Title

Pitch Size, Player Numbers, and Playing Rules: How Small-Sided Game Constraints Shape the Training Demands in Male Academy Soccer

Running Head

Small-Sided Games Shape Training Demands

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Abstract

Small-sided games (SSGs) are part of daily soccer practice and usually manipulated in pitch size, player number, and playing rules. The aim of this study is to identify constraints that significantly impact the physical demands in SSGs in youth elite soccer players. Training sessions from an under-18 Spanish academy team were monitored, including 87 SSGs. SSGs were labelled for area per player (ApP), number of players, type of game, playing duration, goal size, use of floater players and goalkeepers, and number of touches. Relative physical demands were measured as total distance (TD), high-speed running (HSR), sprint distance (SD), and acceleration (ACC) and deceleration (DEC) distance. A linear mixed-effects model analysis was performed estimating the effects of SSG constraints (α set at 0.05). Greater ApP consistently increased TD, HSR, SD, ACC, and DEC. In contrast, increasing the number of players and longer playing duration reduced TD, HSR, ACC, and DEC. Additionally, specific playing rules, such as the use of floater players, limited touches, and small goals primarily impacted ACC and DEC. These findings highlight the important role of ApPs in shaping physical demands, while also showing that team size, playing duration, and specific playing rules contribute to the physical demands of SSGs. Understanding the magnitude and direction of these manipulations allows coaches to design SSGs more effectively to meet training objectives.

Key words: football, training format, training load, locomotor activities, team sports, performance

INTRODUCTION

Soccer is characterized by its dynamic and intermittent nature, with frequent transitions between high-intensity and low-intensity periods occurring approximately every four to six seconds (11,30,45). These activities are part of natural soccer behavior as a result of offensive and defensive actions in the pursuit of scoring goals, driven by ball possession and a direction of play (25). To replicate these demands in training, coaches frequently use small-sided games (SSGs), which provide a representative learning environment by preserving affordances inherent to match-play (2,35). Unlike drill-based exercises, SSGs a meaningful training environment where players interact with team members and opponents, and where ball possession create soccer-specific affordances (2). Simultaneously, SSGs support the development of locomotor (39), physiological (8), technical (12) and tactical (34) skills. As such, SSGs offer coaches a versatile and powerful training tool which provide effective training stimuli.

SSGs can be defined as training formats that are derived from the match with manipulations in pitch size, number of players, and/or playing rules (1,4,11,24). These task constraints shape players' behaviors and determine the physical load imposed (11,24,37). Sport scientists have experimented with these manipulations to explore players' acute response to SSGs. Research consistently demonstrates that larger pitch sizes increase total distances covered and high speed running (11,37,40,41). Conversely, smaller pitch dimensions, combined with concurrent alterations in player numbers, overload primarily acceleration and deceleration efforts, whilst reducing high speed running (5,14,20).

Despite a wide range of pitch sizes, most SSGs are typically played on considerably small pitch sizes compared to the official match. Expressed as the area per player (ApP; or relative pitch area; (6,9,37)), SSGs are predominantly played on an ApP <150m^2 per player (1,24) compared to the ApP ~320m^2 per player of the match (32–34). Such small ApPs consequently result in lower physical demands in SSGs compared to match demands (7). Previous research has experimented with playing SSGs on varying ApPs to closely mimic match demands. Pitch dimensions of 200m^2 – 320m^2 ApP can replicate the high intensity activities (41,42), technical actions (40), and the team tactical performance (34) of the match. This underscores the important role of pitch size as a key constraint on shaping the performance demands in SSGs. Yet, in practice, the pitch size is rarely manipulated in isolation in SSGs.

Coaches frequently adjust other constraint such as team size and playing rules – often simultaneously – either to meet training objectives or due to logistical factures like player availability. While team size alone appears to have minimal impact when pitch dimensions remain constant (9), playing rules like changing the scoring format, including floater and bounce players, and limiting ball touches can significantly influence running demands (13,23). For example, the use of floater players, common for creating numerical imbalances (24), has shown some mixed results: some studies report reduced load (3), other no effect (36), albeit in small teams on a small ApP (i.e., <150m^2 per player). The nuanced influence of playing rules on both physiological and running aspects further highlights the intricate nature of constraints within SSGs.

While previous research has examined how task constraints affect physical demands of SSGs, these have largely been studied in isolation under controlled conditions. In training, SSGs involves multiple interacting elements. As a result, there remains a lack of clarity around how such constraints interact in typical academy training contexts, and how their combinations influence players' locomotor and biomechanical demands.

It is a common practice for soccer teams to monitor the training load with player tracking technology devices (44). Demands of the training often get accompanied by information on the training drills which can help contextualise the training load. This is especially useful in SSGs where a single configuration does not exist and where constraints have various impacts on players' physical demands. Instead, coaches use a variety of task constraints to design SSGs. They use SSGs with teams of varying sizes that engage on various pitch dimensions, constrained by specific playing rules, such as scoring mode, limited ball touches, inclusion and exclusion of goalkeepers, floater players and bounce players, and different goal sizes. Manipulating those constraints concurrently can have varying effects on the players' performance in SSGs. According to the constraint-led approach, seemingly small changes in the SSG design may result in large changes of the locomotor demands, but a combination of multiple manipulations may also cancel each other out and minimal changes can result in large effect (21). To understand the concurrent effects of manipulating SSGs on players' locomotor demands, a holistic approach is required including various configurations of SSGs.

Therefore, this study examines how multiple interacting SSG constraints impact locomotor and biomechanical demands in elite youth soccer across an entire season. To our knowledge, it's the first to systematically analyze a large sample of ecologically valid SSGs with detailed contextual annotations and GPS tracking.

METHODS

Experimental Approach to the Problem

The study is of an observational nature that included all SSGs from a male academy soccer team during a single season and aims to investigate the effect of manipulating SSG constraints on the physical demands of players. The SSG configurations have been labelled for their pitch size, number of players, playing duration and various playing rules. Subsequently, players have been monitored with player tracking technology during the SSGs to capture the physical demands of the games. Accordingly, the effects of the SSGs have been evaluated with a linear mixed-effects model to assess the contribution of the constraints on players' physical demands, hereby accounting for the observational nature of the study, the natural variation of SSGs used by coaches, and the individual differences of players.

Subjects

The study monitored 34 players of an under-18 Spanish male elite academy soccer team (age: 17.1 ± 0.99 years [range 16-19 years]; height: 174.5 ± 6.24 cm; body mass: 66.5 ± 6.34 kg; body fat percentage: 10.3 ± 1.75%) in training sessions during the 2021-2022 season. Goalkeepers were excluded from the analysis. Players who were deemed fit by the medical staff and participated for the entire duration of the practice were included for further analysis. Gatekeeper consent was provided by the club to share deidentified data, which were then compiled in a data repository. The research protocol was approved by the Research Ethics Committee at the University of Milan (Protocol #102/14).

Procedurs

A total of 117 SSGs were monitored across forty training sessions, which were part of the team's regular training program. The SSGs were performed under the supervision and motivation of several coaches. Balls were placed outside the playing area to ensure swift replacement if a ball went out of play. All SSGs were played on artificial turf pitches.

SSG characteristics on pitch dimensions, number of players, scoring mode, and playing rules were captured. The area per player (ApP) was determined as the total pitch area (in m^2) divided by the number of players on the pitch (goalkeepers included) (9,37). The number of players per team and floater players were annotated, and whether a goalkeeper was part of the game. The goal size varied between a big goal (as used in the official match) or a small goal. Lastly, the number of touches were indicated as unlimited or limited (i.e., restricted to two or three touches per player possession). Characteristics of the SSGs are presented in Supplementary material 1.

Data from 1 vs. 1-formats (*n* = 5 SSGs) and single player observation (*n* = 5 players) were excluded. Only games were included that were played with a goal, which excluded possession games (*n* = 6 SSGs). Further, SSGs with more than two floaters were excluded due to the specific nature of those games (*n* = 19 SSGs). Finally, three players who participated in only one practice session were excluded from the dataset. After data processing, the dataset comprised 87 SSGs across 32 training sessions, including 540 player observations of 31 unique players.

Locomotor and biomechanical demands were collected using Catapult Optimeye S5 (CatapultSport, Melbourne, Australia) tracking devices. Locomotor demands were measured as total distance (TD, in meters), distance covered at high intensity (HSR, 18-21km/h), and sprint distance (SD, >21km/h). Biomechanical demands were determined as the distance covered of accelerations (ACC, >1m/s^2) and decelerations (DEC, <-1m/s^2). Data were normalised to time (m/min) to account for different SSG durations. Data were organized in OpenField software, and data quality was ensured by consistent device usage by all players in each training session.

Data analysis and processing were performed using Jupyter Notebook. Monitoring data from training sessions were exported as .csv files and compiled for analysis. The SSG design information was integrated into the data using Excel. Relevant data preprocessing, including exclusions and normalization, was conducted in Jupyter Notebook, leading to the creation of a .csv file for subsequent analysis in R.

Statistical Analysis

A linear mixed-effects model was developed to evaluate to what extent SSG constraints contribute to players' physical demands in SSGs. Locomotor and biomechanical variables were treated as the dependent variables, while SSG constraints were treated as fixed effects. The model incorporated players as a random intercept to account for player variability. Distribution of the data was visually inspected for the assumptions of linearity and normality. Statistical significance of the estimates was evaluated by calculating 95% confidence intervals (CIs) from the regression models and observing the respective *p*-values (significance level $\alpha \leq 0.05$). All statistical analysis was performed using the *lme4* package for linear mixed-effects modelling and *lmerTest* package for significance assessment in R (version 4.3.1., R Core Team).

RESULTS

A total of 87 SSGs were included in the analysis. Descriptive statistics are presented in Table 1 and Figure 1. The formats range from 2 vs. 2+GKs to 10 vs. 10+GKs. The ApP ranges from 33.0m^2 per player to 293.1m^2 per player. Across all games, there is a variation of rules imposed relating to the use of GKs, presence of a floater player, touch restrictions, and the goal size.

*** Table 1 near here ***

*** Figure 1 near here ***

Findings of the linear mixed-effects model analysis for the locomotor and biomechanical variables are summarized in Table 2. ApP had a significant positive effect on all physical demands. An increase in ApP increased the TD, HSR, SD, ACC and DEC while holding other factors constant. Player number holds a negative significant effect on TD, ACC, and DEC. With an increase in player numbers, the TD, ACC, and DEC would decrease, while holding other factors constant. Similarly, a longer duration of the SSG resulted in a lower TD, HSR, ACC, and DEC.

The presence of a goalkeeper, the use of a floater player, limited touches, and the use of a small goal are categorical variables and hold significant effects on some physical demands. To illustrate, the use of a floater player (vs. no floater player involved) would decrease the TD and HSR by 3.97 m/min and 1.32 m/min, respectively, and the ACC and DEC by 1.69 and 2.02 m/min, respectively. In contrast, limiting the touches per player would lead to an increase in TD, ACC, and DEC. The presence of a GK negatively impacts the HSR, and the use of a smaller goal size negatively impacts the ACC and DEC, whilst keeping all other factors constant.

*** Table 2 near here ***

The linear mixed-effects model explained the variance in the dataset for 39.7–47.6% when the individual player was included as a random effect (Table 2). The linear mixed-effects model explained the variance in the dataset for 39.7–47.6% when the individual player was included as a random effect (Table 2). Such a model has increased the explained variance compared to including fixed factors (i.e., SSG constraints) only.

DISCUSSION

This study aimed to evaluate the effect of different SSG constraints on locomotor and biomechanical demands in youth elite soccer players. SSGs are versatile in use and coaches usually manipulate the pitch size, number of players, and various playing rules concurrently in line with the aim of the session, but those constraints can pose different effects on physical demands. The main finding of this study is that the most used SSG constraints, ApP, player number, playing duration, use of GKs, use of floater players, limited touches, and different goal sizes, have different effects on players' physical demands in these training formats. More specifically, i) the ApP impacts all locomotor and biomechanical demands, but player number mainly impacts biomechanical demands, ii) SD is only impacted by the ApP, but not by any other SSG constraint, and iii) an increase in playing duration would decrease locomotor and biomechanical demands in SSGs.

Manipulating the ApP had a significant positive effect on all physical demands, indicating that TD, HSR, SD, ACC, and DEC increased with a greater ApP. These results align with previous research reporting that greater ApPs lead to increased physical responses in SSGs (10,11,32). However, unlike current findings, Riboli et al. (41) did not observe effects of ApP on ACC and DEC in U18 players, and De Dios-Alvarez et al. (15) highlighted a reduction in ACC and DEC with greater ApP. Such discrepancies across studies may reflect the inherent variability of soccer performance (22), which is also evident during SSGs (31,34). This variability arises from the complex, dynamic interactions between players and SSG constraints, and can lead to different physical responses even when similar pitch areas are used. The current analysis, by incorporating multiple constraints and accounting for player-level variability through random effects in the linear mixed-effects model, aimed to address some of this complexity. Nevertheless, these findings reinforce that ApP is a robust constraint, not only for enhancing running demands, but also for modulating biomechanical load. despite the natural variability typical of training environments.

Further, the current findings highlight that, although the effects of the ApP on physical demands may appear relatively small on a per-unit basis, their practical significance becomes substantial when considering the full range of ApP used in this study. To illustrate, each $10m^2$ increase in ApP corresponded to an increase of 1.5m/min in TD and 0.3m/min in SD. Given the broad range of ApP observed (i.e., 33-293m^2 per player), these small incremental effects can compound into large and meaningful changes in physical demands. The current model suggests greater physical demands on a larger ApP. Previous studies suggest that specific SSG configurations may replicate match demands even without matching the 320 m^2 ApP of the official match (32,41,42). Based on this and current findings, manipulating the ApP is an essential component of designing SSGs as representative learning tasks (35), as it helps preserve the affordances and intensity profiles of match play. Notably, coaches should carefully consider ApP as a constraint when aiming to simulate match-like conditions in training.

The number of players had a significant negative effect on the physical demands. Specifically, an increase in the number of players resulted in a decrease of TD, ACC, and DEC when all other constraints were kept constant. This highlights the isolated influence of team size on physical demands, particularly on the biomechanical demands (i.e., ACC and DEC), while running demands (i.e., HSR and SD) remained unaffected. Current findings aligned with previous studies that highlighted greater acceleration and deceleration demands with a smaller number of players in elite soccer players when the ApP was kept similar (14). Although prior studies suggested that total distance might not differ when ApP is kept constant across different team sizes (e.g., 7 vs 9 vs 11 players) (9), current results extend this by demonstrating that biomechanical demands do vary. This indicates that even at the same ApP, smaller formats may inherently increase stop–start intensity due to greater involvement per player and more frequent role changes.

A longer playing period of SSGs resulted in lower physical demands (accounted for time). This seems an intuitive consequence of players pacing their efforts over longer playing durations. Prior knowledge to playing duration influences the internal and external load experienced by players in SSGs. Fanchini et al. (19) demonstrated a lower internal load in SSGs with longer vs. shorter duration in senior amateur and elite soccer. Additionally, continuous (i.e., 12-min) or intermittent SSGs of a longer duration seem to lower the external load in male (under-18) and female (under-23) players (18,26). Although those studies have explicitly used the playing duration as a constraint to manipulate in an experimental design, those findings seem to translate to the current dataset with SSGs played in a regular training season. Players at later stages of the academy system, i.e. under-18, seem to regulate their physical efforts based on the playing duration. This underscores the importance of regulating playing duration in SSGs as a strategic training variable: shorter bouts may be used to increase intensity during high-load phases or in sessions targeting high-intensity conditioning, whereas longer bouts can support volume accumulation and reflect the intermittent nature of match-play.

Coaches often implement rule modifications that do not occur in official match-play, such as playing without GKs, using floater players, limiting touches on the ball, and using small goals. These variations were present in 8-20% of the observed SSGs. Such constraints are commonly applied in combination rather than in isolation (see Supplementary Material 1), contributing to varying effects on players' physical demands. However, none of those constraints impacted the players' sprint demands. A SSG without a GK or with a floater player negatively impacted the HSR demands. Using limited touches increased the ACC and DEC, but using a floater player or a small goal decreased those biomechanical demands. This demonstrates the delicate balance of imposing playing rules in SSGs. From an ecological perspective, combining constraints may interact in ways that either offset or amplify their effects on physical demands, depending on how they shape player behavior and affordances within the game.

The magnitude of the effect of playing rules should be considered carefully. Playing without a GK seems to have a large negative impact on HSR, which decreases HSR by 5.17m/min. Previous research demonstrated both positive and negative impacts of presence of a GK, either resulting greater responses of the internal and external load in SSGs without GKs (29) or lower responses in external load (27,43). SSGs without GKs were always played with small goals in the current study and, for the majority, on a small ApP (i.e. <100m^2, Supplementary Material 1), which will likely contributed to reduced HSR demands. This has implications for session planning, as removing the GK (e.g., to shift focus toward possession) may unintentionally reduce running intensity and should be adjusted based on session objectives.

Additionally, coaches commonly impose restrictions on the number of touches in ball possession with the aim of encouraging more dynamic off-the-ball movements, which increase players' involvement in creating space, offering pass options, and reacting to turnovers. Current findings highlight a positive impact of touch restrictions on ACC and DEC of 3.18m/min and 3.28m/min, respectively. This aligns with previous observations showing that limited touches increase movement demands (16,17). The increased biomechanical demands likely stems from technical errors, such as more unsuccessful passes, duels, and losses of ball possession (16). Consequently, transitioning between in-possession and out-of-possession demands players to reposition frequently. This constraint may be used purposefully to promote mechanical load while also emphasizing quick responses during transitions between attack and defense.

Lastly, the presence of a floater player decreased TD, HSR, ACC, and DEC. A floater creates a numerical superiority for the team in possession and exerted lower loads compared to regular team players (28,38). Potentially, this temporary numerical overload leads to longer ball possession phases where players engage in longer phases of attack and defense, which reduced the need for high-intensity efforts for the whole team. This suggests that even seemingly minor constraints can change the intensity profile of the entire game, and coaches should consider these broader effects when designing SSGs.

The current study has some limitations that should be considered in interpreting the findings. First, the majority of SSGs were played on an ApP less than 150m^2, and only exceeded 150m^2 when a greater team size was used (i.e., 9 vs. 9 – 11 vs. 11). As such, a very high correlation was observed between ApP and number of players (i.e., the model showed multicollinearity). This limited variation of SSGs may have undermined the effect of number of players and the model in general on physical demands. Generally, low values of sprint distances were observed across all SSGs. This is a typical observation for SSGs played on smaller pitch dimensions. Second, although the study was observational of nature without an intervention of the research team, decisions were made to exclude SSGs with a chronic overload/underload of teams, bounce players, more than two floater players, and possession games. This has resulted in an exclusion of thirty SSGs (and seven training sessions) in total. Third, specific playing positions were not included in the model. Instead, individual players were included as random effects, and this has increased the explained variance of the model by 8-18%.

In conclusion, this study examined the effects that various SSG constraints had on players' physical demands. The ApP has a positive effect on all locomotor and biomechanical demands, although the effects may have been limited by a limited variation of pitch areas used in this study. Sprint distance is only affected by this ApP, which may also have been controlled by variation of the dataset. Lastly, all constraints (except for the use of GKs) positively or negatively affected the biomechanical demands. This highlights the delicate use of constraints in SSGs and their effects on physical demands.

PRACTICAL APPLICATIONS

These findings provide valuable guidance for SSGs design. To target high speed running and emphasise sprinting, coaches may increase the ApP, but should also pair this with a short playing duration, the inclusion of GKs, and the exclusion of floater players. On the other hand, when aiming to increase biomechanical load (e.g., increase the acceleration and deceleration distance), coaches can still use a greater ApP, while also opting for smaller team formats, shorter duration, and rules such as limited touches, big goals, and again avoiding the use of floater players. Essentially, coaches can strategically manipulate constraints as part of a broader SSG design toolkit by tailoring physical demands according to training objectives.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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FIGURE LEGEND

Figure 1. Distribution of the small-sided games for the area per player and number of players. Bigger dots indicate a bigger proportion of games played. GK = goalkeeper

FIGURE

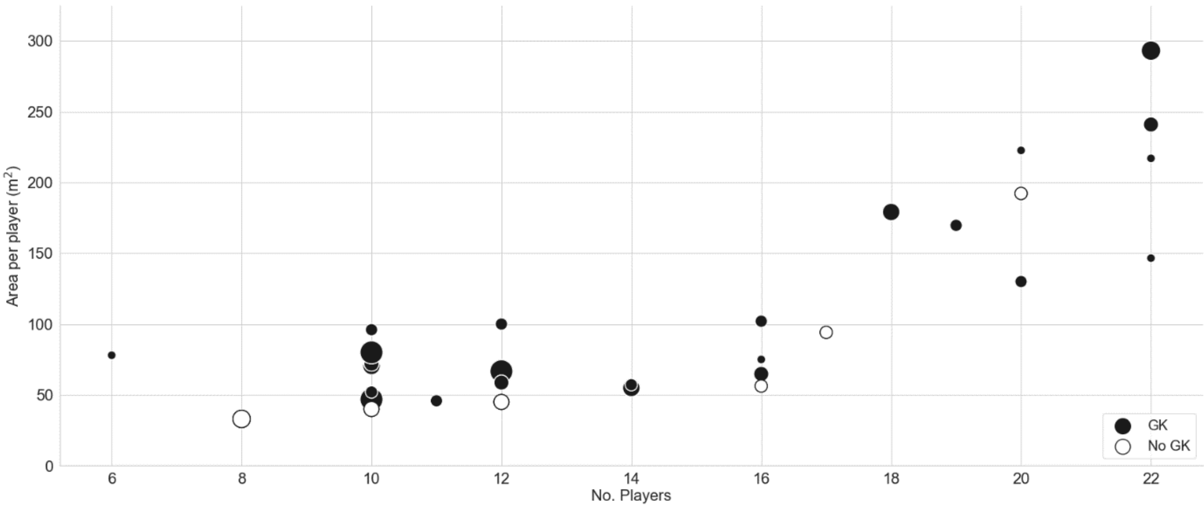

Figure 1. Distribution of the small-sided games for the area per player and number of players. Bigger dots indicate a bigger proportion of games played. GK = goalkeeper.

TABLES

Table 1. Descriptive statistics of the SSG constraints and locomotor and biomechanical variables. Continuous variables are indicated as mean (± SD) and the categorical variables are indicated as count (percentage)

Fixed factors		
ApP (m²/player)		99.6 (71.6)
Format	2 vs. 2	1 (1.1%)
	3 vs. 3	11 (12.6%)
	4 vs. 4	23 (26.4%)
	5 vs. 5	15 (17.2%)
	6 vs. 6	9 (10.3%)
	7 vs. 7	3 (3.4%)
	8 vs. 8	10 (11.5%)
	9 vs. 9	3 (3.4%)
	10 vs. 10	12 (13.8%)
Duration (min)		5.0 (3.1)
Goalkeeper	GK	71 (81.6%)
	No GK	16 (18.4%)
Floater	Floater	26 (29.9%)
	No floater	61 (70.1%)
Touch restrictions	Limited	8 (9.2%)
	Unlimited	79 (90.8%)
Goal size	Big	69 (79.3%)
	Small	18 (20.7%)
Dependent variables		
TD (m/min)		112.0 (10.9)
HSR (m/min)		6.6 (4.2)
SD (m/min)		2.2 (2.1)
ACC (m/min)		19.1 (3.2)
DEC (m/min)		22.3 (3.8)

ApP: area per player; GK: goalkeeper; TD: total distance; HSR: high speed running; SD: sprint distance; ACC: acceleration distance; DEC: deceleration distance

Table 2. Estimates of the fixed effects [95% confidence intervals] in the small-sided games for locomotor and biomechanical variables. The explained variance is included for fixed factors (i.e. SSG constraints) and the random effect (i.e. individual players).

	TD	HSR	SD	ACC	DEC
Estimates					
Intercept	119.09	4.27	-0.05	27.21	32.96
Fixed factors					
ApP	**0.15 [0.12, 0.19]**	**0.06 [0.05, 0.07]**	**0.03 [0.02, 0.04]**	**0.02 [0.01, 0.03]**	**0.01 [0.00, 0.03]**
Player number	**-0.99 [-1.48, -0.49]**	-0.12 [-0.31, 0.07]	-0.01 [-0.10, 0.09]	**-0.51 [-0.66, -0.35]**	**-0.64 [-0.80, -0.48]**
Duration	**-0.71 [-1.26, -0.15]**	**-0.26 [-0.47, -0.05]**	-0.07 [-0.18, 0.04]	**-0.27 [-0.44, -0.09]**	**-0.28 [-0.46, -0.09]**
No goalkeeper (vs. GK)	-4.63 [-14.00, 4.69]	**-5.17 [-8.77, -1.59]**	-1.66 [-3.46, 0.13]	0.97 [-1.95, 3.85]	1.49 [-1.64, 4.58]
Floater (vs. no floater)	**-3.97 [-6.81, -1.10]**	**-1.32 [-2.41, -0.22]**	-0.33 [-0.87, 0.22]	**-1.69 [-2.57, -0.79]**	**-2.02 [-2.97, -1.06]**
Limited touches (vs. free play)	**6.17 [1.96, 10.36]**	-0.35 [-1.96, 1.25]	-0.17 [-0.98, 0.63]	**3.18 [1.89, 4.48]**	**3.28 [1.89, 4.67]**
Small goal (vs. big goal)	-4.08 [-13.52, 5.41]	3.69 [0.07, 7.35]	1.45 [-0.36, 3.28]	**-3.15 [-6.08, -0.20]**	**-4.08 [-7.21, -0.91]**
Variance explained					
SSG constraints	22.9%	30.3%	34.5%	25.7%	34.7%
SSG constraints + individual players	41.4%	39.7%	42.8%	41.6%	47.6%

Bolded results indicate a significant effect. ApP: area per player; GK: goalkeeper; SSG: small-sided game; TD: total distance; HSR: high speed running; SD: sprint distance; ACC: acceleration distance; DEC: deceleration distance