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Research article

Determinants of Cardiovascular Load Variability During Small-Sided Games: Influence of Game Format, Bout Intensity, and Yo-Yo Intermittent Recovery Performance

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Abstract

Using a randomized, counter-balanced cross-over design in under-19 male soccer players, this study examined whether within-player cardiovascular load variability during small-sided games (SSGs) is more strongly associated with game format (3v3 vs 5v5), intermittent aerobic capacity, or the mean heart-rate intensity achieved across bouts. Sixty players (17 - 19 years) completed two weeks of SSGs, performing four 3-min bouts per format with 2-min recovery. Heart rate (HR) was recorded continuously. Cardiovascular variability for each format was quantified for each player as the coefficient of variation of bout-level HRmean across the four 3-min bouts (CV% = SD/mean × 100). Intermittent aerobic capacity was assessed using the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1). Linear mixed-effects modelling examined the independent associations between format, Yo-Yo IR1 performance, mean HR intensity, and CV% was log-transformed to address skewness and improve model residuals. Paired comparisons showed that HRmean was higher in 3v3 than in 5v5 ($p < 0.001$), whereas between-player variability (CV%) was higher in 5v5 than in 3v3. Specifically, CV% was 1.97 ± 0.81% in 3v3 versus 2.61 ± 1.21% in 5v5, while mean HR intensity was 180.9 ± 2.8 bpm in 3v3 compared with 173.6 ± 3.6 bpm in 5v5. The mixed model indicated that mean HR intensity was the only significant predictor of cardiovascular variability (β = -0.027, 95% CI = -0.050 to -0.005, $p = 0.019$). Neither SSG format (β = 0.056, $p = 0.618$) nor Yo-Yo IR1 performance (β = -0.00008, $p = 0.385$) were significant predictors. The fixed-effects structure explained 13.6% of the variance (marginal $R^2 = 0.136$). Within the training conditions studied, higher mean HR intensity was associated with lower bout-to-bout HR variability. However, the fixed effects explained a modest proportion of variance, indicating that additional unmeasured factors likely contribute to cardiovascular load variability.

Key words: Heart rate, physiological responses, football, sports training, training design.

Introduction

Small-sided games (SSGs) are widely implemented in soccer as an integrated training modality that concurrently develops technical, tactical, and physical capacities under game-representative constraints (Owen et al., 2004; Hill-Haas et al., 2011; Petiot et al., 2026). Across competitive levels, SSGs elicit high cardiovascular and perceptual loads, with players frequently exercising at intensities above 80 - 90% maximal heart rate (HR) range depending on constraints (e.g., pitch size, encouragement, and rules) (Clemente et al., 2025). Similar high relative intensities have also been reported in youth players during varied SSG formats (Hill-Haas et al., 2009; Dellal et al., 2011). Compared with larger-sided match play, SSGs often produce comparable or even greater internal loads while allowing coaches to manipulate technical–tactical objectives within shorter, more controllable bouts (Asci, 2016). HR monitoring has therefore become one of primary strategies to quantify the internal load imposed by SSGs in both professional and developmental contexts (David and Julen, 2015). The manipulation of task constraints such as pitch size and individual playing area meaningfully alters HR responses and time spent near maximal intensities during SSGs, underscoring the sensitivity of cardiovascular load to game design (Casamichana and Castellano, 2010).

A consistent finding is that formats with fewer players and a fixed pitch area, such as 3v3 compared with 5v5 or 7v7, impose higher relative HR, blood lactate, and rating of perceived exertion, indicating greater cardiovascular load (Randers et al., 2018). Similarly, varying team size between 3v3, 5v5, and 7v7, even under standardized coaching and tactical instructions, substantially modifies both internal and external training loads experienced by individual players (Asian-Clemente et al., 2022). Manipulating bout duration and individual interaction space further shapes HRpeak, HRmean, and locomotor demands, confirming that SSG format and structure strongly condition cardiovascular stress across repeated bouts (Castillo et al., 2021). Additional constraints such as defensive rules or the presence of goals, for example using mandatory man-marking in 3v3 formats, can increase HR reserve and modify the consistency of intensity between repetitions (Ngo et al., 2012). When SSGs are compared with intermittent running or other high-intensity conditioning drills, they frequently achieve similar mean HR responses but display greater inter-subject dispersion in percentage HR reserve, suggesting lower homogeneity of cardiovascular load in game-based formats (Dellal et al., 2008).

Despite this extensive work on manipulating mean intensity, the primary internal load indicators used in SSG research remain session-average HR, time in pre-defined HR zones, and HR-derived training impulse, with limited emphasis on within- or between-bout variability of cardiovascular load (Younesi et al., 2021). Although session-to-session variability and between-player dispersion of internal load during SSGs has been increasingly examined, less

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is known about within-player, within-session bout-to-bout variability (i.e., each player's CV of HRmean across the bouts within a session and format) in HR-derived load. Studies examining reliability and reproducibility of SSGs typically report intraclass correlation coefficients and coefficients of variation (CV) for average HR or percentage of HRmax, indicating good session-to-session stability but also non-trivial random variation in internal load (Milanović et al., 2020). Work in youth and adult players shows that exercise intensity during SSGs is sensitive to task manipulations while typical error expressed as coefficient of variation for %HRmax generally ranges between 2–5%, highlighting both controllability and inherent variability of HR responses (da Silva et al., 2011). Recent analyses of within- and between-player variability in professional SSGs have reported substantial differences between individuals in HR-derived internal load, even under standardized formats, underscoring the need to better understand determinants of cardiovascular load variability (Silva et al., 2022).

Intermittent aerobic fitness, commonly assessed in soccer by the Yo-Yo Intermittent Recovery (YYIR) tests, is a determinant of players' ability to sustain repeated high-intensity efforts and recover between bouts (Bangsbo et al., 2008). Cardiorespiratory responses during Yo-Yo intermittent testing correlate strongly with maximal oxygen uptake and match running performance, supporting its validity as a proxy of intermittent aerobic power in youth and adult players (Krustrup et al., 2003). More recent work has reinforced the criterion validity and responsiveness of Yo-Yo intermittent tests, including submaximal variants, for tracking aerobic fitness changes in both recreational and trained footballers (Castagna et al., 2020). High-intensity, soccer-specific conditioning drills designed around positional demands often target intensities close to 90% of HRmax and demonstrate improvements in Yo-Yo IR1 performance, reinforcing the interaction between intermittent aerobic capacity and cardiovascular demands in training contexts (Le Cuong et al., 2023).

Most SSG studies have focused on mean internal load (e.g., mean HR, time in HR zones, training impulse) and how it changes with task constraints (Bujalance-Moreno et al., 2019). Much less is known about the within-player, within-session bout-to-bout variability of HR-derived load under standardized prescriptions, and whether that variability is better explained by format, intermittent aerobic capacity, or the intensity actually achieved. Prior work (Hill-Haas et al., 2010) has described variability in HR responses during repeated SSG exposures, but typically without separating the contributions of structural constraints (format), physiological capacity (intermittent fitness), and situational intensity achieved within the session. Current investigations manipulating SSG formats, recovery durations, and preparatory routines typically interpret internal load using mean HR metrics or time in intensity zones, providing limited insight into the structure of cardiovascular load variability itself (Köklü, 2012; Koklu and Alemdaroglu, 2016; Köklü et al., 2024). Conceptually, determinants of cardiovascular load variability in SSGs can be grouped into structural determinants (e.g., player number, pitch dimensions, and rule constraints), physiological determinants (e.g., intermittent aerobic capacity influencing recovery and tolerance to repeated efforts), and situational determinants (e.g., the intensity actually achieved in a given session due to pacing, engagement, tactical context, or fatigue) (Castellano et al., 2013; Riboli et al., 2022). This motivates a model that tests whether format and fitness explain variability independently of achieved intensity. Such knowledge would enable practitioners to better tailor SSG prescriptions and preparatory strategies, as recent work has shown that even factors like warm-up duration can meaningfully alter internal and external load profiles during the same nominal game formats (Yilmaz et al., 2025). Therefore, the present study aimed to analyze whether the coefficient of variation of HR across bouts during 3v3 and 5v5 small-sided soccer games is more strongly associated with game format, players' aerobic capacity as assessed by the Yo-Yo Intermittent Recovery test, or the HR intensity achieved over successive bouts. We hypothesized that (i) 3v3 would elicit higher mean HR than 5v5, and (ii) higher achieved HR intensity (and potentially higher Yo-Yo IR1 performance) would be associated with lower bout-to-bout HR variability, with any format effect on variability largely mediated by achieved intensity.

Methods

Experimental approach

This investigation employed a randomized, counter-balanced, cross-over design to compare cardiovascular load variability during two SSGs soccer game formats (3v3 and 5v5). The study was conducted over two consecutive training weeks during the first third of the competitive season. Players were recruited from three under-19 soccer clubs, both competing in regional-level leagues and following comparable weekly training schedules. Prior to the experimental period, all players completed a Yo-Yo Intermittent Recovery Test Level 1 (YYIR1) under standardized conditions to determine their intermittent aerobic capacity.

Following baseline fitness assessment, participants were randomly assigned (using a computer-generated randomization list stratified by club affiliation) to one of two sequences for the two-week intervention. Group A completed the 3v3 condition in Week 1 and the 5v5 condition in Week 2, whereas Group B completed the formats in the opposite order, ensuring counter-balancing and controlling for potential order or learning effects (Figure 1). Training sessions occurred on Tuesdays and Thursdays of each week, consistent with teams' routine weekly mesocycles and ensuring a minimum of 48 hours between sessions. Each player completed two SSG sessions per format (Tuesday and Thursday within the assigned week). CV% was first computed within each session (across the four bouts) and then averaged across the two sessions to yield one CV% value per player per format. Participants were allocated 1:1 to sequence groups (3v3-first vs 5v5-first) using stratified randomization by club. All sessions were performed on standard outdoor synthetic turf pitches, at each team's regular training facility, during the same time range (18:00 - 20:00) to minimize circadian and environmental variability. Teams followed their usual in-season microcycle (typically four field sessions/week plus one weekend

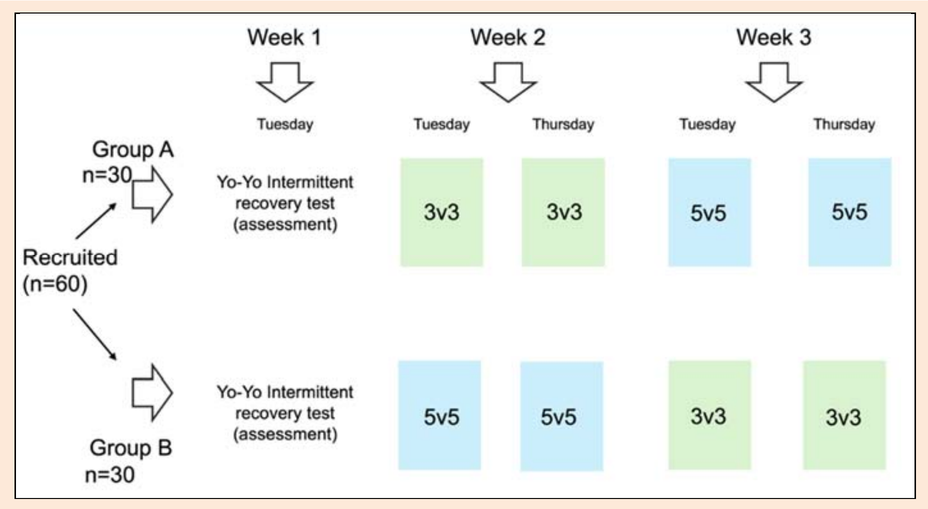

Figure 1. **Study design illustrating the randomized, counter-balanced, cross-over approach.**

match). The SSG interventions were consistently performed mid-week (Tuesday/Thursday) to reduce systematic variation due to match proximity.

Each session consisted of four bouts of 3 minutes of play, interspersed with 2-minute passive recovery periods. These bout and rest durations were selected to replicate common high-intensity short-format SSG prescriptions used in applied soccer training. All sessions were supervised by members of the research team and by the athletes' coaching staff to maintain consistency, verbal encouragement, and adherence to standardized SSG rules. Players were instructed to compete with maximal effort and maintain tactical discipline aligned with their usual training methodology. Throughout all SSG bouts, players were continuously monitored using telemetric HR systems sampling at 1 Hz. HR monitors were fitted at least 10 minutes before the start of the warm-up to ensure signal stability. Players were required to abstain from strenuous exercise for at least 24 hours before each data collection session, avoid caffeine intake for 6 hours prior, and follow standardized hydration guidelines. All participants wore their usual soccer boots and training apparel to enhance ecological validity.

Participants

Male youth soccer players from three local-level under-19 teams were recruited for this study. Eligibility criteria included: (i) being an outfield player between 17 and 19 years of age, (ii) having a minimum of 3 years of structured soccer training experience, (iii) participating in ≥3 organized training sessions per week plus competitive weekend matches, and (iv) being free from musculoskeletal injury or medical conditions that could restrict high-intensity exercise in the 2 months preceding data collection. Goalkeepers were excluded due to the specificity of their physical and tactical roles. All players were required to have maintained regular training participation (>90% attendance) in the season to ensure homogeneity of fitness and training background.

A total of 60 players met the inclusion criteria and volunteered to participate. Players were recruited from three clubs (Club 1: n = 20; Club 2: n = 20; Club 3: n = 20). Playing positions were: central defenders (n = 13), fullbacks (n = 15), central midfielders (n = 16), wide midfielders/wingers (n = 9), and forwards (n = 7). Across the sample, players presented the following anthropometric characteristics: height 173.1 ± 6.7 cm, body mass 61.2 ± 7.9 kg, body mass index 20.4 ± 2.1 kg·m^{-2}, and age 17.5 ± 0.5 years (Table 1). All participants were actively engaged in their teams' standard in-season microcycles, typically consisting of four weekly field-based training sessions and one official weekend match.

Table 1. **Sample characteristics.**

Variable	Mean	SD	Min	Max
Age (years)	17.5	0.5	17.0	18.0
Height (cm)	173.08	6.71	153.0	187.0
Weight (kg)	61.18	7.93	41.4	74.6
BMI (kg/m²)	20.39	2.13	15.08	25.5
Yo-Yo IR1 (m)	1795.67	378.76	1120.0	2600.0

BMI: body mass index; Yo-Yo IR1: Yo-Yo Intermittent Recovery test level 1

Before enrolment, all players and their legal guardians (when applicable) received a detailed explanation of the study procedures, risks, and benefits. Written informed consent was obtained from all participants. The study adhered to the principles of the Declaration of Helsinki and was approved by the Ethical Comitee of University of Physical Education and Sport in Gdańsk (Ethical Commission approval 14/3/2025). Participants were informed of their right to withdraw at any point without consequences for their sporting participation. No adverse events or injuries occurred during the study protocol.

Small-sided games

Players completed standardized SSGs in two formats: 3v3 and 5v5, played without goalkeepers using two mini-goals (3 m wide) positioned centrally on each end line. To ensure comparable spatial constraints between formats, pitch dimensions were set so that both the individual playing area (m² per player) and the length-to-width ratio were effectively identical across conditions. For the 3v3 format, games were played on a 30 × 20 m pitch (100 m² per player), with the long side used as length. For the 5v5 format, games were played on an approximately 38.7 × 25.8 m pitch (100 m² per player), thereby maintaining the same individual playing area and a consistent length:width ratio of 1.5:1 in both formats. Pitch boundaries were marked with cones, and distances were measured using a tape measure.

Each SSG session consisted of 4 bouts of 3 minutes (Dellal et al., 2015), interspersed with 2 minutes of passive recovery, as part of the regular field-based training session. A standardized 15-minute warm-up (low-intensity running, dynamic mobility, and progressive ball drills) preceded the first SSG bout. Players were instructed to perform with maximal, game-like effort throughout all bouts. The same bout structure (4 × 3 min, 2 min rest) was used in both formats and across all sessions and weeks to allow direct comparison of cardiovascular responses and variability.

Rules were standardized and kept simple and consistent across teams and sessions. Games were played using official size-5 balls, with no offside rule, and all restarts (when the ball went out of play) were executed as kick-ins from the touchline or end line, with the ball placed on or just behind the line and play resumed immediately. No restrictions were imposed on the number of ball touches per player, and coaches were instructed to provide continuous verbal encouragement but no explicit tactical coaching during bouts. The primary objective communicated to players was to maintain ball possession and create scoring opportunities, ensuring a high and competitive match-like intensity. Teams within each format were fixed across the two sessions of a given week as far as possible to maintain stability in tactical relationships, while initial team allocation was performed to balance playing positions and perceived ability between sides. All SSGs were conducted on the teams' usual synthetic turf training pitches during the same evening time window to minimize environmental variability.

The Yo-Yo Intermittent Recovery test

Intermittent aerobic fitness was assessed using the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1), which evaluates an individual's ability to repeatedly perform intense exercise bouts with brief recovery periods and is widely used in intermittent team sports such as soccer (Bangsbo et al., 2008). Yo-Yo IR1 was selected because it is widely used and well-validated for assessing intermittent endurance in youth and sub-elite soccer populations (Deprez et al., 2014), whereas Yo-Yo IR2 is more commonly applied to higher-elite adult cohorts. The Yo-Yo IR1 has demonstrated strong construct validity and sensitivity to competitive level and seasonal changes in intermittent sports performance, with higher-level players consistently achieving greater distances and improvements closely tracking changes in match-related running performance and maximal oxygen uptake (Krustrup et al., 2003). Reliability studies in youth and young adult soccer players have reported excellent test–retest reproducibility for Yo-Yo IR1 distance, with intraclass correlation coefficients typically in the range of 0.87 -0.98 and coefficients of variation between ~3 - 8%, confirming its suitability for monitoring intermittent fitness in this population (Deprez et al., 2014).

The Yo-Yo IR1 was administered one week prior to the SSG intervention period under standardized conditions on an outdoor synthetic turf pitch at each club's training facility. Players had performed Yo-Yo IR1 in prior seasons as part of club monitoring. Testing took place in the same early evening time window as the SSG sessions, following a 15-minute standardized warm-up of low-intensity running and dynamic stretching, and at least 24 hours after the last strenuous training session or match to minimize residual fatigue. Players were instructed to arrive well hydrated, to refrain from caffeine intake for at least 6 hours, and to avoid vigorous exercise in the preceding 24 hours. All tests were supervised by the research team, with standardized verbal encouragement provided throughout to ensure maximal effort.

The test consists of repeated 2 × 20 m shuttle runs performed at progressively increasing speeds dictated by a pre-recorded audio signal, interspersed with 10 seconds of active recovery involving 2 × 5 m jogging between runs (Krustrup et al., 2003). Players started behind the 0 m line and were required to reach the turning line exactly in synchrony with the audio beeps. The test was terminated when the participant twice failed to reach the line on time or voluntarily stopped due to exhaustion. The total distance covered (in meters) at the point of termination was recorded as the performance outcome and used as the continuous measure of intermittent aerobic capacity in all analyses.

Heart rate monitoring

Heart rate was continuously monitored throughout all SSGs sessions using a Polar Team Pro system (Polar Electro Oy, Kempele, Finland), which combines chest-strapped heart rate sensors with a team-based receiver and dedicated analysis software. Each player was fitted with an individual HR sensor approximately 10 minutes before the standardized warm-up to ensure stable signal acquisition and allow for proper skin-electrode contact. Heart rate was recorded at 1 Hz during the entire SSG protocol, including warm-up, all four 3-minute bouts, and the intervening recovery periods. To ensure consistent measurement conditions, players were instructed to wear the strap in the same position across all sessions, and sensors were checked for correct functioning prior to each training session by the research staff.

Mean heart rate for each bout (HRmean) was extracted as the arithmetic mean of all valid HR samples recorded within the 3-minute playing period, excluding the 2-minute recovery intervals. This HRmean per bout was used as the operational measure of exercise intensity for that bout. For each player and SSG format (3v3 and 5v5), an overall intensity measure was calculated as the mean of HRmean values across the four bouts within a session. To quantify the within-player variability of cardiovascular load across bouts, the coefficient of variation (CV%) of HRmean values was computed for each player, format, and session. Specifically, for each condition, CV% was calculated as:

CV% = (standard deviation HRmean across 4 bouts / mean of HRmean across 4 bouts) × 100.

This CV% was used as the primary outcome representing cardiovascular load variability during SSGs, while the corresponding mean HRmean served as the intensity predictor in the statistical models.

Sample size estimation

An a priori sample size estimation was performed for the planned linear mixed-effects analysis, with the primary outcome being the coefficient of variation of heart rate (CV%) across bouts in each SSG format. Because closed-form power procedures for linear mixed models are not readily implemented in standard sample-size software, we adopted the commonly used strategy of approximating the design with a two-condition repeated-measures ANOVA (F-test family) in GPower 3.1, treating this as a conservative proxy for the within-player structure of the planned mixed model (Kang, 2021). Assumptions for the calculation were informed by previous SSG research showing CVs for HR outcomes typically in the range of ~2 - 5% and moderate between-format differences in internal load when comparing 3v3 and 5v5 formats (Castellano et al., 2013). Accordingly, we specified a medium effect size for the within-subject factor (Cohen's f = 0.25), a two-tailed α = 0.05, desired power (1-β) = 0.80, and a moderate within-subject correlation (r = 0.50), compatible with the reproducibility of HR responses reported. Under these assumptions, the GPower calculation indicated that a minimum of 18 players would be sufficient to detect medium within-subject effects.

Statistical analysis

All analyses were performed using a linear mixed-effects modelling approach to account for the repeated-measures, cross-over structure of the study. The primary analysis included N = 120 format-level observations (60 players × 2 formats), using a random intercept for player. The primary dependent variable was the coefficient of variation of heart rate (CV%) across the four SSG bouts for each player and format. Because each participant contributed observations under both formats (3v3 and 5v5), with sessions nested within players and players nested within clubs, mixed models were used to address the non-independence of observations and to provide unbiased estimates of within- and between-player effects.

The main analytical model included SSG format (3v3 vs 5v5), intermittent aerobic capacity (Yo-Yo Intermittent Recovery Test Level 1 performance), and mean HR intensity across bouts as fixed effects. These predictors were selected a priori based on the study aim of determining whether cardiovascular load variability is more strongly associated with game format, aerobic fitness, or intensity achieved during the exercise bouts. In addition, session order (format completed first) and club were evaluated as potential covariates and retained if they improved model fit. To allow for individual differences in baseline cardiovascular variability, a random intercept for each player was included in all models. A random intercept for club was also tested but only retained when supported by convergence and fit criteria. Model residuals were inspected for normality and heteroscedasticity. Where appropriate, CV% was log-transformed and back-transformed for reporting to ensure homoscedastic residuals and improve model stability. Potential period and carry-over influences were evaluated by including sequence (3v3-first vs 5v5-first) and period (week 1 vs week 2) as fixed effects. Session day (Tuesday vs Thursday) was exploratory tested as an additional covariate.

Model parameters were estimated using restricted maximum likelihood. Fixed-effect estimates are presented as unstandardized coefficients (β) with 95% confidence intervals. The relative contribution of each predictor to explaining CV% was assessed using marginal R^2 (variance explained by fixed effects) and conditional R^2 (variance explained by fixed and random effects). Additional inference regarding the importance of format, YYIR performance, and HR intensity was obtained by comparing the full model with reduced models omitting each predictor in turn; changes in marginal R^2, Akaike Information Criterion (AIC), and likelihood-ratio tests were used to evaluate the unique explanatory value of each factor. Standardized effect sizes (standardized β coefficients) were also computed to facilitate interpretation of relative magnitudes. All statistical tests were two-tailed with α = 0.05. Analyses were conducted in R (version 4.5.2) using the lme4, lmerTest, and performance packages. Data are reported as mean ± SD unless otherwise specified.

Results

Descriptive examination of cardiovascular responses revealed that mean HR intensity differed between formats (Table 2), with players working at higher intensities during 3v3 (180.9 ± 2.8 bpm) compared with 5v5 (173.6 ± 3.6 bpm). Conversely, between-bout cardiovascular variability showed an opposite directional trend, with CV% being lower in 3v3 (1.97 ± 0.81%) and higher in 5v5 (2.61 ± 1.21%). Yo-Yo IR1 performance demonstrated substantial inter-individual differences (1795.7 ± 378.8 m), indicating a wide range of intermittent aerobic capacity within the cohort. Because CV% violated normality assumptions, the log-transformed variable was used in subsequent mixed-effects models, which resulted in a markedly improved distribution suitable for linear modelling. The player-level random intercept variance was near zero, yielding a low intraclass correlation coefficient (ICC), indicating limited clustering by player for log-CV beyond fixed effects. As a sensitivity check, a fixed-effects-only model produced substantively similar estimates for the main predictors.

Table 2. Heart rate responses and cardiovascular load variability during 3v3 and 5v5 small-sided games.

Format	HRmean Bout 1 (bpm)	HRmean Bout 2 (bpm)	HRmean Bout 3 (bpm)	HRmean Bout 4 (bpm)	HRmean overall (bpm)	CV% (mean ± SD)
3v3	178.85 ± 2.88	180.88 ± 3.02	181.58 ± 2.88	182.17 ± 3.33	180.87 ± 2.79	1.97 ± 0.81
5v5	170.57 ± 3.54	173.15 ± 3.87	174.93 ± 3.69	175.68 ± 3.82	173.58 ± 3.56	2.61 ± 1.21
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	0.002

HR: heart rate; CV: coefficient of v

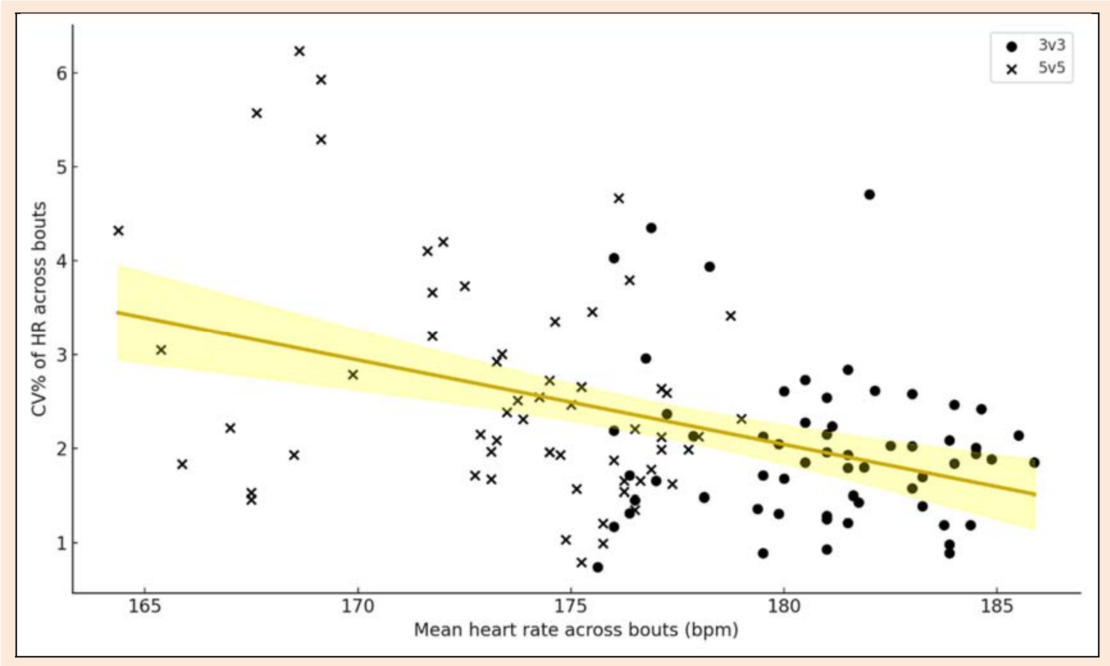

Figure 2. Relationship between cardiovascular intensity and heart-rate (HR) within-player coefficient of variation (%) during small-sided games.

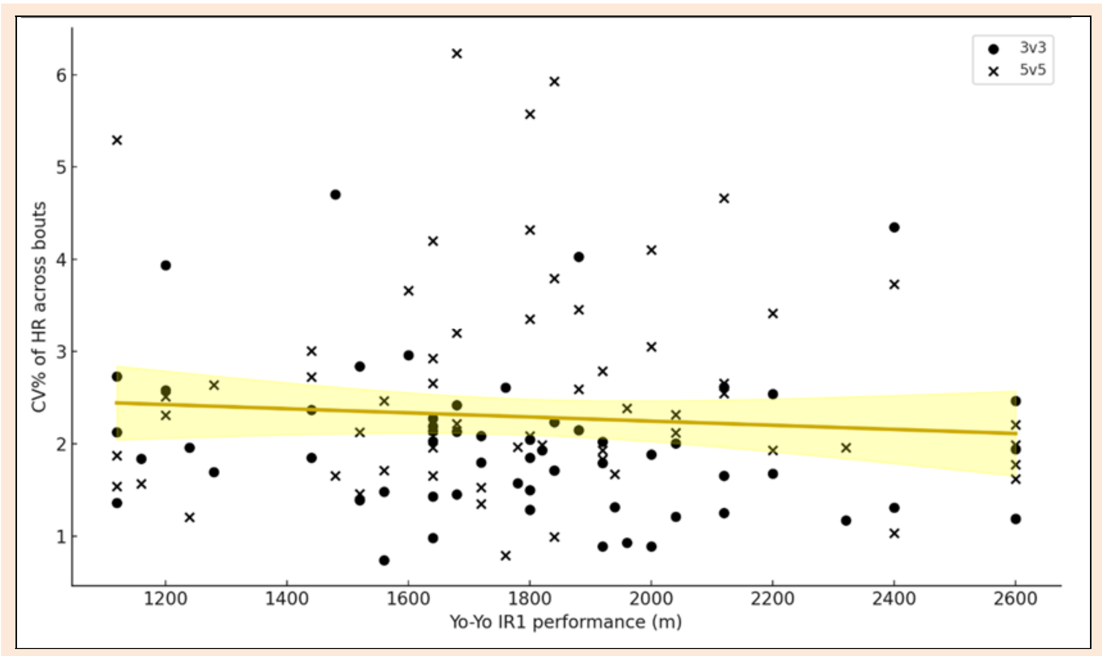

Figure 3. Relationship between intermittent aerobic capacity and heart-rate (HR) within-player coefficient of variation (%) during small-sided games.

The linear mixed-effects analysis examined whether variability in cardiovascular load across bouts was associated with SSG format, aerobic capacity, or the mean HR intensity achieved during each format. The model included format, Yo-Yo IR1 distance, and HR intensity as fixed effects, with player ID included as a random intercept to account for repeated measures within individuals. The random-effects variance approximated zero, suggesting little unexplained between-player heterogeneity in baseline CV%. Inspection of fixed-effect estimates indicated that the only significant predictor of log-CV was HR intensity. Specifically, higher mean HR values across bouts were associated with lower variability in cardiovascular load ($\beta = -0.027$, 95% CI = -0.050 to -0.005, $p = 0.019$), indicating that players who sustained relatively higher working intensities across repetitions demonstrated more stable heart-rate responses (Figure 2). When back-transformed, this coefficient corresponded to an approximate 2.7% decrease in CV% for each additional beat per minute in overall intensity, representing a meaningful stabilizing effect at higher physiological loads.

In contrast to HR intensity, neither SSG format nor Yo-Yo IR1 performance significantly predicted log-CV. The comparison between 3v3 and 5v5 did not reach statistical significance (β = 0.056, p = 0.618), despite descriptively larger CV% values in 5v5 (Figure 3). These findings indicate that differences in bout-to-bout heart-rate variability between formats can be largely attributed to the intensity achieved during play, rather than to the structural characteristics of the format itself. Similarly, aerobic capacity, as measured by Yo-Yo IR1 performance, did not significantly contribute to explaining individual variability (β = –0.00008, p = 0.385), suggesting that intermittent fitness level alone does not modulate the stability of cardiovascular responses across repeated SSG bouts under the conditions examined.

Evaluation of model fit demonstrated that the fixed effects explained 13.6% of the variance in log-CV, with identical marginal and conditional R^2 values, reflecting minimal influence of random effects. Further examination of reduced models showed that HR intensity accounted for the greatest proportion of unique explained variance, as removing this predictor led to the largest drop in marginal R^2 (from 0.136 to 0.097). Conversely, removing format or Yo-Yo IR1 resulted in negligible changes in explained variance, reinforcing the limited contribution of these factors to cardiovascular variability.

Discussion

The aim of this study was to determine whether the within-player variability of cardiovascular load (expressed as coefficient of variation of heart rate across bouts) during two SSG formats (3v3 vs 5v5) is more strongly associated with the game format, players' intermittent aerobic capacity, or the overall heart-rate intensity achieved during play. Mean HR intensity was the only measured factor that showed a statistically significant association with HR variability. However, the modest marginal R^2 indicates that a substantial proportion of variability remains unexplained and may reflect tactical interactions, pacing, fatigue/recovery status, and contextual factors. Although format and Yo-Yo IR1 were non-significant predictors in the adjusted model, the direction of effects suggested slightly higher variability in 5v5 and a weak negative association between Yo-Yo IR1 distance and variability.

The finding that mean HR intensity was the only significant predictor of HR variability aligns with previous investigations showing that more intense exercise yields more consistent physiological responses across repeated bouts. The results suggest that intensity achieved, rather than format per se, explains the observed differences in variability. For instance, in youth soccer players performing repeated SSGs, within-player coefficients of variation for heart rate were relatively small (~3 - 11%) and appeared smaller in higher-intensity formats (3v3) than in less intense formats (5v5) despite higher locomotor variability in the smaller format (Silva et al., 2022). This supports the notion that when players work at higher relative intensities, cardiovascular responses become more homogeneous across repetitions (Dellal et al., 2015). The justification may be that at high intensity, physiological systems (cardiovascular, autonomic, metabolic) are recruited near maximal or near-saturating levels, thus reducing the relative variation between bouts, whereas at lower intensities the degree of physiological drift, recovery differences, or tactical fluctuations may exert a greater influence on responses (Cipryan et al., 2017; Wan et al., 2023). This interpretation is consistent with exercise-physiology evidence showing that higher intensities produce more stable HR responses across time and less residual variability from preceding bouts (Manolopoulos, 2012; Mascarin et al., 2018). This indicates that when a coach wants predictable cardiovascular load from SSG bouts, designing the activity such that players are pushed to higher HR levels may reduce between-bout variation.

In contrast, we observed that the structural format (3v3 vs 5v5) did not independently predict HR variability once intensity and fitness were accounted for. This is somewhat surprising given that some studies have shown format (team size, area per player) as a primary modifier of intensity and load in SSGs. For example, research shows that fewer players (e.g., 3v3) and smaller individual playing areas often yield greater %HRmax and physiological load than larger formats (Manolopoulos, 2012; Gantois et al., 2023). However, our results suggest that the format per se may not guarantee lower variability- it may only do so insofar as it elevates mean HR intensity. That is, the format's effect on variability appears mediated through intensity rather than being a direct driver (Castellano et al., 2013). A plausible explanation is that tactical and technical fluctuations inherent to each format produce different sources of variation (Praca et al., 2022) but when the burden of physiological load is high (i.e., high HR), those fluctuations may contribute proportionally less to variability. In smaller or less intense formats, variability from tactical interactions, ball contacts, positional changes or rest intervals may account for a larger share of observed HR variation. This aligns with evidence that while format influences external load consistency, the internal load (HR) may become more stable when higher demands are imposed (Silva et al., 2022).

The absence of a significant effect of intermittent aerobic capacity (Yo-Yo IR1 performance) on HR variability is also noteworthy. We found that within the context of repeated SSG bouts, aerobic capacity did not help explain why some players exhibited more or less HR player variability across bouts. One possible explanation is that once players are already fit at a relatively homogeneous level (in our sample late-adolescent outfield players with 5 - 7 years' experience), the incremental role of fitness in stabilising HR response might be small compared with the dominant effect of intensity (Massamba et al., 2021). Moreover, the dynamic nature of SSGs may impose such variable stimulus that fitness alone cannot buffer the influences of tactical variability, recovery status, and neuromuscular fatigue, all of which may contribute to HR variability (Halouani et al., 2014). That is, even highly fit players may show variation in HR responses if the game stimulus varies through possession changes, pressing patterns or rest intervals.

In terms of practical application, our results suggest that when coaches seek to produce consistent cardiovascular load across repeated SSG bouts, the main lever is to elevate and maintain higher HR intensities across those bouts. Structurally modifying formats (3v3 vs 5v5) may be less relevant unless such changes translate into consistent higher HR. In planning SSGs, practitioners might thus monitor mid-session HRmean and adjust rest, encouragement, playing area, or tactical constraint to sustain high intensity and thereby reduce HR variability. However, if the objective is to allow more individual variation (for example to encourage intermittent recovery, variability in stimulus, or to individualise load) then intentionally using lower-intensity formats might permit greater variability and thus heterogeneity in cardiovascular strain.

While our study offers useful implications, some limitations must be acknowledged. The sample consisted of youth male players, which may limit generalisability to female players, older or elite professional players. Moreover, although we controlled for format and intensity, the SSGs still included inherent tactical and technical variations (player interactions, ball possession changes, individual involvement) which are difficult to standardise fully and may have contributed to HR variability. Limitations also include the absence of concurrent external-load and perceptual measures, which are factors limiting inference about broader SSG designs and about multi-domain load variability. Also, non-linear relationships or interactions were present and must be considered in future research. Finally, we did not assess day-to-day recovery status, sleep, or readiness markers which might moderate within-player variability across sessions. Future studies should examine the interplay of tactical constraints, individual readiness, and load variability in SSGs across different populations and contexts.

Conclusion

In under-19 male players performing 4 × 3-min SSG bouts with 2-min recovery, higher achieved mean HR was associated with lower bout-to-bout HR variability, while format and Yo-Yo IR1 performance were not independent predictors. Higher achieved HR intensity (more than format or Yo-Yo IR1) was associated with lower bout-to-bout HR variability during short intermittent SSGs, although most variability remained unexplained. While descriptive differences between formats were observed, the extent to which format plays a direct role in modulating bout-to-bout variability remains uncertain and may be mediated by its influence on intensity rather than by structural properties themselves. Similarly, the absence of a detectable association between aerobic fitness and cardiovascular variability should be interpreted cautiously, as it may reflect the characteristics of the present sample rather than a general lack of relationship. In practical terms, players who sustained higher cardiovascular intensity during SSG bouts tended to show more consistent (less variable) bout-to-bout HR responses. This suggests that to promote a more reproducible internal-load stimulus, coaches may need to emphasize task constraints that reliably elevate intensity, while recognizing that format effects on average HR do not necessarily translate into effects on variability.

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The author reports no actual or potential conflicts of interest. 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 manuscript.

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Key points

- Higher mean heart-rate intensity was the only significant predictor of cardiovascular load variability—higher HR during bouts was associated with lower variability across repetitions.
- Game format (3v3 vs 5v5) did not independently influence cardiovascular variability once intensity was accounted for, despite descriptively higher CV% in 5v5.
- Intermittent aerobic capacity (Yo-Yo IR1 performance) showed no significant association with bout-to-bout cardio-vascular variability in these youth players.

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