 0.190, $p < 0.001$). Pairwise comparisons showed a progressive recovery with time, with RSI at 24 h and 48 h significantly higher than post (-0.284 and -0.469, both $p < 0.001$) and 48 h also higher than 24 h (-0.185, 95% CI -0.207 to -0.163, $p < 0.001$).

Ratings of perceived exertion (CR10 Borg scale) were similar between conditions (Figure 6). Mean RPE during SSGbasket was 6.96 ± 0.86 a.u., while during SSGpossession it was 6.78 ± 1.05 a.u. The paired-samples t test showed no significant difference between formats, $t(35) = 0.91$, $p = 0.371$, with a small effect size (Cohen's $d_x = 0.15$; mean difference = 0.18 a.u., 95% CI [-0.22, 0.59]).

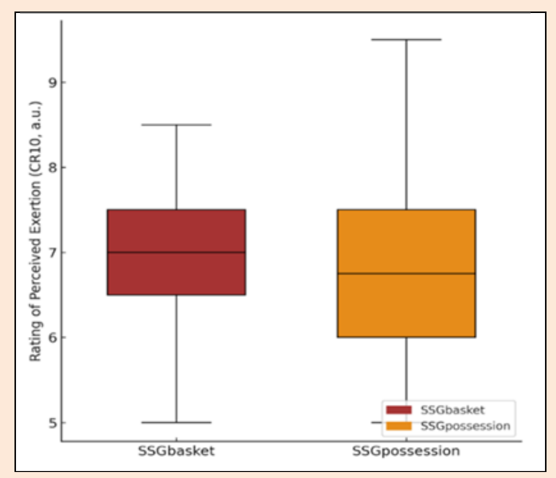

Figure 6. Comparisons of rating of perceived exertion between small-sided with baskets (SSGbasket) and in ball possession (SSGpossession). Higher values indicate greater perceived session intensity.

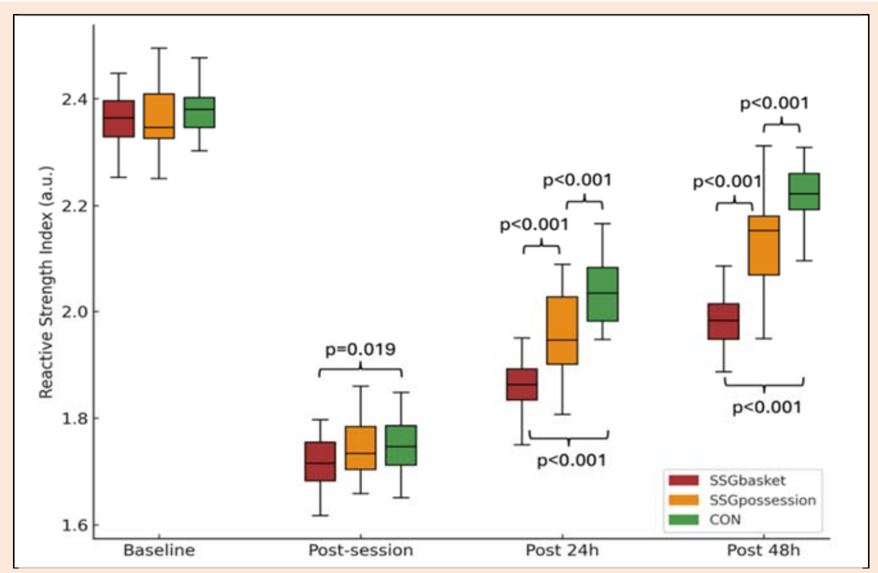

Figure 5. Reactive strength index (RSI) levels over the four different time points considering the conditions of small-sided with baskets (SSGbasket), in ball possession (SSGpossession) and control (CON). Lower RSI values indicate greater neuromuscular impairment (reduced jump performance).

Discussion

The present study compared the acute and short-term responses to three basketball training conditions (SSGbasket; SSGpossession; and CON) across four time points (baseline, post, 24 h, 48 h). There were clear condition and time interactions for CK, PPT, VAS muscle soreness, and RSI, indicating that both the magnitude and time course of biochemical and neuromuscular responses, soreness, and neuromuscular impairment differed between formats. SSGbasket systematically induced the largest and most prolonged disturbances in all outcomes (higher CK and VAS, lower PPT and RSI), and SSGpossession produced an intermediate response. These findings show that rule manipulations that promote scoring in basketball SSG substantially increase both the peripheral and neuromuscular recovery cost of a basketball training session.

The salivary CK data indicate that all three formats produced substantial elevations in this indirect marker of muscle membrane stress, with delayed peaks and incomplete recovery at 48 h, but with much greater increases in SSGbasket than in SSGpossession and CON. These findings are consistent with exercise-induced muscle stress and possible muscle damage, but should not be interpreted as definitive evidence of structural muscle injury, given that we did not include direct structural assessments (like imaging) or strength testing beyond RSI, and reference thresholds for salivary CK in this specific population are not well established. In addition, there was no non-exercise control day to separate normal day-to-day CK variability from training-related changes, so our inferences focus on relative differences between conditions rather than absolute pathological elevations. A study (Doma et al., 2018) reported substantial increases in CK and decrements in performance 24 h after a basketball-specific training session involving repeated jumps, sprints, and game-based drills in elite female players, highlighting the sensitivity of CK to sport-specific neuromuscular loading in this population. Another study (Pliauga et al., 2015) similarly showed that a simulated basketball game elicited >200% increases in CK at 24 h and elevated values still present at 48 h, alongside impaired sprint and jump performance, clearly evidencing muscle damage and delayed recovery after a single competitive-intensity bout. In our study, the greater CK response in SSGbasket is plausibly explained by a higher frequency of accelerations, decelerations, changes of direction, and jumps induced by scoring-oriented constraints, which would amplify eccentric load and mechanical stress relative to both SSGpossession and the more regular team training session used as the control condition. This interpretation is supported by recent basketball match-analysis evidence showing that the number of high-acceleration movements is closely related to CK elevation and perceived exertion after games (Koyama et al., 2022). However, because we did not collect external-load or time–motion measures (e.g., jump counts, acceleration counts, distance, player load) in the present study, we cannot directly attribute the observed CK differences to specific movement demands, and this explanation should be interpreted as speculative.

After training all conditions showed lower PPT (greater mechanical sensitivity) and higher VAS, peaking around 24 h and only partially resolving by 48 h. SSGbasket elicited the largest drop in PPT and the highest soreness at 24 h, SSGpossession showed a moderate, transient sensitization, and CON produced smaller but still evident changes. This trajectory matches classic DOMS descriptions, where eccentric or high-intensity exercise induces tenderness and pain that peak 24 - 48 h post-exercise and gradually subside thereafter (Cheung et al., 2003). Previous evidence has shown that eccentric-biased exercise causes micro-injury, inflammatory responses, and a temporary rise in CK together with depressed muscle function and increased pain, exactly the triad observed here with CK, PPT, and VAS (Serinken et al., 2013). For example, an eccentric exercise model in wheelchair basketball players reduced performance and increased soreness, and a case report in a young basketball athlete illustrated typical DOMS features with imaging evidence of muscle edema (Serinken et al., 2013). Contemporary work in basketball has also emphasized that DOMS after training or competition is substantial enough to warrant targeted recovery interventions such as vibration therapy to restore performance (Uysal and Ozmen, 2024). In our data, the disproportionately greater reduction in PPT and increase in soreness in SSGbasket possibly suggest the combination of higher eccentric loading (more explosive starts, stops, and jumps) and higher perceived stress due to the scoring emphasis, consistent with soccer SSG data showing that scoring-method manipulations increase heart-rate intensity and decision-making load (Qiao et al., 2025), which possibly would intensify both peripheral nociceptor activation and central pain modulation.The VAS time course also reveals how strongly players "feel" the difference between formats. While pre-session soreness scores were very low and similar across conditions, both SSG formats caused a meaningful rise immediately post-session and at 24 h, with SSGbasket consistently highest, SSGpossession intermediate, and CON much lower. A similar pattern has been reported after basketball games and dense competition periods, where high internal loads are accompanied by increased DOMS ratings and reduced perceived recovery. A study (Brini et al., 2023) observed that a congested game schedule in professional male basketball players increased DOMS and decreased total quality recovery, particularly when sleep and recovery opportunities were constrained. In elite female basketball players, a study (Doma et al., 2018) also showed large increases in DOMS 24 h after a single high-intensity, basketball-specific training session, with soreness associated with decrements in sport-specific performance. Our results extend these findings by showing that even within basketball-specific training, changing the game constraints (scoring-focused versus possession-focused versus more regular team training session used as the control condition) meaningfully shifts the magnitude and persistence of soreness. That SSGbasket still showed substantially elevated VAS at 48 h, while SSGpossession and CON had largely recovered, suggests that this format should be viewed as a "heavy" neuromuscular stimulus on the DOMS spectrum and scheduled accordingly within the microcycle.

All three conditions induced large acute reductions in RSI immediately after the session, with only partial recovery at 24 and 48 h, and again with the greatest and most persistent impairment in SSGbasket, an intermediate response in SSGpossession, and the smallest but still meaningful decrements in CON. This is in line with basketball studies showing that both training and competition can substantially depress jump- and RSI-based measures for at least 24 h. A study (Doma et al., 2018) reported significant reductions in countermovement jump (CMJ) height and other performance tests 24 h after a basketball-specific training session, coinciding with elevated CK and DOMS. During a Division I men's preseason (Heishman et al., 2020) it was found periods of higher external training load were accompanied by decrements in CMJ performance, illustrating a clear load–neuromuscular fatigue relationship in basketball players. RSI and its derivatives have been highlighted as particularly sensitive to fatigue since in recreationally trained basketball players, repeat-sprint protocols produced substantial drops in RSImod during drop jumps, and recent work suggests that RSImod or rebound-jump metrics are among the most responsive indicators of day-to-day neuromuscular status in collegiate and professional basketball athletes (Philipp et al., 2023). Against this background, the present RSI data indicate that SSGbasket can elicit neuromuscular impairments of a magnitude that may approach those reported 24 h after demanding training blocks or official games in previous literature, while SSGpossession and CON appear to sit at moderate and lower ends of that same continuum. However, because CK, RSI, and soreness responses were not monitored after official games or high-load training periods in this specific sample, this possibility should be interpreted cautiously.

The way reactive strength and soreness behaved over time also aligns with emerging evidence on basketball SSG specifically. A study (Rodríguez-Fernández et al., 2025) showed that altering court orientation and bout-ending rules in 3×3 SSGs significantly affected external load and led to detectable pre- to post-changes in CMJ performance, with more demanding formats inducing greater fatigue. Our study extends this concept by showing that when scoring-orientated rules are used in SSGbasket, the resulting internal and external load is sufficient to produce not only immediate, but also pronounced delayed effects on both neuromuscular function (RSI) and indirect muscle-damage markers (CK, PPT, VAS) up to 48 h later. Coupled with evidence that high-acceleration movements are strongly linked to CK and perceived exertion in basketball games (Koyama et al., 2022), it is reasonable to infer that SSGbasket increases the frequency of such mechanically costly actions, explaining the larger and more persistent declines in RSI compared with SSGpossession and CON.

From an applied perspective, the present data suggest that SSGbasket should be treated as a more demanding neuromuscular stimulus, whereas SSGpossession imposes a moderate but more rapidly resolving load. Coaches can therefore use these findings to inform microcycle design (for example, avoiding SSGbasket within the final 48 h before competition and instead scheduling it earlier in the week when ≥72 h of recovery are available), while using SSGpossession for mid-week sessions (for example, 48 - 72 h before a game) when some residual fatigue is acceptable, and favouring CON-type sessions without additional SSGs on days when only minimal extra fatigue can be tolerated. These results also have implications for monitoring and recovery strategies in basketball. The broadly similar time courses observed across CK, VAS, PPT, and RSI in the present sample suggest that these biochemical, neuromuscular, and subjective markers are all responsive to the imposed training stress; however, we did not formally analyse correlations or multivariate relationships between them, so the extent to which they provide redundant versus complementary information remains uncertain. Accordingly, we interpret them as complementary indicators that should be considered together rather than in isolation when monitoring players. Given the documented impact of DOMS on performance and injury risk (Cheung et al., 2003), incorporating evidence-based recovery modalities (e.g., load management, adequate sleep, nutrition) may be especially valuable after scoring-oriented SSGs.

Some limitations should be recognized. External load variables such as total distance, number of jumps, accelerations, and player-load measures were not reported here, which limits the ability to directly link specific movement patterns to the observed changes in CK, PPT, VAS, and RSI. Given that both match-play and SSG research in basketball have shown that rule and court modifications can substantially alter external load and internal responses, future studies should integrate time–motion or tracking data to quantify the mechanical impact on neuromuscular fatigue in different SSG formats. In addition, the three experimental conditions were implemented across consecu tive in-season weeks with ongoing weekend competition and no formal washout period; although the microcycle structure was standardized and each experimental session was scheduled at a comparable time point (72 h after the preceding match), the 24 - 48 h responses reported here are superimposed on players' accumulated in-season load, and some carryover or interference from prior-week training and match demands cannot be completely excluded. The design also means that SSGbasket and SSGpossession represented additional training content superimposed on regular practice, whereas CON comprised regular practice alone; therefore, differences between conditions may reflect the combined effects of extra training volume, the sequencing of SSGs relative to team drills, and the specific tactical objectives of the SSGs rather than the tactical constraints in isolation. Accordingly, our conclusions should be interpreted as comparing regular training alone versus regular training plus different SSG formats. Moreover, although players were instructed to maintain their usual sleep, nutrition, and recovery routines, these behaviors were not formally monitored (for example, via daily logs or questionnaires), so uncontrolled use of recovery strategies and day-to-day variability in sleep or dietary practices may have contributed additional unexplained variance in CK, soreness, and RSI responses. The observation window was limited to 48 h, so future research should consider a longer follow-up to capture the full recovery curve after highly demanding sessions or games, particularly for SSGbasket. Furthermore, PPT and perceived soreness were assessed only over the dominant hamstring, which does not capture potential differences in quadriceps, calf or non-dominant limb musculature and therefore should be interpreted as a localized rather than whole-body index of muscle tenderness. Taken together, these constraints mean that the large effects observed (especially for SSGbasket) should be interpreted in the context of in-season accumulated load, added SSG content, uncontrolled recovery behaviors, and localized outcome measures rather than as a complete picture of whole-body recovery.

Conclusion

In conclusion, this study suggests that different SSG formats in basketball impose distinct physiological and neuromuscular demands in male under-21 regional-level players performing 2 vs 2 games embedded within a typical in-season microcycle. Scoring-oriented SSGbasket produced the largest increases in salivary CK (an indirect marker of muscle damage), greater muscle soreness, and the most persistent decrements in RSI over 48 h, whereas SSGpossession induced moderate but still meaningful disturbances and the control training day the smallest changes. Although all three conditions resulted in incomplete recovery 48 h after the session, the magnitude and time course of responses were format dependent, supporting the need to match SSG content to the desired training load and the available recovery window. These conclusions are specific to the 2 vs 2 formats, rule constraints, and competitive level examined here, and extrapolation to other formats (e.g., 3 vs 3 or 4 vs 4 SSGs, different court dimensions or scoring rules), other competitive levels (elite/professional), and female or mixed-sex populations should be regarded as speculative and confirmed in future research.

Acknowledgements

While the datasets generated and analyzed in this study are not publicly available, they can be obtained from the corresponding author upon reasonable request. All experimental procedures were conducted in compliance with the relevant legal and ethical standards of the country where the study was carried out. The authors declare that no Generative AI or AI-assisted technologies were used in the writing of this manuscrip

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Key points

- SSGbasket caused the greatest fatigue, with significantly higher CK, soreness, lower PPT, and larger RSI impairments than other formats (all $p < 0.001$).
- SSGpossession induced moderate physiological and neuromuscular stress, smaller and shorter-lasting than SSGbasket (all $p < 0.01$).
- SSGbasket should be scheduled when longer recovery windows are available, while SSGpossession is more suitable for days requiring moderate load and faster recovery.

AUTHOR BIOGRAPHY

DongMing ZHU
Employment
College of Sports and Health, Nanchang Institute of Science & Technology, 330100 Nanchang, China
Degree
MEd
Research interests
Sports performance, humanities and sociology, etc.
E-mail: m15717910402@163.com

✉ **DongMing Zhu**
College of Sports and Health, Nanchang Institute of Science & Technology, 330100 Nanchang, China