Beyond the Pitch: Unveiling the Concave Hull as Soccer's Ecological Niche in Practice Design.

DEUKER, Albert, WITTKUGEL, Joris, DUBLIN, Yannis, BRAUNSTEIN, Bjoern, REIN, Robert, DAVIDS, Keith <http://orcid.org/0000-0003-1398-6123> and VOGT, Tobias

Beyond the Pitch: Unveiling the Concave Hull as Soccer's Ecological Niche in Practice Design

Deuker, Albert [ab]; Wittkugel, Joris[a]; Dublin, Yannis[c]; Braunstein, Bjoern[defg]; Rein, Robert[c]; Davids, Keith[f]; Vogt, Tobias[a]

[a]*German Sport University Cologne, Section Didactics and Methodology in Sports, 50933 Cologne, North Rhine-Westphalia, Am Sportpark Müngersdorf 6, 50933 Cologne, DE*

[b]*German Sport University Cologne, Section Training Pedagogy and Martial Research, 50933 Cologne, North Rhine-Westphalia, Am Sportpark Müngersdorf 6, 50933 Cologne, DE*

[c]*German Sport University Cologne, Institute of Training and Computer Science in Sport, 50933 Cologne, North Rhine-Westphalia, Am Sportpark Müngersdorf 6, 50933 Cologne, DE*

[d]*German Sport University Cologne, Institute of Movement and Neuroscience, 50933 Cologne, North Rhine-Westphalia, Am Sportpark Müngersdorf 6, 50933 Cologne, DE*

[e]*German Sport University Cologne, Institute of Biomechanics and Orthopaedics, 50933 Cologne, North Rhine-Westphalia, Am Sportpark Müngersdorf 6, 50933 Cologne, DE*

[f]*German Sport University Cologne, German Research Centre of Elite Sport, Cologne, North Rhine-Westphalia, Am Sportpark Müngersdorf 6, 50933 Cologne, DE*

[g]*German Sport University Cologne, Center for Health and Integrative Physiology in Space, 50933 Cologne, North Rhine-Westphalia, Am Sportpark Müngersdorf 6, 50933 Cologne, DE*

[f]*Sheffield Hallam University, Sport & Human Performance Research Group, 535782 Sheffield, UK*

Corresponding author:

Albert Deuker[ab]

[a]*German Sport University Cologne, Section Didactics and Methodology in Sports, 50933 Cologne, North Rhine-Westphalia, Am Sportpark Müngersdorf 6, 50933 Cologne, DE*

[b]*German Sport University Cologne, Section Training Pedagogy and Martial Research, 50933 Cologne, North Rhine-Westphalia, Am Sportpark Müngersdorf 6, 50933 Cologne, DE*

German Sport University Cologne, Germany
Am Sportpark Müngersdorf 6
50933 Cologne
Germany

Email: albert-deuker@web.de

ABSTRACT

An ecological niche is a field in a landscape of affordances, rich in information that invites its inhabitants to develop functionality and effectiveness of their behavior. This idea means that, in sports like soccer, the playing area encapsulates an ecological niche, replete with affordances available to invite collective and individual technical-tactical actions, contextualized with associated psychological and physical demands. To examine the co-adaptive relationships that frame players actions in their ecological niche, the present study employed a crossover design with repeated measures to compare the players transactions within 11vs.11 training games across four different field dimensions (from official size to a small-sided game). Player transactions with the performance environment were analyzed across 40 game sequences, using 10 Hz GPS to collect positional data. Metrics such as convex hull dimensions, field occupancy, and proximity to opponents were derived. Repeated-measures ANOVA revealed significant differences between tendencies for forming synergies constrained by field dimension scaling. When field size was reduced, the convex hull dimension significantly decreased. Additionally, values of relative field occupancy, and distance to nearest opponent exhibited significant changes, especially when contrasted with performance transactions emerging on the official size field. These observations underline the essential functional relationship between playing field dimension and emergent player actions. Such findings are relevant for understanding of soccer coaches and training designers, underscoring the need to integrate specificity of field dimension scaling in training designs to represent competitive performance contexts. Focusing on values of spatial constraints, derived from data analytics ofcompetitive matches, may help researchers and coaches/practitioners improve task representativeness in practice and performance preparation, supporting optimality of training niches in soccer.

Keywords: soccer training, ecological niche, representative design, playing area dimension scaling, synergy formation, collective system dynamics

INTRODUCTION

> *"A species of animal is said to utilize or occupy a certain niche in the environment. This is not quite the same as the habitat of the species; a niche refers more to how an animal lives than to where it lives. I suggest that a niche is a set of affordances."* (Gibson, 1979, p. 120)

In James Gibson's theory of direct perception, an ecological niche refers to the behavioral transactions that emerge between an individual and their environment during performance. In these transactions, an important concept is an *affordance*, referring to the opportunities for or invitations for action that a particular performance environment offers an individual. An affordance encompasses what the environment provides or furnishes, in terms of possibilities for an individual's behavioral transactions with their surroundings (Gibson, 1979). With development, learning and experience, a complementary relationship can emerge between an individual and their performance environment. A competitive performance landscape presents opportunities that a performer can perceive and act upon (Vilar et al., 2012). The inherent relationship between an environment and its inhabitants is vital when observing behaviors within a particular ecological niche. Clearly, an individual's 'ecological niche' profoundly influences the behavior of its inhabitants and vice versa.

This concept has clear implications for understanding skill adaptation in talent development programs in sports, such as soccer (association football), where daily tasks, customs, beliefs, behaviors, and attitudes influence the evolution of an athlete's capabilities (Rothwell et al., 2023). In the context of skill development in sport, an 'ecological niche' is typically discussed when framing a broader training environment (Rothwell et al., 2020). This perspective often focuses on the macro-level aspects of training, where various contextual factors such as athlete development practices (skill and psychology), coaching and training methodologies (physiology and pedagogy), and attitudes (social, cultural and historical concepts) collectively influence the 'form of life' (Wittgenstein, 1989) underpinning the skill adaptation process of the athletes involved. For example, in soccer, a club director might establish a rule mandating that all youth teams engage in 20 minutes of 'rondo' per practice session, with the aim of cultivating a possession-oriented playing style (Vaughan et al., 2021).

In this regard, a soccer organisation can be understood as a complex, non-linear system in perpetual interaction with its environment (Gréhaigne et al., 1997). Within this dynamic setting, players grapple with the challenges of adapting to opponents, synchronizing actions with teammates (synergy formation), and handling competitive pressures of performance. The present study sought to evaluate how a soccer team's 'ecological niche' impacted on practice designs at the micro-level of training, focusing on the influence of immediate contextual constraints influencing players during games and practices.

This study's hypotheses and interpretations are anchored in the 'Ecological Dynamics' theory (Vilar et al., 2012). According to this theory, individual and collective behaviors are co-adapted to the distinct ecological niche of performance (Araújo & Davids, 2016). In soccer, this translates to player-player transactions that emerge under a collective, self-organization process, when forming synergies in order to achieve intended performance outcomes (Araújo et al., 2016). Self-organization tendencies are manifest nonlinear systems, for example during soccer performance, in the continuous adaptations and adjustments at an individual level (Orth et al., 2014), within sub-groups (Silva et al., 2016), such as defensive pairings or midfield units, and macro-level strategies across the entire team (Duarte et al., 2013). Collectively, evidence suggests how individuals and groups coordinate and co-adapt their movements and co-positioning to achieve a functional solution to challenges emerging during competitive performance. For instance, four defenders in a team can collectively, coordinate their actions to establish a stable defensive grid, seeking to thwart the opposing team's offensive maneuvers, preventing goal-scoring opportunities (Silva et al., 2014). Players' adaptive skills and collective strategies, in the performance context, are expressed dynamically, aligning with the evolving demands and changing objectives in a match (Fradua et al., 2013). Consequently, it is paramount that training contexts (i.e., the ecological niche of practice design) closely represent contexts which may emerge in competition (i.e., the ecological niche of the official soccer match). Representative practice designs ensure that skills are practiced in scenarios which are transferable to the competitive performance environment (Pinder et al., 2011). These ideas emphasize the need for coaches to design performance preparation environments that incorporate affordances that are available in competitive matches (Dhami et al., 2004).

In this design process, niche construction theory helps to sharpen the focus on task representativeness in soccer. As, the niche in training determines which opportunities or invitations for action (i.e., set of affordances) are available for players in practice contexts. For instance, a 'maximum two-touch' constraint affords (invites quick passing and movement off the ball), but does *not* invite dribbling opportunities. Therefore, practice involves the exploration of niches that allow players to develop a tightly knit relationship with the environment they face in competition (QUELLE). However, due to the frequent engagement in decomposed rehearsing drills (QUELLE trains as you play DEUKER), and the high involvement in small-sided and games (SSG), it is possible that a scaling problem may emerge in soccer practice designs. Consequently, through the lens of niche construction, the present study aims to provide insights on the role of spatial affordances made available in contemporary practice designs in ecological niche of soccer. These insights could support the achievement of a smoother fit between the ecological niches constructed in training and those which become available in competition.

Th scaling challenge in soccer training

In soccer training, coaches face the daily challenge of determining which aspects of competitive performance warrant immediate attention. Their choices may be shaped by augmented information from performance analysts, inevitably shaped by the available affordances, such as player numbers, their current physical performance capacities and the competitive scheduling. To address these environmental constraints, many turn to small-sided games (SSG), which present an invaluable tool (Almeida et al., 2012). SSG, characterized by their reduced player count and smaller playing areas (Davids et al., 2013), allow coaches to design a practice context where players engage in game-oriented movement tasks, facilitating increased action frequencies. There are numerous ways to manipulate SSG to adjust physical and tactical challenges for players. One might reduce the number of players involved or introduce overload contexts (Castellano et al., 2013; Nunes et al., 2020). The most frequent adjustment in daily training involves modifying the playing area dimension per player (APP) (Clemente et al., 2023). Diminishing this area increases the possibility of immediate pressure from opponents (Andrienko, 2017) due to close proximity of participants, reduces the time available for decisions, and amplifies the frequency of in-game actions (Dellal et al., 2012; Katis & Kellis, 2009).

Smaller field dimensions also serve to manage training intensity (Clemente et al., 2023). For example, Owen et al. (2014) observed fewer high-intensity runs and shorter sprint distances in SSG compared to scenarios with larger field dimensions. The dynamic interplay between the field dimensions and the number of players involved in practice might mean that altering one variable contextualizes both individual and collective team behaviors (Clemente et al., 2021). Research has tied field dimension scaling to the APP, a measure derived by dividing the total field size by number of participants (Silva et al., 2014; Silva et al., 2015). Adaptations in players' tactical behaviors resulting from these modifications can be quantified for analysis through various metrics. Notably, the APP affects player-player transactions, leading to observable changes in several parameters of synergies formed under competitive performance constraints, including changing distance values between competing sub-groups (e.g., the back four versus attackers) and inter-team distances (Araújo & Davids, 2016; Passos et al., 2016).

In the literature on scaling playing areas in soccer training designs, two major concerns emerge. First, in investigation and comparison of different game formats, the number of players involved is often reduced, along with a reduction in field dimensions (Clemente et al., 2023). However, when modifications to both the number of players and the field dimensions occur simultaneously, it becomes challenging to interpret which specific change is driving the observed behavioral adaptations or training effects. Therefore, in our study, we exclusively altered the *playing area dimensions*, while keeping the number of involved players constant, enabling us to examine player behaviors under this specific task constraint. Our approach, involving a full 11vs.11 player setup, has been relatively rare in research compared to use of SSG. This research approach to studying SSG as a complex adaptive system seeks to attribute observed effects to the empirical manipulation of playing area.

*** Please insert **Figure 1** about here ***

Second, an underestimated parameter when scrutinizing the design of soccer training formats may be the 'convex hull' (**Figure 1, A**). The 'convex hull' defines the smallest convex shape that encompasses a given set of 2D points (Bueno et al., 2021). In sport, the 'convex hull' value estimates the effective playing area of both teams, effectively representing the "outline" or spatial boundary of team formations (Bueno et al., 2021; Ötting & Karlis, 2023). In the literature on soccer training designs, the concept of the 'convex hull' plays a pivotal role, forming the structural foundation for estimating team spatial boundaries in SSG (Fradua et al., 2013). The effective playing area observed in full-scale matches is believed to serve as an authentic relational model to replicate collective tactical characteristics of soccer performance in SSG designs. Thus, by extrapolating the individual playing area from the convex hull representation of full-size matches, it can be argued that researchers and coaches can design SSG formats that offer players representative action spaces for learning and performance preparation. These spaces may provide players with affordances available for engaging in focused, game-related contexts during training, ultimately enhancing training effects and outcomes (Clemente et al., 2021). However, for enriching representative design in practice, it is important to consider the task constraints shaping emergent player behaviors in competitive full-size matches. A key observation is that in full-size matches, the emerging effective playing space occupied by the two competing teams is much smaller than the total available playing area. These tendencies in field usage may be primarily attributed to the official offside law, acting as a fundamental task constraint, shaping a more compact, effective playing area. Players also tend to self-regulate in synergy formation, seeking optimal distances from teammates and opponents for participating in combination play or defensive strategies. Consequently, the effective playing space – the 'convex hull' – occupied by both teams emerges in response to the affordances of the full-size field. This point emphasizes the need to contextualize (the task constraints of) practice at all times, raising a significant question: when coaches employ task changes to afford their players less space in training, do the spatiotemporal conditions accurately represent those of (specific contexts in) a competitive match? As a result, training sessions based on the dimensions of the 'convex hull' might actually take place in much tighter spaces compared to those that become available in competitive matches. These theoretical considerations are supported by findings of a study from Clemente et al. (2018), which indicated that in a half-field setting, inter-player distance values diminish markedly. This alteration in space leads to players, and consequently teams, being positioned closer to each other in practice, than may be representative of competitive matches. This discrepancy becomes an imposition when the vacant space encircling both teams considerably regulates player behavioral tendencies that emerge. We conceptualize this spatial envelope, surrounding the effective playing area, as the 'concave hull' (**Figure 1, B**), which serves as the counterpart to the 'convex hull'.

To summarise so far, practice scenarios confined to a surface derived from the 'convex hull' area (**Figure 1, A**) may not be representative of the way that spatiotemporal constraints emerge in competitive performance contexts. These playing area-scaling issues in soccer training designs form the crux of the present study. Considering that current soccer training designs, particularly SSG, tend to employ more compact field dimensional constraints, compared to those which are experienced in full-size competitive 11vs.11 matches, this investigation sought to understand how team spatiotemporal dynamics change with alterations in playing area scaling in an 11vs.11 performance setup. The following hypotheses are posited: (I) Reducing the playing area per player within the training design will lead to a contraction of the 'convex hull's area'. (II) A reduced area per player in the training design will cause a significant decrease in values of inter-player distance. Furthermore, it is conjectured that (III), a constriction of area per player will reduce the size of the 'concave hull', equivalent to an increase in players' 'relative field occupancy'.

MATERIAL AND METHODS

Participants

22 male players from an amateur soccer club participated in this study (age: 21±3 years, height: 181±8 cm, mass: 76±7 kg). These players, active in the top German amateur league (5th division), trained thrice weekly, in addition to competing in one regular match. The study took place during the pre-season after the winter break. All participants gave written consent after confirming their understanding of the study procedure. The study was approved by the Ethics Committee of the German Sport University Cologne (184/2022).

*** Please insert **Figure 2** about here ***

Study design

The analysis of collective performance was undertaken on a natural grass pitch, following official laws of the game. After a 20-minute warm-up, the head coach divided the players into two balanced teams, based on their regular playing positions. The composition of both teams remained unchanged throughout the entire data collection process. The design was a crossover, controlled, trial-based approach (Low et al., 2021), comparing performance in 11vs.11 games across four field sizes (**Figure 2**). The initial playing area dimensions mirrored a standard competitive game (**Figure 2, a.**), halving by the third condition (**Figure 2, c.**). The other two playing dimensions were informed by research designs of Owen et al. (2014) (**Figure 2, b.**) and Frencken et al. (2012) (**Figure 2, d.**), adjusting the area per player accordingly.

Experimental Units

Each team undertook five offensive trials, consistently in a 4-4-2 formation, against a defending team using a 4-4-2 midfield pressing strategy, across all conditions (Low et al., 2021; Low et al., 2022), totaling N=40 trials (10 per condition), with each trial being independent and defined as an experimental unit (Lazic et al., 2018). Trials commenced in a standardized way, with an initiating build-up pass from the goalkeeper and concluded with the emergence of a goal, change of possession, interruption in play (e.g., from offside, defensive fouls, or the ball going out of play), or termination after 60 seconds. Defenders claimed possession either by a successful pass or two consecutive ball touches. After each attempt, players resumed their starting positions for the next trial. Following five trials and a break period, the roles of offense and defense were swapped between teams.

Data collection

Player positioning was tracked using the Catapult© global positioning system (GPS), which determines each player's global location via a tracking device, worn in the pocket of a lycra vest (proximal of cervical spine C7 i.e., ‘cervicothoracic junction’). The system recorded latitude and longitude at a frequency of 10 Hz. Additionally, a GoPro Hero 6 Black© camera documented the entire pitch from an elevated perspective (height about 5m), offering a 30 Hz video documentation to verify and double check GPS measurements.

Data processing

The positional data obtained from player movements were converted into data on collective system tactical performance variables (Low et al., 2020). This analysis was carried out across two specific systematic organizational levels. At the game level, the main metrics were associated with the 'convex hull'. The 'convex hull' represents the smallest possible area that encloses all players from both the attacking and defending teams (Ötting & Karlis, 2023). For each trial, an average 'convex hull' area was computed to provide a consistent measure of space occupation by a team during performance. Another primary metric of performance is 'relative field occupancy', which quantifies the proportion of the pitch that all 20 outfield players actively use during play. Accordingly, this metric represents the portion of the total field area covered by the 'convex hull' (Alexander et al., 2019). An average field occupancy was determined for every trial in our study to offer a comparative measure of spatial distribution and effective occupation by participants across varying conditions. Simultaneously, at the team level, the 'distance to nearest opponent' value for the attacking team was calculated to quantify opposition pressure across varying conditions. This value was determined for every attacking player (relative to the nearest opponent) and then averaged for the entire team per trial. The entire data processing was performed with RStudio (version 1.4.1564).

Statistical analysis

Before analysis, data quality was assessed. Missing values spanning less than two consecutive seconds were imputed using the 'approx' function from the 'zoo' package using linear interpolation. The dataset was subjected to tests for normality of distribution using the Shapiro-Wilk test and homogeneity of variances using the Levene Test.

For each trial, the mean values for the convex hull, relative field occupancy of all 20 outfield players, and 'distance to nearest opponent' for the attacking team were calculated. Resulting values underwent analysis through a repeated-measures ANOVA using RStudio (version 1.4.1564). An alpha level of $\alpha = 0.05$ was set as the threshold for statistical significance. Following the ANOVA, effect size values were calculated using Eta-squared values. Effect sizes were categorized as: small ($\eta^2 < 0.06$), moderate ($0.06 \leq \eta^2 < 0.15$), and large ($\eta^2 \geq 0.15$) (Cohen, 2013). Where ANOVA results indicated statistical significance levels, post hoc pairwise comparisons were conducted using Tukey's pairwise-testing to ascertain differences between specific manipulations of the independent variable.

RESULTS

*** Please insert **Table 1** about here ***

*** Please insert **Figure 3** about here ***

Convex hull

Decreasing the playing area consistently resulted in a smaller 'convex hull' across all manipulated conditions (**Figure 3**). Statistical analysis using a repeated measures ANOVA indicated a statistically significant main effect, $F(3,27) = 135.7$, $p < .0001$. The effect size, measured using Eta-squared, was found to be $\eta^2 = 0.94$, indicating a large effect. Subsequent post-hoc testing indicated statistically significant differences between all conditions. On the pitch, we observed that the smaller the playing area spatial dimensions, the closer the players co-positioned to each other in attack. In defense, we observed a strong tendency for player-marking, especially in the 'Small' area condition. This finding is illustrated in **Figure 4**. Descriptive statistics and post-hoc results are shown in **Table 1**.

Relative field occupancy

Statistical analysis for relative pitch occupancy indicated a statistically significant outcome $F(3,27) = 45.5$, $p < .0001$, $\eta^2 = 0.84$, suggesting a large effect. As depicted in **Figure 3**, relative pitch occupancy increased with decreasing APP. On the 'Competitive' field, players occupy roughly 20% of the entire area. But as the field dimensions diminishes, this proportion increases, peaking at 30% for the smallest area condition. This trend is further highlighted in **Figure 4**, which demonstrates that, in practical terms, the smaller the playing area, the more that space behind the back line is reduced. While the 'Competitive' condition allows ample space for through-ball opportunities, the 'Small' area condition offers much fewer opportunities for attacking actions behind the back four, resulting in more inter-individual duels. Descriptive statistics and post-hoc results are shown in **Table 1**.

Distance to nearest opponent

Analysis of the value of distance to nearest opponent via a repeated measures ANOVA indicated a statistically significant effect for playing area condition, $F(3, 27) = 51.5$, $p < .0001$, with a large effect size, $\eta^2 = 0.83$. Distance to nearest opponent values decreased with decreasing APP, althoughpost-hoc testing revealed that only the 'Half' and 'Small' playing area conditions yielded statistically significant reductions (**Table 1**). In a trend similar to that observed with the 'convex hull' variable, reducing the field dimensions consistently led to a decrease in the 'distance to nearest opponent' in every subsequent condition (**Figure 3**). For example, the average distance to nearest opponent in the smallest condition was roughly 70% of that observed in the initial condition, equating to an average distance of about 4.5

meters. Practically, this observation indicates a very tight player-marking strategy, leading to more duels in the ‘Small’ playing area condition, compared to the ‘Competitive’ field.

*** Please insert **Figure 4** about here ***

DISCUSSION

In this study, we utilized digital player positioning data to examine the constraining influence of reducing a soccer playing area (i.e., APP) on the dynamics of the convex hull variable between competing teams. From the resulting x-y coordinates of the 20 outfield players, we assessed values of inter-player distances and the overall spatial occupation on field (Low et al., 2020).

Proportionality between playing area and the convex hull area

Our statistical analyses revealed significant differences in the convex hull across all conditions ($p < .0001$; $\eta^2 = 0.94$, Large). As the playing area reduced, the convex hulls of the 20 outfield players also diminished. On a standard 'Competitive' size field, the convex hull averaged over 1400 m^2, reducing to about 1200 m^2 under the 'Large' area condition, about 980 m^2 under the 'Half' field condition, and further to 670 m^2 in the 'Small' condition (**Figure 3**). This observation of emergent player adaptations to constraints was not explicitly directed by coaches and supports hypothesis (I), which posits that reducing the APP in training design leads to a contraction of the convex hull area. A similar observation of player interactions has been reported by Clemente et al. (2018), who found that under half-field conditions, players co-positioned closer to each other, with the reported stretch index value being lower than reported infull-pitch conditions. This observation indicates more compact, effective playing transactions between players in the half-field setting, aligning with the current study's results. The reduced size of the convex hull value also indicated that players positioned themselves closer to their nearest opponents ($p < .0001$; $\eta^2 = 0.83$, Large), thereby substantiating the second hypothesis, (II): 6.47±0.57 m on the 'Competitive' field, 6.16±0.55 m on the 'Large' field, 4.97±0.25 on the 'Half' field, and 4.49±0.28 on the 'Small' field. This co-adaptation process between players could lead to intensified opponent pressure, supporting findings from the SSG literature, evidencing that smaller spaces result in increased opponent pressure (Clemente et al., 2023). This co-adaptation, in turn, elevates the frequency of actions, thereby enhancing players' capacity to cope with such pressure. Therefore, we may conclude that player actions are closely constrained by surrounding spatial conditions. These constraints act as information which facilitates adaptive responses in players to available spatial affordances emerging in a performance landscape (Clemente, Owen, et al., 2018; Clemente et al., 2023). These findings make it clear that the available playing space is a crucial task constraint on emergent player behaviors when designing training sessions in team sports like soccer.

Increased field occupancy, reduced concave hull

Remarkably, although the convex hull value became smaller with decreasing APP, the decline was disproportionate to the available total playing area. For example, in the 'Half' dimensions condition, where the total playing area was reduced by 50%, the convex hull occupied nearly 70% of the area seen in the baseline 'Competitive' condition. In contrast, when the total field area was reduced by 31% in the 'Large', and 69% in the 'Small' conditions, the convex hull decreased to about 48%, and 86% respectively

(**Figure 3**). These findings suggest that reductions in convex hulls of players may not be directly proportional to reductions in playing areas, giving rise to the interpretation that players attempt to maintain representative distances for combination plays (synergy formation), counteracting the re-scaling of playing area. It is plausible to suggest that, this type of modification needs to be carefully considered by coaches, since it may create an artificial situation for the players, if they encounter spatial conditions that do not accurately represent typical competitive performance conditions. In particular, from a practical performance preparation perspective, training in soccer should allow players opportunities to attune to changes in spatial information. Coaches' sensitivity to players' needs for attunement to surrounding information may help them learn to utilize the affordances representative of those available in a competitive performance landscape (Pinder et al., 2011). This practice adaptation necessitates that the informational constraints presented during training sessions should closely represent (simulate) those to be encountered in specific performance context (Dhami et al., 2004). This is a most important observation given that competitive playing field areas can diverge (governed by realistic values within the laws of the game).

To follow our interpretation of the data, for instance, one could consider the fundamental offensive skill of a 'one-two' (also known as 'give-and-go' (wall pass), 'um-dois', 'Doppelpass', or 'una pared') expressed within a dyad during a competitive match. This maneuver involves two players bypassing opponents through a rapid exchange of passes. However, the affordance of realizing a 'one-two' varies significantly between the performance contexts of futsal and soccer due to differences in the available spatial constraints. In futsal, where the APP is approximately 80 m^2, players often face immediate pressure from opponents in tight dyadic spaces. This specific task constraint necessitates early scanning of the environment before receiving the ball (Jordet et al., 2020), allowing players to orient their bodies to effectively 'address the performance environment' to create immediate passing angles to teammates (Otte & Davids, 2023). The exchange here is typically a swift, direct sequence of passes, with players using their body orientation to hide their passing intentions from opponents. In contrast, soccer, with a larger APP of around 320m^2 and greater inter-team distances, presents a different set of spatial constraints to its players. Here, the dyads are part of a defensive collective sub system that needs to cover a more substantial amount of space. This contextual constraint provides attackers in soccer with more space to receive the ball away from opponents (seen in the values of the variable 'distance to nearest opponent' across conditions **Figure 3**). To effectively realize a 'one-two' in this context, a player might initiate a dribble towards the direct opponent while scanning for a nearby teammate who adopts a position to offer a passing option. The player in possession of the ball aims to engage and bind an immediate defender, creating an opportunity for an attacking teammate to participate in the 'one-two' to shake off their marker. This maneuver requires precise timing; the attacker must be just close enough to the defender (but not too close) to ensure that the pass and subsequent run are performed at a moment when the defender is committed to move forward and intercept the ball and cannot quickly turn, thus being successfully bypassed. This example highlights the continual need for players to attune to spatiotemporal constraints and information sources in their environment. The effectiveness and intentionality behind skill performance and practice, such as the 'one-two combination', are intrinsically linked to these spatio-temporal performance features.

Based on this consideration, an exploration of the third hypothesis reveals another practically-relevant observation. . As the APP is reduced, a notable change is observed in the surrounding unoccupied space of the two teams. Specifically, when the field area shrinks, players end up occupying a larger proportion of the available space. This phenomenon is reflected in the 'relative field occupancy' metric (Alexander et al., 2019); as field dimensions decrease, the team's 'relative field occupancy' increases significantly across different area values ($p < .0001$; $\eta^2 = 0.84$, Large). The increased 'relative field occupancy' value that emerges under constraints of smaller fields leads to a marked contraction of the unoccupied area outside the convex hull, termed 'the concave hull' (**Figure 1**). This observation confirms hypothesis III, which posits that a constricted APP reduces the size of the concave envelope.

As an example, the area of the convex hull in the smallest condition was approximately half of that in the 'Competitive' field condition ('convex hull': 'Small': 672±71 m^2, and 'Competitive': 1412±12 m^2). However, the average concave hull, 1551 m^2 in the 'Small' area condition, was nearly four times smaller than on the competition field ('concave hull': 'Competitive' field: 5728 m^2). From a practical application viewpoint, it has become clear that modifying the field conditions may inherently restrict the players' scope of action (this shift in field occupation dynamics is evident in **Figure 4)**. With about a 70% reduction in the concave hull, the representativeness of both offensive and defensive strategies that emerge from cooperating players likely diminishes. Offensively, exploiting space becomes markedly more challenging as the attacking team has less space to invade, while defensively, the constricted space oversimplifies the covering task in a manner that may not be useful in practice because it does not realistically represent competitive match conditions.

Furthermore, these spatial manipulations could also extend to affecting the athletic demands placed on players. Given the diminished playing area, one might infer fewer high-speed runs and overall sprints in highly restricted spatial conditions, inadvertently ensuring that players are exposed to a potentially unrepresentative training context. This concern aligns with the findings of Savoia et al. (2021), who monitored an elite Italian soccer team in both official matches and training sessions over four months. Their kinematic data analysis revealed that the metabolic power data recorded during training sessions do not accurately represent the dynamics of competitive performance contexts. Consequently, they suggested that there may be an ill-considered emphasis on SSG in current training practices, when coaches use a 'copy and paste' approach to performance preparation (O'Sullivan et al., 2023). They recommend that coaches should instead, place a greater attention to detail in designing sessions that closely represent the athletic conditions encountered in official matches. From a practical standpoint: context means everything. The findings of our study suggest that when designing spatial dimensions of playing areas in practice, sport practitioners need to carefully consider what specific outcomes may be needed from players with regards to skill adaptation aligning with conditioning effects. The major finding of the present study underscores the adaptable nature of players' behavior and the close dependence of their interactions with their surroundings (Vilar et al., 2012; Vilar et al., 2014). In other words, players are highly adaptive and context means everything! When restricted to a markedly smaller field, players adjusted their individual and collective tactical behaviors to counterbalance the modifications to spatial constraints. Consequently, they tend to maximize the use of the available space, striving to maintain playable distances from opponents and teammates, ensuring that their performance remains functional.

Limitations and future directions

The primary limitation of the current study is that the trials involved only two competing teams, raising questions about the generalization of these findings for other teams (Lazic et al., 2018). Clearly, further research that dissects athletic parameters across different field sizes, while maintaining a constant number of players, would provide further valuable insights for coaches. Future investigations should address this issue and provide more evidence about what might happen in other 11vs.11 balanced teams when the spatial conditions are heavily modified.

Similarly, incorporating the ball-position parameter into future investigations would enable a greater focus on variables such as opponent pressure or spatial control. This approach would further clarify the effects of adjusting the APP in soccer. The current results raise the serious issue that practitioners should judiciously determine when and why to drastically adjust field dimensions, given the potential side effects that could inadvertently subvert defensive actions, impede offensive actions, and thereby diminish game representativeness.

More specifically, future research might consider varying the number of players involved, such as using a 4vs.4 setup to create an SSG-like scenario or a 7vs.7 format, which aligns with competition scenarios in certain child age groups, to explore these effects in youth soccer. Additionally, utilizing a more diverse sample could strengthen the conclusions of future studies. Nonetheless, due to the large effects observed across the calculated parameters, it is likely that similar trends will be observed in many experiments. This implication aligns with the general objective of our study, suggesting that researchers and practitioners should be more sensitive to spatial constraints within their intervention designs. Intervention studies could reveal the consequences of training designs with different spatial constraints on the skill adaptation process. To address this issue, future research should not only compare changes between SSG (small-sided games) formats (e.g., how floaters/jokers or rule changes influence player behaviors within one SSG compared to another), but also explore how specific practice regimes affect transfer effects in full-sized matches. While tracing a specific behavior in a match back to the practice environment may be challenging due to various interferences, for a comprehensive understanding of skill acquisition research should avoid the limitation of examining training and competition separately (i.e., different ‘forms of life’). Therefore, it is worth looking beyond the pitch at the ecological niche in both training and competition environments.

The Concave Hull: An Ecological Niche within Soccer's Practice Design

Our findings suggest that the 'concave hull' may be considered as an 'ecological niche' within the formats of soccer's practice designs. Rothwell et al. (2023) extensively explored the macro perspective of talent development in sports, they particularly highlighted the role of the performance environment, sociocultural contexts, and developmental practices as comprising an ecological niche which shapes an athlete's trajectory. Just as the 'ecological niche', on a macro scale, underscores the interplay between performers and their surroundings (Rothwell et al., 2020; Rothwell et al., 2023), our findings encourage viewing this concept on a micro scale as well. In this context, the soccer field, may be seen as an organic setting where collective actions emerge, emphasizing the importance of the design and scaling of the concave envelope. This perspective frames the soccer field as an 'ecological niche'. The visual representation, particularly of the 'concave hull', further highlights the significance of its structure and merits heightened attention and awareness in sport science research.

For coaches, the concept of the 'concave hull' provides valuable information that can enhance action fidelity in practice. Our data reveal that a reduced APP value leads to closer player-player positioning, which practically translates to a tighter marking strategy. Additionally, previous studies investigating midfield pressing or high-press strategies have shown that defensive backlines tend to position themselves at varying distances from the goal line, depending on their pressing strategy (QUELLE). Therefore, this vacant space behind defenders can be considered for therepresentative design of practice tasks, not only when setting up large-sided training scenarios (e.g., 8vs.8 to 11vs.11) but also in sub-task designs, with fewer players in SSG. For instance, when coaches want to develop the co-adaptation of players in a defensive dyad (e.g., two central defenders), they often start near the penalty box, where the space behind the defenders is approximately 16-18 meters. This is a simple setup, typically done to focus the defenders' attention, as beside dribbling, and combination play, the attackers have good shooting opportunities. However, considering the ecological niche within soccer's practice design, the data reported here suggest the need to take into account potential benefits when positioning the defensive dyad 37 to 40 m from the goal (QUELLE) which creates a different affordance landscape. In a 2 vs.2 scenario near the goal, attackers are constantly presented with available shooting affordances, which forces defenders to stay close to block shots. On the other hand, at 37 to 40 m from the goal, shooting becomes less likely, while affordances for playing through-balls become more prominent. With more space at the back to cover, a tight marking strategy is less effective, as attackers can easily knock the ball into space or perform a one-two (as mentioned earlier in the futsal example). In this case, the defenders must attune their (co-)positioning to the pace of the attackers (higher dribbling pace due to greater distance to goal), co-adapting with their partner to limit through-ball opportunities. These practice design modifications can also help the dyad partners to keep in mind, that when attackers approach the goal, shooting affordances become more and more available. This example for setting up a representative 2 vs.2 practice design suggests how coaches could become more conscious of spatiotemporal task representativeness to effectively channel each player’s action readiness for full-sized matches (competition).

Considering the 'concave hull' as an ecological niche within soccer practice design helps coaches become increasingly aware of the actual affordances that emerge and disappear in a full-sized match. Representative spatial conditions in training ensure that, when players return to the competitive performance environment, they will be able to find similar information sources which they have attuned to during practice (i.e., skill transfer). Conversely, when the ecological niche in practice does not provide the relevant information sources that players will face in competition, the practice environment may not provide adequate support for them to prepare for demands of competitive performance. Therefore, to design practice formats with a high sensitivity to spatial task representativeness, coaches conceptualised as sport ecology designers may ask (WOODS): Where and how does a situation emerge in competitive performance? and, What are the spatial affordances (concave hull) surrounding the players?

CONCLUSION

The 'concave hull', which signifies the space around the outfield players, forms a critical spatial constraint influencing the emerging interpersonal distance values among the players. Consequently, this space remains highly significant for ensuring the representativeness of actions within training designs. However, particularly in SSG training, this space is often situated beyond the playing area, potentially resulting in an artificial and non-representative training environment where players may struggle to find relevant information to attune to and available affordances of an intended performance context.

As a result, the findings of our study emphasize that the 'concave hull' represents an 'ecological niche' at the micro level, a niche that directly constrains players' behaviors within the designs of soccer training activities. By defining the field size, positioning the goals, and manipulating task constraints, coaches are actually creating an 'ecological niche' for adaptation of player actions on a micro level. Consequently, for a seamless and effective skill transfer of performance from training to actual games, the 'ecological niche' established in training should seek to contextualize the dynamics and intricacies of specific performance environments. Given the prevalent focus on smaller spaces in training, particularly in SSG, future research should delve into the potential of representative scaling to enhance action fidelity, especially within sub-task designs. For instance, a 4vs.4 setup – such as the back-four against the attacking line – is often played in a space double the size of the penalty area for convenience's sake (Olthof et al., 2018), but to improve learning effects, it may be arranged with representative spatial conditions that mirror actual gameplay Investigating and establishing more representative ecological niches in training may offer a promising avenue for nurturing player and team development, ensuring a more seamless performance transfer aligned with authentic competitive demands. Looking beyond the conventional wisdom of soccer practice design helps coaches and researchers avoid treating training and competition as two distinct 'forms of life'. Hence, the concave hull as soccer's ecological niche in practice design is an approach that facilitates improved task representativeness in practice and intervention designs, creating a more vital set of affordances for players that align with their natural habitat – the full-sized soccer field.

ACKNOWLEDGEMENTS

The authors would like to thank in particular Mr. Claudius Müller from Catapult. He continuously and proactively supports the academic community with his knowledge and was always the point of contact when it comes to efficient technical and professional problem solving.

AUTHOR CONTRIBUTION

JW was responsible for data collection and comprehensive analysis of the dataset. YD played a supervisory role in data collection and actively participated in the process. BB and RR both contributed to conceptualizing the study's methodology, with BB focusing on supervising the data collection and RR providing support in data analysis. KD critically reviewed and improved the manuscript, ensuring the accuracy and appropriateness of content, particularly in relation to the Ecological Dynamics framework. TV provided considerable revisions to the manuscript, contributing scientifically valuable insights and improvements. AD was pivotal in conceptualizing the study's idea, overseeing both data collection and analysis. AD also drafted the initial manuscript and coordinated the integration of feedback from co-authors.

CONFLICT OF INTEREST DISCLOSURE

The authors declare they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, AD, upon reasonable request.

FUNDING

No funding was received.

DECLARATION OF INTEREST STATEMENT

All authors declare no conflict of interest.

REFERENCES

Alexander, J. P., Spencer, B., Sweeting, A. J., Mara, J. K., & Robertson, S. (2019). The influence of match phase and field position on collective team behaviour in Australian Rules football. *Journal of Sports Sciences*, *37*(15), 1699–1707. https://doi.org/10.1080/02640414.2019.1586077

Almeida, C. H. (2012). Manipulating Task Constraints in Small-Sided Soccer Games: Performance Analysis and Practical Implications. *The Open Sports Sciences Journal*, *5*(1), 174–180. https://doi.org/10.2174/1875399X01205010174

Almeida, C. H., Ferreira, A. P., & Volossovitch, A. (2012). Manipulating Task Constraints in Small-Sided Soccer Games: Performance Analysis and Practical Implications. *The Open Sports Sciences Journal*, *5*(1), 174–180. https://doi.org/10.2174/1875399X01205010174

Andrienko, G. (2017). Visual analysis of pressure in football. *Data Mining and Knowledge Discovery*, 1–47. https://doi.org/10.1007/s10618-017-0513-2

Araújo, D., & Davids, K. (2016). Team Synergies in Sport: Theory and Measures. *Frontiers in Psychology*, *7*, 1449. https://doi.org/10.3389/fpsyg.2016.01449

Araújo, D., Ramos, J. P., & Lopes, R. J. (2016). Shared affordances guide interpersonal synergies in sport teams. *Interpersonal Coordination and Performance in Social Systems*, 165–178.

Bueno, M. J. d. O., Silva, M., Cunha, S. A., Torres, R. d. S., & Moura, F. A. (2021). Multiscale fractal dimension applied to tactical analysis in football: A novel approach to evaluate the shapes of team organization on the pitch. *PloS One*, *16*(9), e0256771. https://doi.org/10.1371/journal.pone.0256771

Castellano, J., Casamichana, D., & Dellal, A [Alexandre] (2013). Influence of game format and number of players on heart rate responses and physical demands in small-sided soccer games. *Journal of Strength and Conditioning Research*, *27*(5), 1295–1303. https://doi.org/10.1519/JSC.0b013e318267a5d1

Clemente, F. M., Owen, A [Adam], Serra-Olivares, J., Correia, A., Bernardo Sequeiros, J., Silva, F. G. M., & Martins, F. M. L. (2018). The effects of large-sided soccer training games and pitch size manipulation on time–motion profile, spatial exploration and surface area: Tactical opportunities. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, *232*(2), 160–165. https://doi.org/10.1177/1754337117722658

Clemente, F. M., Praça, G. M., Aquino, R., Castillo, D., Raya-González, J., Rico-González, M., Afonso, J., Sarmento, H., Silva, A. F., Silva, R., & Ramirez-Campillo, R. (2023). Effects of pitch size on soccer players' physiological, physical, technical, and tactical responses during small-sided games: A meta-analytical comparison. *Biology of Sport*, *40*(1), 111–147. https://doi.org/10.5114/biolsport.2023.110748

Clemente, F. M., Ramirez-Campillo, R., Sarmento, H., Praça, G. M., Afonso, J., Silva, A. F., Rosemann, T., & Knechtle, B. (2021). Effects of Small-Sided Game Interventions on the Technical Execution and Tactical Behaviors of Young and Youth Team Sports Players: A Systematic Review and Meta-Analysis. *Frontiers in Psychology*, *12*, 667041. https://doi.org/10.3389/fpsyg.2021.667041

Clemente, F. M., Sequeiros, J. B., Correia, A., Sierra-Olivares, J., González-Víllora, S., Silva, F., & Martins, F. M. L. (2018). How dots behave in two different pitch sizes? Analysis of tactical behavior based on position data in two soccer field sizes [¿Cómo se comportan los puntos en dos campos diferentes? Análisis del comportamiento táctico basado en los datos de posición en dos tamaños de campo de fútbol]. *RICYDE. Revista Internacional De Ciencias Del Deporte*, *14*(51), 16–28. https://doi.org/10.5232/ricyde2018.05102

Cohen, J. (2013). *Statistical Power Analysis for the Behavioral Sciences*. Routledge. https://doi.org/10.4324/9780203771587

Davids, K., Araújo, D., Correia, V., & Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exercise and Sport Sciences Reviews*, *41*(3), 154–161. https://doi.org/10.1097/JES.0b013e318292f3ec

Dellal, A [A.], Owen, A., Wong, D. P., Krustrup, P., van Exsel, M., & Mallo, J. (2012). Technical and physical demands of small vs. Large sided games in relation to playing position in elite soccer. *Human Movement Science*, *31*(4), 957–969. https://doi.org/10.1016/j.humov.2011.08.013

Dhami, M. K., Hertwig, R., & Hoffrage, U. (2004). The role of representative design in an ecological approach to cognition. *Psychological Bulletin*, *130*(6), 959–988. https://doi.org/10.1037/0033-2909.130.6.959

Duarte, R., Araújo, D., Correia, V., & Davids, K. (2012). Sports Teams as Superorganisms. *Sports Medicine (Auckland, N.Z.)*, *42*(8), 633–642. https://doi.org/10.1007/BF03262285

Duarte, R., Araújo, D., Folgado, H., Esteves, P., Marques, P., & Davids, K. (2013). Capturing complex, non-linear team behaviours during competitive football performance. *Journal of Systems Science and Complexity*, *26*(1), 62–72. https://doi.org/10.1007/s11424-013-2290-3

Fradua, L., Zubillaga, A., Caro, O., Iván Fernández-García, A., Ruiz-Ruiz, C., & Tenga, A. (2013). Designing small-sided games for training tactical aspects in soccer: Extrapolating pitch sizes from full-size professional matches. *Journal of Sports Sciences*, *31*(6), 573–581. https://doi.org/10.1080/02640414.2012.746722

Frencken, W., Poel, H. d., Visscher, C., & Lemmink, K. (2012). Variability of inter-team distances associated with match events in elite-standard soccer. *Journal of Sports Sciences*, *30*(12), 1207–1213. https://doi.org/10.1080/02640414.2012.703783

Gibson, J. J. (1979). *The ecological approach to visual perception*. *Psychology Press classic editions*. Psychology Press; Psychology Press Taylor & Francis Group.

Gréhaigne, J. F., Bouthier, D., & David, B. (1997). Dynamic-system analysis of opponent relationships in collective actions in soccer. *Journal of Sports Sciences*, *15*(2), 137–149. https://doi.org/10.1080/026404197367416

Jordet, G., Aksum, K. M., Pedersen, D. N., Walvekar, A., Trivedi, A., McCall, A., Ivarsson, A., & Priestley, D. (2020). Scanning, Contextual Factors, and Association With Performance in English Premier League Footballers: An Investigation Across a Season. *Frontiers in Psychology*, *11*, 553813. https://doi.org/10.3389/fpsyg.2020.553813

Katis, A., & Kellis, E. (2009). Effects of Small-Sided Games on Physical Conditioning and Performance in Young Soccer Players. *Journal of Sports Science & Medicine*, *8*(3), 374–380.

Lazic, S. E., Clarke-Williams, C. J., & Munafò, M. R. (2018). What exactly is 'N' in cell culture and animal experiments? *PLoS Biology*, *16*(4), e2005282. https://doi.org/10.1371/journal.pbio.2005282

Low, B., Coutinho, D., Gonçalves, B., Rein, R., Memmert, D., & Sampaio, J. (2020). A Systematic Review of Collective Tactical Behaviours in Football Using Positional Data. *Sports Medicine (Auckland, N.Z.)*, *50*(2), 343–385. https://doi.org/10.1007/s40279-019-01194-7

Low, B., Rein, R., Raabe, D., Schwab, S., & Memmert, D. (2021). The porous high-press? An experimental approach investigating tactical behaviours from two pressing strategies in football. *Journal of Sports Sciences*, *39*(19), 2199–2210. https://doi.org/10.1080/02640414.2021.1925424

Low, B., Rein, R., Schwab, S., & Memmert, D. (2022). Defending in 4-4-2 or 5-3-2 formation? Small differences in footballers' collective tactical behaviours. *Journal of Sports Sciences*, *40*(3), 351–363. https://doi.org/10.1080/02640414.2021.1993655

Nunes, N. A., Gonçalves, B., Coutinho, D., & Travassos, B. (2020). How Numerical Unbalance Constraints Physical and Tactical Individual Demands of Ball Possession Small-Sided Soccer Games. *Frontiers in Psychology*, *11*, 1464. https://doi.org/10.3389/fpsyg.2020.01464

Olthof, S. B. H., Frencken, W. G. P., & Lemmink, K. A. P. M. (2018). Match-derived relative pitch area changes the physical and team tactical performance of elite soccer players in small-sided soccer games. *Journal of Sports Sciences*, *36*(14), 1557–1563. https://doi.org/10.1080/02640414.2017.1403412

Olthof, S. B. H., Frencken, W. G. P., & Lemmink, K. A. P. M. (2019). A Match-Derived Relative Pitch Area Facilitates the Tactical Representativeness of Small-Sided Games for the Official Soccer Match. *Journal of Strength and Conditioning Research*, *33*(2), 523–530. https://doi.org/10.1519/JSC.0000000000002978

Orth, D., Davids, K., Araújo, D., Renshaw, I., & Passos, P. (2014). Effects of a defender on run-up velocity and ball speed when crossing a football. *European Journal of Sport Science*, *14 Suppl 1*, S316-23. https://doi.org/10.1080/17461391.2012.696712

Ötting, M., & Karlis, D. (2023). Football tracking data: a copula-based hidden Markov model for classification of tactics in football. *Annals of Operations Research*, *325*(1), 167–183. https://doi.org/10.1007/s10479-022-04660-0

Owen, A. L., Wong, D. P., Paul, D., & Dellal, A [A.] (2014). Physical and technical comparisons between various-sided games within professional soccer. *International Journal of Sports Medicine*, *35*(4), 286–292. https://doi.org/10.1055/s-0033-1351333.

Passos, P., Davids, K., & Chow, J. Y. (2016). *Interpersonal Coordination and Performance in Social Systems*. Routledge. https://doi.org/10.4324/9781315700304

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *Journal of Sport & Exercise Psychology*, *33*(1), 146–155. https://doi.org/10.1123/jsep.33.1.146

Rothwell, M., Davids, K., Stone, J [Joe], Araujo, D., & Shuttleworth, R. (2020). The talent development process as enhancing athlete functionality: Creating forms of life in an ecological niche. In

Rothwell, M., Stone, J [Joseph], & Davids, K. (2023). Exploring niche construction in sport coaching: an ecological dynamics analysis. *Sports Coaching Review*, *12*(2), 209–231. https://doi.org/10.1080/21640629.2021.1974692

Savoia, C., Iellamo, F., Caminiti, G., Doran, D. A., Pullinger, S., Innaurato, M. R., Annino, G., & Manzi, V. (2021). Rethinking training in elite soccer players: Comparative evidence of small-sided games and official match play in kinematic parameters. *The Journal of Sports Medicine and Physical Fitness*, *61*(6), 763–770. https://doi.org/10.23736/S0022-4707.20.11400-2

Silva, P., Chung, D., Carvalho, T., Cardoso, T., Davids, K., Araújo, D., & Garganta, J [Júlio] (2016). Practice effects on intra-team synergies in football teams. *Human Movement Science*, *46*, 39–51. https://doi.org/10.1016/j.humov.2015.11.017

Silva, P., Duarte, R., Sampaio, J., Aguiar, P., Davids, K., Araújo, D., & Garganta, J [Júlio] (2014). Field dimension and skill level constrain team tactical behaviours in small-sided and conditioned games in football. *Journal of Sports Sciences*, *32*(20), 1888–1896. https://doi.org/10.1080/02640414.2014.961950

Silva, P., Esteves, P., Correia, V., Davids, K., Araújo, D., & Garganta, J [Julio] (2015). Effects of manipulations of player numbers vs. field dimensions on inter-individual coordination during small-sided games in youth football. *International Journal of Performance Analysis in Sport*, *15*(2), 641–659. https://doi.org/10.1080/24748668.2015.11868821

Vaughan, J., Mallett, C. J., Potrac, P., López-Felip, M. A., & Davids, K. (2021). Football, Culture, Skill Development and Sport Coaching: Extending Ecological Approaches in Athlete Development Using the Skilled Intentionality Framework. *Frontiers in Psychology*, *12*, 635420. https://doi.org/10.3389/fpsyg.2021.635420

Vilar, L., Araújo, D., Davids, K., & Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Medicine (Auckland, N.Z.)*, *42*(1), 1–10. https://doi.org/10.2165/11596520-000000000-00000

Vilar, L., Duarte, R., Silva, P., Chow, J. Y., & Davids, K. (2014). The influence of pitch dimensions on performance during small-sided and conditioned soccer games. *Journal of Sports Sciences*, *32*(19), 1751–1759. https://doi.org/10.1080/02640414.2014.918640

Wittgenstein, L. (1989). *Philosophical investigations: Philosophische Untersuchungen* (3nd ed., repr). Blackwell.

APPENDICES

TABLES

Table 1:

	Descriptive Statistics		Multiple Comparison Test (Tukey)				
Contrasted Conditions	**mean±sd**	**mean±sd**	**Estimate**	**SE**	**95%CI**	**t**	**p**
Convex hull [m²]							
'Competitive' vs. 'Large'	1412±12	1210±14	202	38.60	(96, 31)	5.23	.0001
'Competitive' vs. 'Half'	1412±12	978±67	434	38.60	(328, 539)	11.24	<.0001
'Competitive' vs. 'Small'	1412±12	672±71	740	38.60	(634, 846)	19.16	<.0001
Relative pitch occ. [%]							
'Competitive' vs. 'Large'	19.78±1.73	25.24±3.02	-5.46	0.93	(-8.01, 2.91)	-5.86	<.0001
'Competitive' vs. 'Half'	19.78±1.73	27.41±1.90	-7.63	0.93	(-10.18, 5.08)	-8.19	<.0001
'Competitive' vs. 'Small'	19.78±1.73	30.30±3.21	-10.52	0.93	(-13.07, 7.97)	-11.29	<.0001
Dist. to nearest opp. [m]							
'Competitive' vs. 'Large'	6.47±0.57	6.16±0.55	0.31	0.19	(-0.20, 0.82)	1.69	.3497
'Competitive' vs. 'Half'	6.47±0.57	4.97±0.25	1.50	0.19	(0.99, 2.01)	8.06	<.0001
'Competitive' vs. 'Small'	6.47±0.57	4.49±0.28	1.98	0.19	(1.47, 2.49)	10.65	<.0001

TABLE CAPTIONS

Table 1: Statistical results are derived from Tukey's post-hoc pairwise comparisons. The 'Competitive' field serves as the reference condition against which the other three field conditions – 'Large', 'Half', and 'Small' – are compared.

FIGURES

Figure 1:

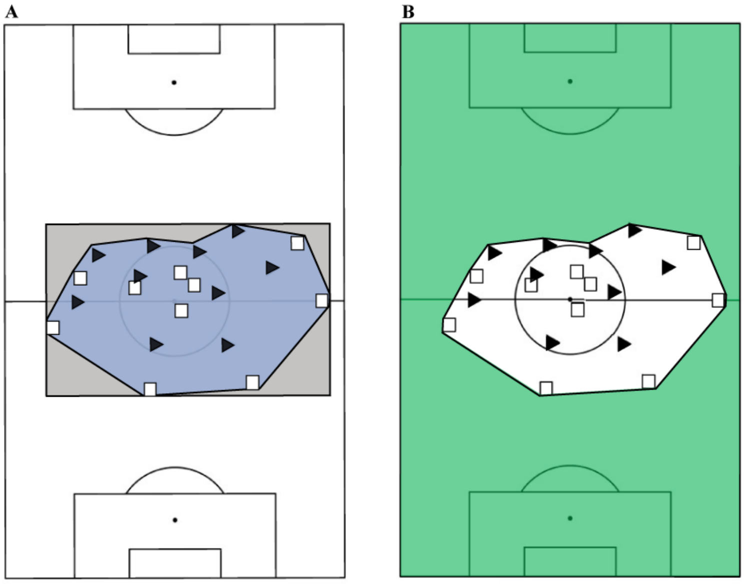

Figure 2:

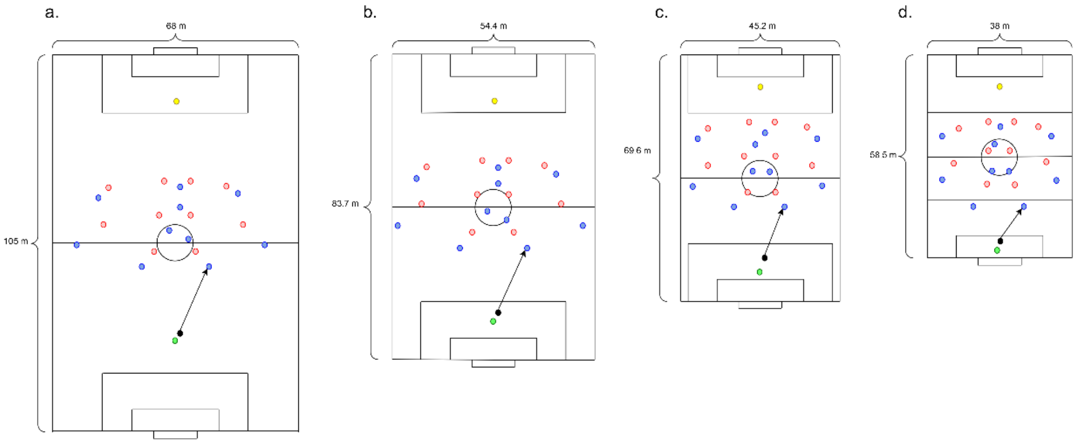

Figure 3:

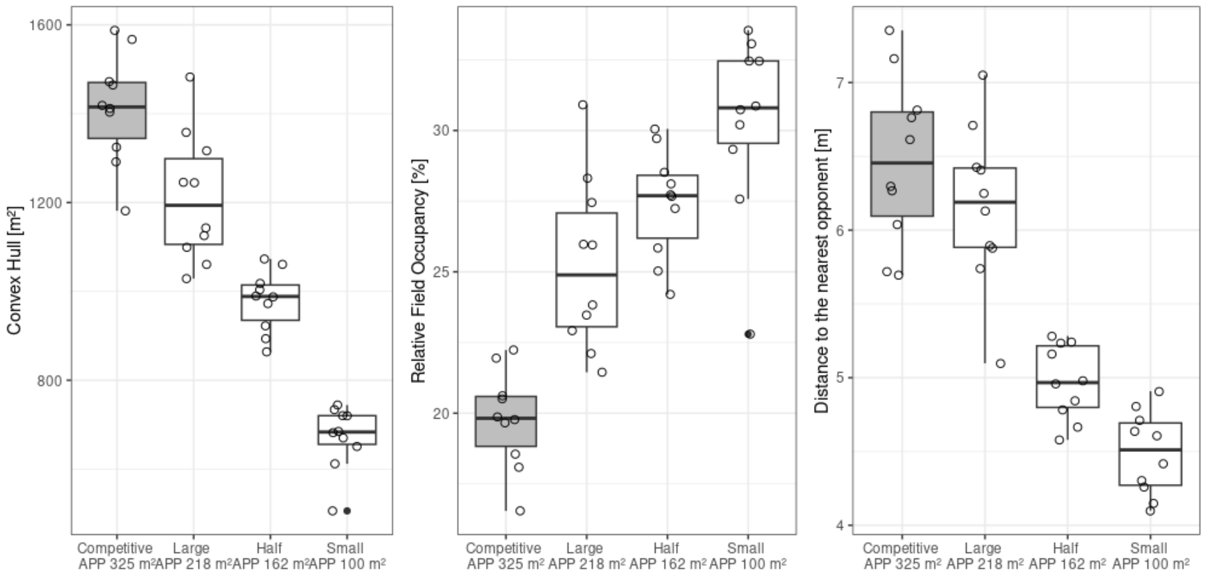
Convex Hull [m²]
1600
1200
800
Relative Field Occupancy [%]
30
25
20
Distance to the nearest opponent [m]
7
6
5
4
Competitive APP 325 m²
Large APP 218 m²
Half APP 162 m²
Small APP 100 m²

Figure 4:

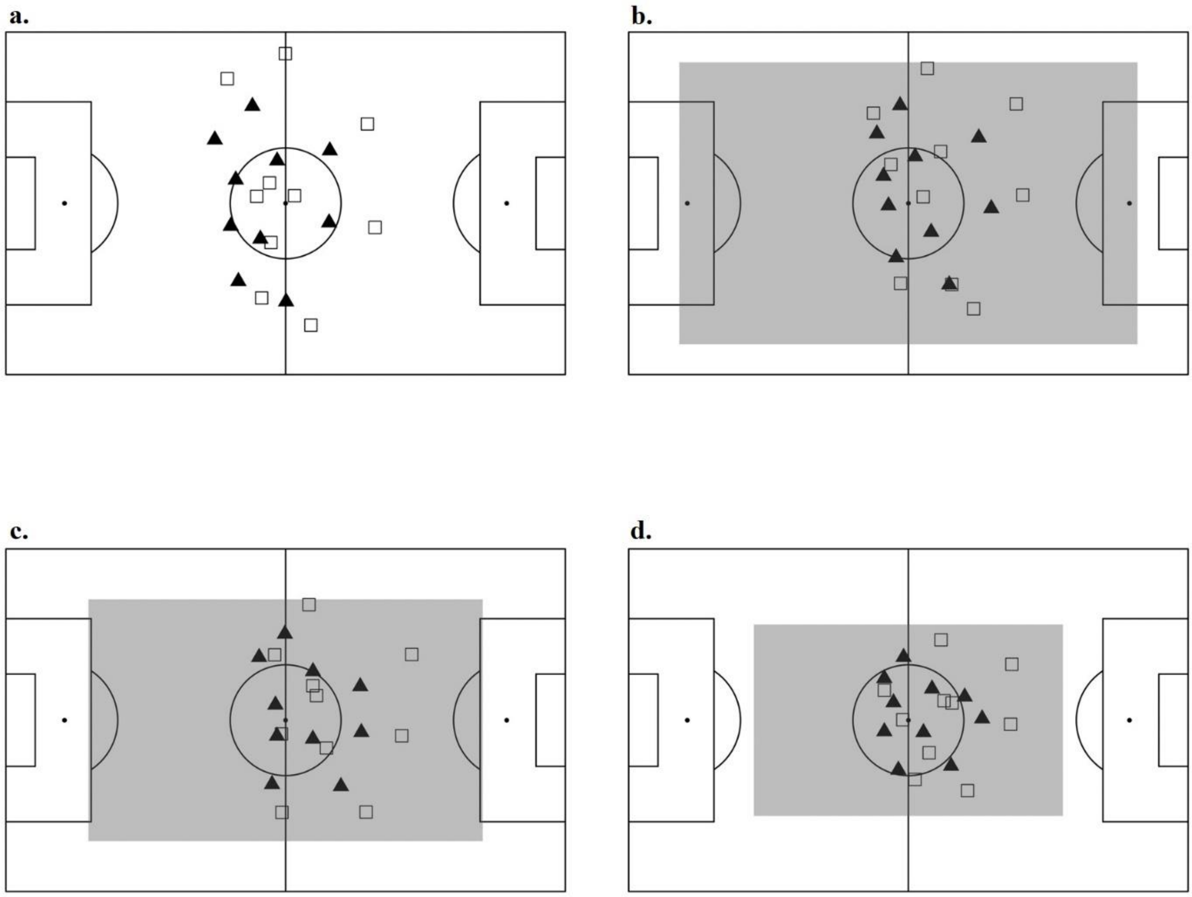

FIGURE CAPTIONS

Figure 1: Exemplary tactical setups of two soccer teams. On the left (A), the 'convex hull', representing the effective playing surface, is delineated by the blue polygon. The derived pitch area from this 'convex hull' (shown as a gray rectangle) is notably smaller than the full field (Fradua et al., 2013). On the right (B), the 'concave hull', highlighted in green, reveals an 'ecological niche' within soccer's practice design.

Figure 2: Scaled representation of the different field sizes: a. 'Competitive': area per player (APP) of 324.55 m²; b. 'Large': Based on Owen et al. (2014), APP of 218.00 m²; c. 'Half': Half field size, APP of 162.27 m²; d. 'Small': Based on Frencken et al. (2012), APP of 100.85 m².

Figure 3: Boxplots illustrating the 'convex hull', 'distance to the nearest opponent', and the 'relative field occupation' across all field conditions. Note that in all three dependent variables, there is a clear difference between the four field conditions, indicating that the players' actions are closely constrained by the surrounding spatial conditions.

Figure 4: Average positions of players (squares indicating attacking positions) across the conditions: a. 'Competitive', b. 'Large', c. 'Half', and d. 'Small' (from top left to bottom right). It can be observed that the less field space is available, the more the co-positioning of players in attack and defense contracts, while the unoccupied space surrounding the players decreases.