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Effects of player number and pitch size on internal and external load in small-sided Ultimate Frisbee games

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This exploratory study examined the effects of player number and pitch size on internal and external load during small-sided Ultimate Frisbee games (SSGs) in elite male athletes and explored associations between playing density, expressed as area per player, and selected load indicators. Eight elite male Ultimate Frisbee players participated in SSGs across eight different configurations involving different player numbers (2v2, 3v3, 4v4) and pitch sizes (small, medium, and large). The 2v2 large-pitch was excluded because it was considered poorly representative of typical small-sided Ultimate Frisbee practice. Internal load was assessed as percentage of individual maximum heart rate (%HRmax), while external load was quantified using GPS-derived total distance, maximum speed, high-intensity running distance, and high-intensity accelerations/decelerations. Linear mixed-effects models examined the effects of player number and pitch size. LOESS curves were used only as descriptive visualizations of potential density-load patterns. Pitch size was associated with differences in locomotor variables, with larger pitches generally eliciting greater total and high-intensity running distances. Smaller formats, particularly 2v2 and 3v3, elicited higher HR responses and greater acceleration/deceleration demands than 4v4. Descriptive density analyses suggested outcome-specific tendencies, with locomotor variables generally greater in configurations providing medium-to-large relative areas per player, whereas acceleration/deceleration responses appeared less consistently related to density alone and may depend on both available space and player number. In this small homogeneous sample of elite male Ultimate Frisbee players, player number and pitch size appeared to modulate acute internal and external load responses during SSGs. However, given the limited sample size and the sparse number of density values, these findings should be interpreted as preliminary and hypothesis-generating rather than as stable effects, definitive thresholds, or practical prescription targets.

Keywords Accelerations, Area per player, GPS monitoring, Heart rate, High-intensity running, Ultimate Frisbee

Small-sided games (SSGs) are widely recognized as an effective training strategy for developing both technical and physiological components in team sports. By manipulating key characteristics such as the number of players, pitch size, game duration, and specific rules, coaches can influence the physical and physiological demands placed on athletes[1,2]. This approach allows for a close replication of sport-specific movements and decision-making processes while providing a controllable environment to target specific physical qualities[3,4].

In team sports such as soccer, SSGs have been extensively investigated to determine how different configurations affect external and internal load. For example, reducing the number of players or increasing pitch size generally increases movement intensity, heart rate (HR), and perceived exertion[1,5–8]. These effects arise because fewer players increase individual involvement and reduce recovery opportunities between high-intensity actions, whereas smaller or more congested pitch areas might constrain running distance and promote higher frequencies of accelerations and decelerations[9].

A critical concept in this context is playing density, often quantified as the pitch area per player. Riboli et al. (2020) found that different area-per-player values are needed in SSGs to replicate match demands in total distance, high-intensity running, sprinting distance and metabolic power[10]. In youth players, area per player also exhibits relationships with locomotor activity: moderate to large correlations have been observed between area per player and running distances, while very high-density conditions can overemphasize mechanical demands (accelerations/decelerations) compared to match play[11]. Moreover, systematic reviews suggest that pitch area per player consistently moderates the acute physiological load (e.g., HR) across SSG formats[12].

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Beyond physiological and locomotor responses, SSGs also provide meaningful opportunities for improving technical and tactical skills. Indeed, a recent meta-analysis showed that SSG-based training programs significantly benefit the technical execution of young and youth players across team sports[13]. This suggests that SSGs effectively integrate conditioning and skill development, making them particularly advantageous for season-long planning or for teams with limited training time.

From a load-management perspective, both internal load, typically assessed via HR responses, and external load, quantified through GPS-derived metrics such as high-speed and sprint running distance, are essential to monitor. The balance between these dimensions provides insight into how players physiologically respond to different game situations[14]. By systematically manipulating SSG constraints (player number, pitch size, and density), practitioners can tailor training to target specific energy systems, mechanical demands, or a mixture thereof[15–17]. More broadly, recent sports analytics research has emphasized the value of integrating performance, health-related, and contextual information to support athlete monitoring and sport-specific decision-making[18,19]. However, although most evidence derives from sports such as soccer, basketball, handball, and other invasion or court sports, caution is required when generalizing these findings to disciplines with different movement patterns, technical-tactical constraints, and energy system demands.

These considerations are particularly relevant to Ultimate Frisbee, an intermittent, high-intensity invasion sport characterized by high-speed running, frequent accelerations and decelerations, and brief recovery periods[20,21]. Despite these demanding characteristics, Ultimate Frisbee has received limited scientific attention regarding the optimization of its training methods. To date, only one study has specifically investigated the physical and technical demands of SSGs in Ultimate Frisbee[22]. However, no study has systematically examined how the combined manipulation of player number and pitch size affects internal and external load in elite Ultimate Frisbee players.

Ultimate Frisbee also presents sport-specific constraints that may influence SSG responses differently from other invasion sports. Unlike many invasion games, the disc carrier cannot run with the disc, and offensive progression depends on passing, off-disc cutting, rapid changes of direction, and repeated creation of separation from defenders. These constraints may alter how player number, pitch size, and relative area per player affect internal and external load responses. Therefore, understanding how SSG constraints regulate the balance among mechanical, locomotor and cardiovascular loads is particularly important for informing training design and load-management strategies in Ultimate Frisbee. However, the current lack of normative data on how different SSG configurations affect physical and physiological responses represents a significant barrier to evidence-based training design.

Thus, the present study aimed to investigate the acute internal and external load responses to variations in player number and pitch size during small-sided Ultimate Frisbee games in elite male players, and to explore preliminary density-related tendencies that may inform applied monitoring. We hypothesized that: (i) larger pitch sizes would elicit greater locomotor demands, particularly total distance and high-intensity running distance; (ii) smaller player-number formats would increase cardiovascular and mechanical demands because of greater individual involvement; and (iii) playing density, expressed as area per player, would show potential outcome-specific density-related tendencies, with larger relative areas favoring locomotor responses and more constrained formats favoring acceleration and deceleration demands.

Methods
Participants
An a-priori power analysis was performed using G*Power 3.1 (Heinrich Heine University, Düsseldorf, Germany) to estimate the minimum required sample size. Considering the within-subjects repeated-measures design adopted in this study, an analysis of variance (ANOVA, repeated measures, within factors) was simulated with an α level of 0.05, statistical power ($1-\beta$) of 0.80, and a medium-to-large expected effect size (Cohen's $f = 0.40$, corresponding approximately to $d = 0.80$), based on previous literature reporting substantial effects of player number and pitch size on internal and external load in small-sided games across team sports. Although the main analyses were conducted using linear mixed-effects models, the repeated-measures ANOVA used for the power analysis can be considered an approximate equivalent of the adopted model structure. The analysis indicated that a minimum of six participants would be sufficient to detect significant effects under these assumptions. Therefore, the inclusion of eight elite players was considered acceptable for the repeated-measures exploratory design and sufficient to detect large within-subject effects under the assumptions of the power analysis. However, given the small and homogeneous nature of the elite sample, the results should be interpreted as preliminary and require confirmation in larger and more diverse cohorts.

Eight elite male Ultimate Frisbee players (mean ± SD age: 25.3 ± 3.1 years; body mass: 73.6 ± 5.8 kg; height: 178.2 ± 4.9 cm) were involved in the study. All players were members of international-level teams and regularly competed in international tournaments. Playing positions were classified as handler ($n = 3$) and cutter ($n = 5$). Participants were free from musculoskeletal injuries in the six months preceding data collection and had at least seven years of competitive experience.

Players were accustomed to SSG configurations used in this study, which were regularly included in their training routines. Two weeks prior to the SSG data collection, they performed the Yo-Yo Intermittent Recovery Level 1 (Yo-Yo IR1) test to determine maximum heart rate (HRmax) and to characterize aerobic capacity. The total distance covered during the Yo-Yo IR1, recorded as a descriptive measure of players' endurance capacity, was 2220 ± 326 m. These values are comparable to, although on average slightly higher than, those previously reported for Ultimate Frisbee players from a university club[20].

The study was conducted in accordance with the principles set forth in the Declaration of Helsinki and its later amendments, and its protocol was approved by the University of Bologna Bioethics Committee (protocol 283721, 04/11/2021). All participants provided their written informed consent to participate.

Experimental design and procedures

A repeated-measures design was adopted to assess the effects of player number (2v2, 3v3, 4v4), and pitch size (small, medium, large) on internal (HR) and external (GPS-derived metrics) load during Ultimate Frisbee SSGs. Each player participated in eight SSG configurations: 2v2 on small and medium pitches, and 3v3 and 4v4 on small, medium and large pitches. The 2v2 format on the large pitch was excluded because the excessively large area per player would have altered the technical, tactical and physical demands compared with typical small-sided Ultimate Frisbee configurations. Pitch dimensions and corresponding player densities are presented in Table 1.

All games were played on natural grass under consistent environmental conditions (temperature: 25°-27 °C with almost no wind). Sessions were distributed across three separate days, with at least 48 h of rest between sessions to ensure full recovery. Each session was dedicated to a specific player-number condition (2v2, 3v3, or 4v4, randomized order). Within each session, pitch size order (e.g., small, medium, large) was randomized using a Latin square design to minimize order effects. A minimum of 20 min of passive recovery was provided between games played on different pitch sizes.

A standardized 10-min warm-up (jogging, dynamic mobility, throwing drills, accelerations, and changes of direction) preceded each session. Each game consisted of two 3-minute bouts separated by 2 min of passive recovery. Mean values across bouts were used for subsequent analyses.

Team compositions were rebalanced after each game to reduce systematic bias related to teammate or opponent familiarity. Only the eight enrolled elite players were included in the statistical analyses. Additional sparring players were used when required to complete specific game formats and maintain competitive balance. However, their GPS and HR data were not included in the analyses. Sparring players were selected from the same competitive environment and had comparable technical experience. Nevertheless, their involvement should be acknowledged as a potential source of contextual variability.

Games were played according to modified Ultimate Frisbee rules designed to preserve the main technical and tactical characteristics of the sport while maintaining continuous play. A stall count of eight was used, with no formal scoring system or time-outs. Standard 175-g discs were used, with spares available on the sidelines to immediately resume play if the disc left the pitch. Each game began with a standardized disc pull to initiate play. No substitutions were allowed during the bouts. Each session was supervised by two experienced Ultimate Frisbee coaches and one researcher, who also recorded observational notes regarding gameplay flow and rule compliance. In the 24 h preceding each session, participants were instructed to maintain their habitual diet and hydration routines and to avoid strenuous physical activity.

Measures

External load

External load variables were recorded using portable GPS units operating at 18 Hz (GPEXE LT, Exelio, Udine, Italy). This system provides reliable and reasonably valid measurements of external load variables in team-sport contexts, with highest accuracy for maximal sprint speed[23]. Devices were worn in a custom-fitted vest positioned between the scapulae and activated 10 min before data collection to ensure optimal satellite signal acquisition (minimum of 8 connected satellites, HDOP < 1.0).

The following variables were analyzed:

- total distance covered (m).
- maximum speed (m/s).
- high-intensity (> 5.5 m/s) running distance (m).
- number of high-intensity (> 2.5 m/s^2) accelerations.
- number of high-intensity (< -2.5 m/s^2) decelerations.

All GPS data were downloaded immediately post-session and processed using the manufacturer's proprietary web application. Data were calculated for each 3-minute bout and then averaged across the two bouts for each game, and mean values across bouts were used for analysis.

Internal load

HR was continuously recorded using chest-strap telemetry (Polar H10, Polar Electro Oy, Finland) and synchronized with GPS data. HR traces were visually checked for artifacts or dropouts. For each bout, HR values

Configuration	Pitch size (m)	Density (m^2/player)
Small 2v2	15 × 20	75
Small 3v3	15 × 20	50
Small 4v4	15 × 20	38
Medium 2v2	20 × 26	130
Medium 3v3	20 × 26	87
Medium 4v4	20 × 26	65
Large 3v3	25 × 32	133
Large 4v4	25 × 32	100

Table 1. Pitch size (endzones excluded) and playing density for each playing configuration.

were averaged over the final minute to reflect steady-state effort. Internal load was expressed as percentage of HRmax.

Statistical analysis

All analyses were conducted using R, version 4.3.1[24]. Descriptive statistics were calculated and presented as mean ± SD. Data distributions, including medians, quartiles, and potential outliers, were visually inspected using boxplots. Linear mixed-effects models were used to examine the effects of player number and pitch size on each internal and external load variable. For each outcome, player number, pitch size, and their interaction were included as fixed effects. Player ID was included as a random effect to account for the repeated-measures structure of the data and inter-individual differences in baseline load responses. Random slopes were considered conceptually but were not included because of the small sample size, the unbalanced design caused by the absence of the 2v2 large-pitch condition, and the limited number of repeated observations per condition, which increased the risk of overparameterized or unstable models.

The mixed-model approach allowed the inclusion of all available observations while accounting for the unbalanced design and for one missing data point for one player in the 4v4 format due to technical issues. Model assumptions were assessed through visual inspection of residuals-vs-fitted plots and normal Q-Q plots of residuals. No major deviations were observed for most outcomes, although some departure from residual normality was noted for high-intensity running distance.

Estimated marginal means were calculated and pairwise comparisons were performed across player number and pitch size using the emmeans package with Bonferroni adjustment for multiple comparisons. Cohen's d effect sizes were calculated for post-hoc pairwise comparisons and standardized using the residual standard deviation derived from the linear mixed-effects model. Cohen's d values were interpreted using the following thresholds for the absolute value of d: small (≥ 0.20), medium (≥ 0.50), large (≥ 0.80), and very large (≥ 1.30). Statistical significance was set at $p < 0.05$. However, because of the small sample size and the number of pairwise comparisons, effect sizes were interpreted as descriptive indicators of magnitude rather than as evidence of stable or generalizable effects.

In addition, the association of playing density, expressed as area per player, and load variables was explored descriptively using locally estimated scatterplot smoothing (LOESS). Although LOESS curves were generated from individual observations, the density variable included only eight unique values. Therefore, the curves were interpreted as exploratory visual summaries. As a qualitative sensitivity check, LOESS curves were inspected using alternative smoothing specifications. These checks indicated that some local curve features were sensitive to smoothing choices, particularly for acceleration and deceleration variables. Therefore, interpretation was limited to broad exploratory tendencies.

Results

Effects of player number and pitch size on load

Descriptive statistics for internal and external load variables across all configurations are reported in Table 2 and visually illustrated in Fig. 1.

The linear mixed-model analysis showed that both pitch size and player number influenced load variables, with significant interactions observed for some variables. The calculated Cohen's d effect sizes for all pairwise comparisons are detailed in Table 3.

Total distance was significantly affected by pitch size ($p < 0.001$), with large pitches eliciting greater distances than medium and small pitches, and by the player number × pitch size interaction ($p = 0.004$), whereas the main effect of player number was not significant ($p = 0.18$). Pairwise comparisons indicated that on the medium pitch, 3v3 games elicited greater total distance than 2v2 (d = 1.55, very large; $p = 0.009$) and 4v4 (d = 1.63, very large; $p = 0.008$). Furthermore, on the large pitch 4v4 elicited greater distance than 3v3 (d = 1.10, large; $p = 0.041$).

Maximum speed showed a significant player number × pitch size interaction ($p = 0.038$) but no significant main effects of pitch size ($p = 0.096$) or player number ($p = 0.096$) were observed. Pairwise comparisons showed a very large effect size for 3v3 reaching higher speeds than 4v4 on the small pitch (d = 1.87; $p = 0.023$).

High-intensity running distance was significantly influenced by pitch size ($p = 0.005$), with the highest distances on medium and large pitches and the lowest on small pitches. Neither the main effect of player number ($p = 0.52$) nor the interaction ($p = 0.47$) reached significance. The largest effect size observed after pairwise

Configuration	Total distance (m)	Maximum speed (m/s)	High-intensity running distance (m)	High-intensity accelerations	High-intensity decelerations	HR (% HRmax)
Small 2v2	384.7 ± 32.0	6.22 ± 0.37	15.3 ± 9.3	6.9 ± 2.0	8.6 ± 2.2	91.7 ± 3.2
Small 3v3	390.7 ± 20.4	6.60 ± 0.58	17.6 ± 9.9	3.8 ± 2.4	5.8 ± 1.8	91.6 ± 2.3
Small 4v4	399.3 ± 28.7	5.79 ± 0.46	9.6 ± 10.2	3.6 ± 2.6	3.9 ± 2.0	86.8 ± 4.2
Medium 2v2	384.9 ± 35.5	6.55 ± 0.40	35.8 ± 25.3	4.8 ± 3.6	6.0 ± 2.8	94.1 ± 2.5
Medium 3v3	422.1 ± 30.4	6.43 ± 0.66	29.8 ± 20.1	3.1 ± 2.8	4.9 ± 3.3	94.1 ± 2.1
Medium 4v4	383.0 ± 20.8	6.33 ± 0.60	22.2 ± 22.4	2.1 ± 1.7	4.0 ± 2.2	89.7 ± 3.1
Large 3v3	424.1 ± 21.4	6.44 ± 0.61	25.3 ± 17.8	1.3 ± 1.3	3.8 ± 1.9	94.1 ± 1.8
Large 4v4	450.3 ± 29.4	6.48 ± 0.58	32.9 ± 24.4	2.7 ± 1.1	3.3 ± 1.4	90.6 ± 4.7

Table 2. Mean ± SD values of GPS-derived metrics and HR over the examined SSG configurations.

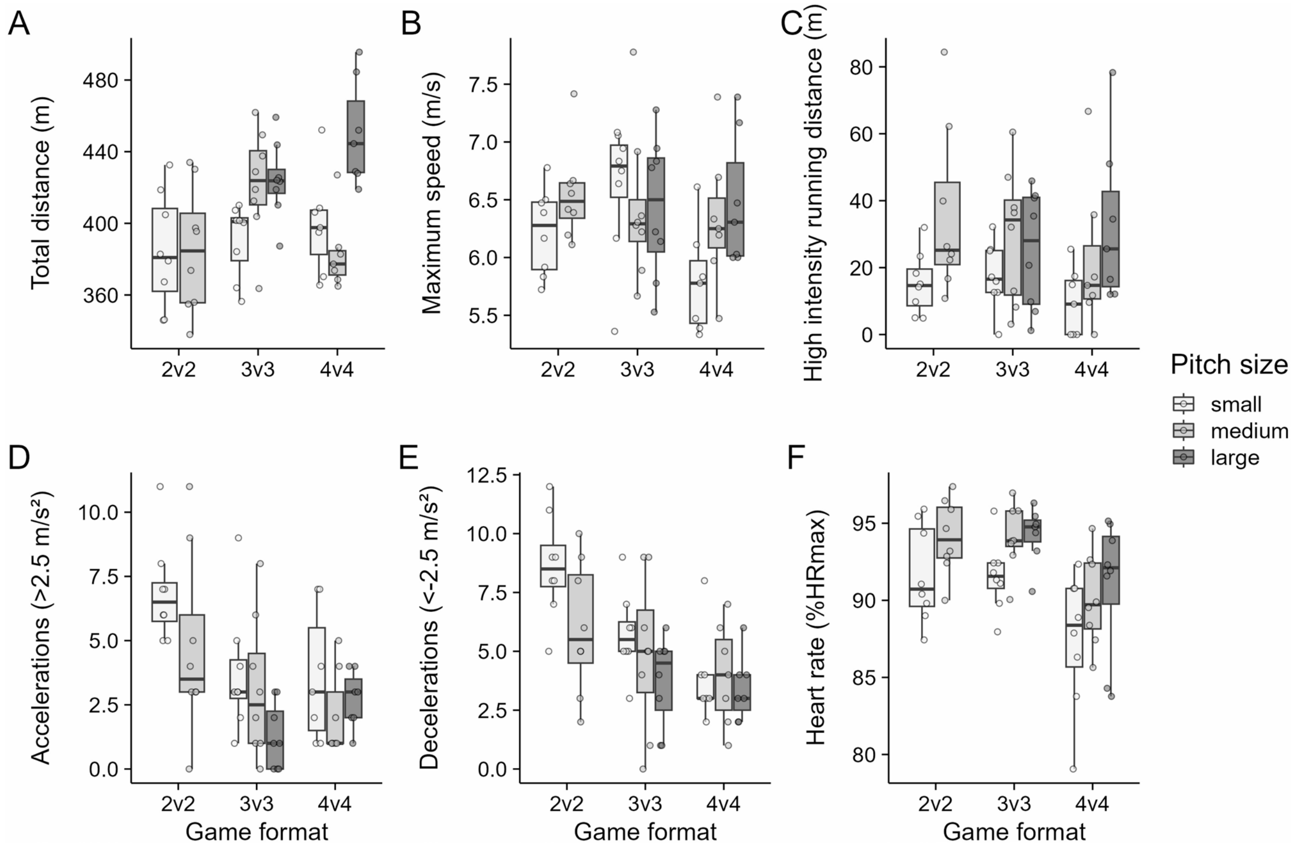

Fig. 1. Distribution of internal and external load variables across SSG formats and pitch sizes. Panels illustrate: (**A**) total distance; (**B**) maximum speed; (**C**) high-intensity running distance; (**D**) high-intensity accelerations; (**E**) high-intensity decelerations; and (**F**) heart rate, expressed as %HRmax. Boxes represent the interquartile range (IQR), the horizontal line inside the box is the median, and whiskers extend to the most extreme data points not considered outliers. Dots represent individual participant data.

comparisons was a medium effect for the 2v2 vs. 4v4 contrast on the medium pitch (d = 0.78), which was not statistically significant ($p = 0.302$).

Accelerations were affected by both player number ($p < 0.001$), with higher values in 2v2 than in 3v3 or 4v4, and pitch size ($p = 0.014$), with higher values on small pitches compared to medium and large pitches, whereas the player number × pitch size interaction was not significant ($p = 0.28$). Pairwise comparisons revealed significant differences localized on the small pitch: the 2v2 vs. 3v3 and 2v2 vs. 4v4 comparisons showed very large effects (respectively, d = 1.60 and d = 1.70, both $p < 0.01$). On the medium pitch also, the number of accelerations was higher in the 2v2 than in the 4v4 format (d = 1.34, very large; $p = 0.034$).

Decelerations showed a main effect of player number ($p < 0.001$), with higher values in 2v2 and 3v3 than in 4v4, whereas pitch size ($p = 0.096$) and the interaction ($p = 0.33$) were not significant. The 2v2 vs. 4v4 contrast on the small pitch showed the largest magnitude of difference, with a very large effect size (d = 2.11, $p = 0.001$). Furthermore, the 2v2 vs. 3v3 comparison on the small pitch showed a large effect (d = 1.28, $p = 0.036$).

Heart rate was influenced by both player number ($p < 0.001$), with 2v2 and 3v3 eliciting higher cardiovascular load than 4v4, and pitch size ($p = 0.001$), with the highest values observed on medium pitches. The player number × pitch size interaction was not significant ($p = 0.98$), suggesting that the effect of player number (i.e., 2v2/3v3 eliciting higher load than 4v4) is consistent across all pitch sizes. Pairwise comparisons revealed significant differences with large to very large effects. For instance, a large effect was found for the 3v3 vs. 4v4 comparison on the large pitch (d = 1.23; $p = 0.022$). Furthermore, very large effects were observed on the medium pitch for the 2v2 vs. 4v4 (d = 1.49, $p = 0.012$) and 3v3 vs. 4v4 (d = 1.50, $p = 0.012$) comparisons, and on the small pitch for the 2v2 vs. 4v4 (d = 1.55; $p = 0.009$) and 3v3 vs. 4v4 (d = 1.52; $p = 0.011$) comparisons.

Exploratory associations between playing density and load

The exploratory LOESS analysis suggested that the association between playing density and load indicators was outcome-specific rather than uniform across variables. These curves should be interpreted as descriptive visualizations of broad trends, because the density variable was represented by only eight unique values (Fig. 2).

Descriptively, locomotor variables, including total distance, maximum speed, and high-intensity running distance, tended to be greater in configurations providing medium-to-large relative areas per player. However,

Variable	Pitch size	Comparison	Estimated mean difference	Cohen's d	*p*-value
Total distance (m)	Small	2v2 vs. 3v3	− 6.0	0.25	0.870
		2v2 vs. 4v4	− 14.6	0.61	0.476
		3v3 vs. 4v4	− 8.6	0.36	0.771
	Medium	2v2 vs. 3v3	− 37.1	1.55	**0.009**
		2v2 vs. 4v4	2.0	0.08	0.986
		3v3 vs. 4v4	39.1	1.63	**0.008**
	Large	3v3 vs. 4v4	− 26.3	1.10	**0.041**
Maximum speed (m/s)	Small	2v2 vs. 3v3	− 0.38	0.90	0.183
		2v2 vs. 4v4	0.41	0.97	0.160
		3v3 vs. 4v4	0.80	1.87	**0.023**
	Medium	2v2 vs. 3v3	0.12	0.29	0.836
		2v2 vs. 4v4	0.20	0.47	0.640
		3v3 vs. 4v4	0.08	0.19	0.932
	Large	3v3 vs. 4v4	− 0.06	0.14	0.783
High-intensity running distance (m)	Small	2v2 vs. 3v3	− 2.3	0.13	0.962
		2v2 vs. 4v4	5.6	0.32	0.809
		3v3 vs. 4v4	7.8	0.46	0.658
	Medium	2v2 vs. 3v3	6.1	0.35	0.762
		2v2 vs. 4v4	13.4	0.78	0.302
		3v3 vs. 4v4	7.3	0.43	0.694
	Large	3v3 vs. 4v4	− 7.8	0.45	0.387
High-intensity accelerations	Small	2v2 vs. 3v3	3.1	1.60	**0.007**
		2v2 vs. 4v4	3.3	1.70	**0.006**
		3v3 vs. 4v4	0.2	0.10	0.980
	Medium	2v2 vs. 3v3	1.6	0.83	0.229
		2v2 vs. 4v4	2.6	1.34	**0.034**
		3v3 vs. 4v4	1.0	0.51	0.592
	Large	3v3 vs. 4v4	− 1.5	0.74	0.160
High-intensity decelerations	Small	2v2 vs. 3v3	2.9	1.28	**0.036**
		2v2 vs. 4v4	4.8	2.11	**0.001**
		3v3 vs. 4v4	1.9	0.83	0.253
	Medium	2v2 vs. 3v3	1.1	0.50	0.580
		2v2 vs. 4v4	2.0	0.88	0.216
		3v3 vs. 4v4	0.9	0.38	0.745
	Large	3v3 vs. 4v4	0.3	0.13	0.796
Heart rate (% HRmax)	Small	2v2 vs. 3v3	0.1	0.04	0.997
		2v2 vs. 4v4	4.2	1.55	**0.009**
		3v3 vs. 4v4	4.1	1.52	**0.011**
	Medium	2v2 vs. 3v3	0.0	0.00	0.999
		2v2 vs. 4v4	4.0	1.49	**0.012**
		3v3 vs. 4v4	4.0	1.50	**0.012**
	Large	3v3 vs. 4v4	3.3	1.23	**0.022**

Table 3. Magnitude of effects (Cohen's d) for pairwise comparisons. P-values for statistically significant differences ($p < 0.05$) are displayed in bold.

these patterns were not monotonic across the observed density values, particularly for total distance, reinforcing that density alone did not fully explain the observed load responses.

Acceleration and deceleration responses appeared less consistently related to density alone. These variables may depend on the combined influence of available space, player number, individual involvement, and sport-specific movement constraints. Therefore, the present data do not support the identification of specific density values for maximizing mechanical load.

Heart rate tended to be higher in some configurations with larger relative areas per player, although this pattern should be interpreted cautiously because density was not independent from player number and pitch size in the present design.

Overall, the density-related analysis suggests preliminary, outcome-specific tendencies. However, these patterns should be considered hypothesis-generating and should not be interpreted as definitive thresholds or prescriptive area-per-player values.

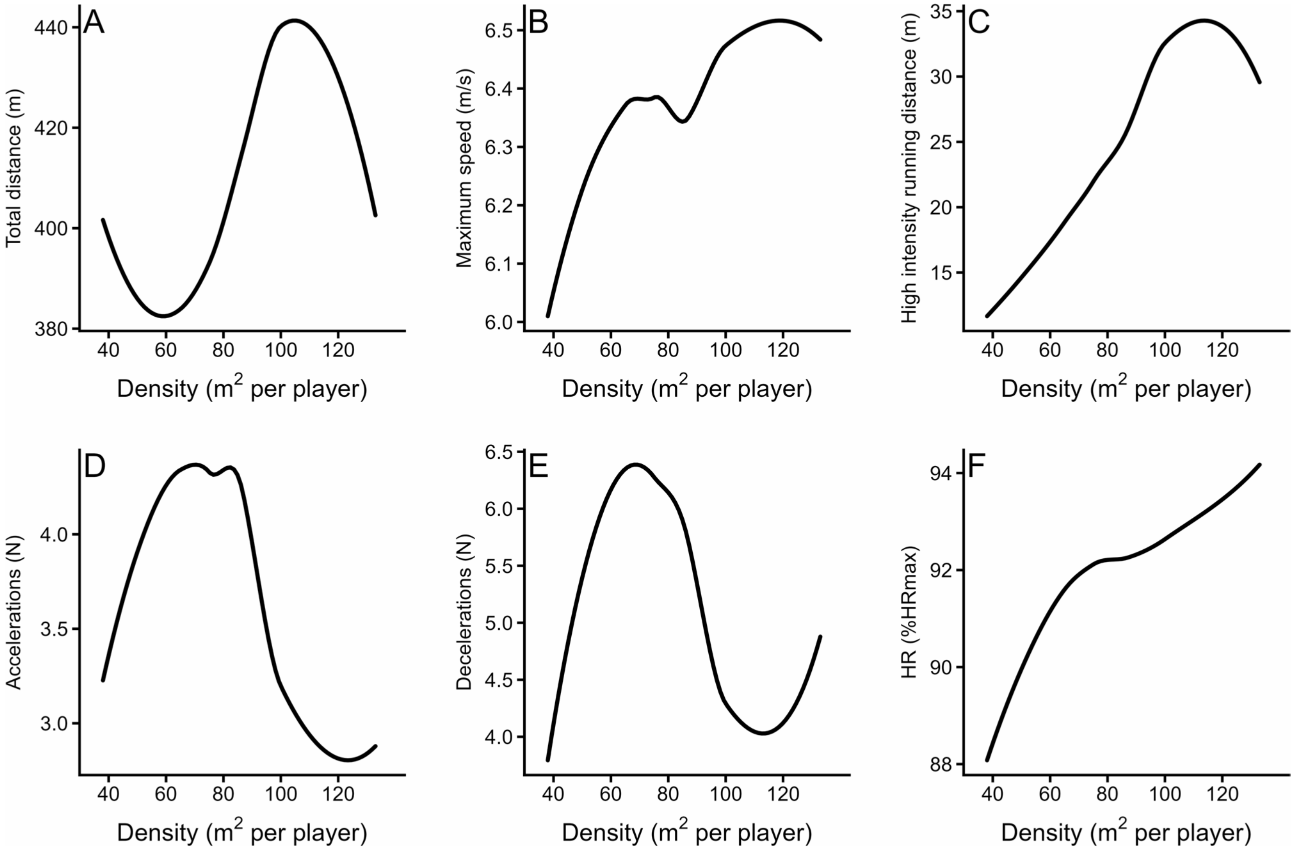

Fig. 2. Descriptive LOESS smoothing curves illustrating exploratory associations between playing density and: (**A**) total distance; (**B**) maximum speed; (**C**) high-intensity running distance; (**D**) number of high-intensity accelerations; (**E**) number of high-intensity decelerations; and (**F**) HR. Curves were generated from individual observations and are presented as exploratory visual summaries. Because the density variable included only eight unique values, the curves should not be interpreted as inferential evidence of non-linear relationships, thresholds, peak values, or optimal density ranges.

Discussion

The primary aim of this exploratory study was to examine the effects of manipulating player number and pitch size on internal and external load during Ultimate Frisbee SSGs in elite male players. A secondary aim was to explore whether playing density, expressed as the relative area per player, showed outcome-specific associations with selected load indicators. Overall, the findings suggest that player number and pitch size may influence acute load responses in this specific sample. However, because the study involved only eight elite male players, an unbalanced design, and multiple pairwise comparisons, the results should be interpreted as preliminary rather than as stable or generalizable effects.

Consistent with previous literature on intermittent team sports such as soccer[6,12] and basketball[3], smaller player-number formats were associated with higher internal load, with 2v2 and 3v3 eliciting significantly greater HR responses than 4v4. This finding is in line with the general observation that smaller team sizes may increase individual involvement, reduce recovery opportunities, and increase the frequency of high-intensity actions[4,15]. In Ultimate Frisbee specifically, each time a player receives the disc they must often decelerate and then accelerate again to create space or continue play. Formats with fewer players, especially 2v2, result in more disc touches per player due to greater individual involvement. Each additional touch consequently increases the frequency of accelerations and decelerations. This pattern reflects the combined influence of both player involvement and area per player: fewer players increase engagement and movement demands, while pitch size also modulates the space available for executing high-intensity actions. Therefore, in Ultimate Frisbee SSGs, mechanical load is influenced by both individual involvement and area per player.

Regarding pitch size, a general increase in the playing area significantly enhanced locomotor metrics (total distance and high-intensity running distance). These results are in agreement with the previous study on Ultimate Frisbee by Kajiki et al. (2021)[22], who reported increased total distance and high-intensity running distance in 3v3 on larger pitches. Our investigation expands on their work by including multiple player numbers and pitch sizes, highlighting that the effects of pitch size may depend partly on player-number format, as suggested by the significant interaction effects observed for total distance and maximum speed. The tendency of larger pitches to promote greater locomotor work is likely due to the increased space allowing players to maintain higher running speeds for longer durations and cover larger linear distances per sequence of play[7,8].

The exploratory density analysis suggested broad, outcome-specific tendencies. Locomotor variables, particularly high-intensity running distance, tended to be higher at larger relative areas per player, whereas acceleration and deceleration responses appeared less consistently related to density alone. This broad pattern is consistent with SSG research in other team sports, where larger relative playing areas generally allow players to cover greater distances and reach higher running intensities, while smaller or more congested formats may increase the frequency of short, intense actions and changes of direction[10,25,26]. However, these comparisons should be interpreted cautiously because Ultimate Frisbee has unique technical and tactical constraints, particularly the rule preventing the disc carrier from running and the frequent off-disc cutting actions required to create passing options.

The density-related findings require particular caution. Although LOESS smoothing was useful for visualizing possible broad tendencies, the analysis was based on only eight unique density values. Moreover, qualitative sensitivity checks indicated that some local features of the curves were affected by smoothing choices, especially for acceleration and deceleration variables. This suggests that the shape of the LOESS curves should not be interpreted as robust evidence of non-linear density-load relationships. Accordingly, the present density-related results should be viewed as preliminary visual patterns that may inform the design of future confirmatory studies, rather than as evidence of thresholds, peak values, or optimal density ranges.

From an applied perspective, the present findings may help generate hypotheses about how player number and pitch size influence acute load responses in Ultimate Frisbee SSGs. In this sample, larger pitches were generally associated with greater locomotor outputs, whereas smaller player-number formats were associated with higher cardiovascular and acceleration/deceleration demands. However, these observations should not be used as fixed training prescriptions or density targets. Coaches and practitioners should integrate them with individual monitoring, technical-tactical objectives, athlete readiness, and the broader training context. Further studies are required before these preliminary patterns can be translated into robust evidence-based training guidelines.

Several limitations should be acknowledged. First, this exploratory study involved only eight elite male Ultimate Frisbee players. Although the repeated-measures design improved within-subject control, the small and homogeneous sample limits statistical power, increases uncertainty around the estimates, and restricts generalizability. The findings may not extend to female players, mixed teams, youth athletes, recreational players, or athletes from different competitive levels. Second, the design was unbalanced because the 2v2 format on the large pitch was excluded for ecological reasons, as it was considered poorly representative of typical small-sided Ultimate Frisbee practice. Although linear mixed-effects models can accommodate unbalanced data, the absence of this condition limits the completeness of the player number × pitch size matrix and may affect the stability of interaction estimates. Third, additional sparring players were used when required to maintain competitive balance. Although their GPS and HR data were not analyzed, their involvement may have influenced contextual game dynamics, including defensive pressure, passing options, and movement behavior. Fourth, the bouts were short and were designed to examine acute SSG responses rather than replicate full match demands, tournament fatigue, or chronic training adaptations. Therefore, no direct inference can be made regarding long-term conditioning effects, performance transfer, or injury risk. Fifth, the study focused on internal and external load variables, whereas technical and tactical indicators such as disc touches, passes, turnovers, defensive actions, and scoring opportunities were not collected. This limits the ability to determine whether the physical load responses observed in each format coincided with desirable technical-tactical learning conditions. Finally, the density-related analysis was purely exploratory. Although LOESS was used as a visual tool to describe possible broad tendencies, only eight unique density values were available. Qualitative sensitivity checks indicated that some local curve features were affected by smoothing choices, especially for acceleration and deceleration variables. Consequently, LOESS-derived trends should be interpreted as descriptive visual summaries rather than as stable, externally valid, or prescriptive density-load relationships.

Conclusions

This exploratory study examined the acute effects of player number and pitch size manipulation on internal and external load during small-sided Ultimate Frisbee games in elite male players. In this small homogeneous sample, larger pitch sizes were generally associated with greater locomotor outputs, whereas smaller player-number formats were associated with higher cardiovascular and acceleration/deceleration demands.

However, the findings should be interpreted cautiously because of the limited sample size, unbalanced design, sparse density values, and exploratory analytical approach. The density-related observations do not support the identification of thresholds, optimal values, or fixed prescription targets.

Future research should replicate these findings using larger multi-team samples, include female and mixed-team athletes, examine different competitive levels, and integrate technical-tactical indicators alongside internal and external load measures. Longitudinal studies are also needed to determine whether acute SSG responses translate into meaningful training adaptations, performance benefits, or injury-related outcomes.

Data availability

The data analyzed during this study and the R analysis code are available from the corresponding author upon reasonable request.

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Author contributions

A.L., D.M., and R.D.M. contributed to the study conception and design, material preparation, and data collection. A.L., D.M., R.D.M. and M.N. conducted the data analysis and manuscript writing. A.L., D.M., R.D.M. and M.N. read and approved the final manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Bioethics Committee of the University of Bologna (04/11/2021, protocol n. 283721).

Consent to participate
Informed consent was obtained from all individual participants included in the study.

Additional information
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