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Cardiorespiratory coordination during exercise recovery: a novel measure for health assessment

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Laura Kluge fighting for the puck in the match between Germany and Hungary during the Eishockey Deutschland Cup, in Landshut, Germany, on November 9, 2024
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Abstract

Cardiorespiratory coordination (CRC), a recently identified biological variable assessing the interaction among parameters derived from cardiopulmonary exercise tests (CPET), has demonstrated a heightened sensitivity to both training effects and functional disorders. Given the critical role of exercise recovery in detecting functional dysregulations, this study aimed to explore CRC during exercise recovery in healthy and physically inactive adults. Fifteen participants underwent a pyramidal CPET performing identical workloads (in inverse order) during the incremental and recovery (decremental) phases. A principal component analysis of selected cardiorespiratory variables was carried out to evaluate CRC. The first principal component eigenvalue and information entropy were calculated. Participants were categorized based on whether they exhibited one or two principal components (1PC and 2PCs groups) during the recovery phase of the CPET. The results revealed that: a) CRC was higher during the recovery phase compared to the incremental phase ($t = -2.67$; $p < .01$; $d = -0.72$), b) the 1PC group displayed higher eigenvalues ($t = 3.756$; $p < .01$; $d = 2.09$) and lower information entropy ($U = 0.00$; $p < .01$; $d = 15.83$) than the 2PCs group, and c) the 1PC group had lower heart rate, ventilation, and rating of perceived exertion at the end of the recovery phase than the 2PCs group ($d = 1.21$, $d = 0.57$, $d = 0.71$, respectively). In conclusion, CRC increased during exercise recovery, and participants with fewer principal components in the recovery phase exhibited greater cardiorespiratory efficiency and better fitness.

Keywords: cardiorespiratory fitness, entropy, exercise test, network physiology of exercise, principal component analysis, submaximal pyramidal exercise.

Introduction

Cardiopulmonary exercise testing (CPET) is widely applied in clinical practice for the evaluations of the cardiac reserve and the cardiorespiratory fitness of all types of populations (Balady et al., 2010). However, isolated physiological variables (e.g., heart rate [HR], expired minute volume [VE], oxygen consumption [VO_2], etc.) and related parameters (e.g., ventilatory threshold, respiratory exchange ratio, etc.), hardly inform about the dynamic coordination of the cardiorespiratory function during exercise (Balagué et al., 2016; Garcia-Retortillo et al., 2017).

Cardiorespiratory coordination (CRC), proposed as a variable to measure the interactions among parameters derived from CPET, has been highly useful to sensitively detecting differences across various conditions, such as repeated maximal exercises (Garcia-Retortillo et al., 2017), diverse populations with and without chromosomal disorders (Oviedo et al., 2021), training levels under hypoxia effects (Krivoshchekov et al., 2021), different training regimes (Balagué et al., 2016; Garcia-Retortillo et al., 2019) and dietary manipulations (Esquius et al., 2022). However, its testing and diagnosing possibilities within sport and medical fields remains largely underexplored.

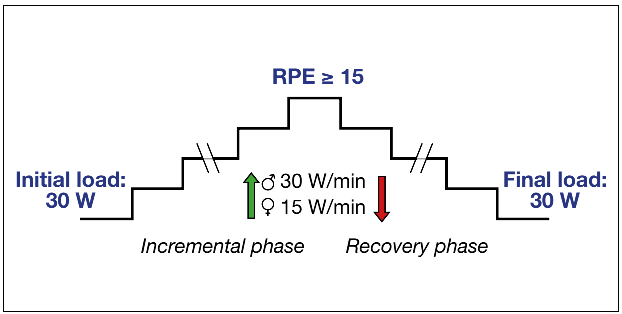
CRC has been commonly assessed through principal component analysis (PCA), a technique that identifies the underlying covariation patterns among time series data from different cardiorespiratory variables (Balagué et al., 2016). When variables share low covariation, the number of principal components (PCs) increases and vice versa. PCs capture the shared variability between these variables in decreasing order of importance. Thus, the first principal component (PC_1) represents the highest covariation between variables, and it is considered the coordinative variable, whereas each subsequent component (PC_2, PC_3, etc.) captures progressively less shared variance (Balagué et al., 2016). The total number of PCs reflects the level of coordination among the studied cardiorespiratory variables, with fewer PCs suggesting more efficient coordination (Balagué et al., 2016). In contrast, an increase in the number of PCs may indicate the formation of new coordinative patterns (Haken, 2000), and consequently, lower efficiency. This lower efficiency has been identified as a consequence of effort accumulation (Garcia-Retortillo et al., 2017; Garcia-Retortillo et al., 2019), cardiorespiratory disorders (Oviedo et al., 2021), and the effects of training under hypoxia (Krivoshchekov et al., 2021).

As a complement of PCA, the information entropy measure serves as a tool for assessing the complexity of coordinative states within the system (Seely & Macklem, 2012). Higher entropy indicates a more disordered state of the system, requiring a greater amount of information to describe its current state. In contrast, as the system stabilizes to fewer states, its entropy decreases (Naudts, 2005). The sensitivity of CRC to the effects of effort accumulation and general overload appears to offer more relevant information about internal load compared to commonly used variables such as maximal workload or maximal oxygen consumption (Balagué et al., 2016; Garcia-Retortillo et al., 2017).

Common CPET protocols often include incremental and maximal exercises with short resting periods (3 to 10 min) or submaximal active recovery phases at constant workload. However, the evaluation of the exercise recovery period contains crucial information about the adaptivity of regulatory systems during exercise. Exercise recovery represents a dynamic phase in which various activated mechanisms try to return to their initial states (Bartels et al., 2018; Romero et al., 2017). The cardiovascular system, in particular, assumes a crucial role in redistributing blood to satisfy the changing energy and oxygen demands, and rapid post-exercise regulation is crucial for cardiovascular health (Pocock et al., 2013). Therefore, exercise recovery may be considered as a crucial phase for detecting coordinative dysfunctions between the cardiovascular and respiratory systems.

A pyramidal exercise protocol (see Figure 1), which involves progressively increasing and then symmetrically decreasing workloads, may reveal potential dysregulation of cardiorespiratory functions. The gradual reduction in intensity could provide sensitive indicators of recovery efficacy and efficiency of the cardiorespiratory system. While a pyramidal exercise protocol has not yet been employed to assess CRC, it proves particularly valuable for comparing the cardiorespiratory responses to the same workload between incremental and recovery (decremental) phases. Consequently, it allows an assessment of the exercise recovery after being stressed by increasing workloads (Montull et al., 2020).

Figure 1
Pyramidal cycling protocol with progressively increasing and decreasing workloads (W) as a symmetrical mirror. Adapted from Montull et al. (2020), with permission.



This study aimed to explore the potential of CRC assessment during exercise recovery using a submaximal pyramidal protocol for evaluating the cardiorespiratory fitness of healthy and physically inactive adults. Our hypothesis was that the recovery phase would present a reduced number of PCs and lower information entropy compared to the incremental phase. Additionally, individuals with lower cardiorespiratory fitness were expected to demonstrate a higher number of PCs, increased information entropy, and poorer psychobiological recovery during the recovery phase.

Methodology

Participants

Fifteen healthy but inactive (< 30 min of daily physical activity) adults (seven males and eight females: 53.07 ± 3.31 y.o., 169.27 ± 13.26 cm, 80.24 ± 13.26 kg, and BMI 28.43 ± 6.57 kg·m^{-2}) participated voluntarily in the study. Conducting a power analysis using G*Power 3.1 (Faul et al., 2007) to determine the sample size, and considering large effect sizes of CRC during exercise (Balagué et al., 2016), we estimated a sample size of 12 participants ($d = 1$, $\alpha < .05$, power $(1 - \beta) = .80$).

The exclusion criteria were the following: (a) cardiovascular diseases; (b) contraindications to exercise; (c) use of medications that may influence the exercise response of HR. After being informed about the study procedures, participants signed an informed consent before the intervention. Experimental procedures were approved by the Clinical Research Ethics Committee of the local Sports Administration (ref. 07/2015/CEICEGC) and carried out according to the Helsinki Declaration.

Procedures

A pyramidal exercise protocol using a cycle ergometer (Excalibur, Lode, Groningen, Netherlands) was performed (see Figure 1). After a warm-up cycling at 30 W, the workload was increased 30 W/min (males) and 15 W/min (females), until participants reported a Rating of Perceived Exertion (RPE) ≥ 15 (hard) at the Borg's 6-to-20 scale. At this point, the workload was reduced inversely until 30 W. The cycling frequency was always maintained at 70 rpm. Participants were familiarized with the testing procedures and the RPE (6–20) scale (Borg, 1998) during submaximal incremental exercises at least two times in the month prior to the experiment.

Data acquisition

During the test, participants breathed through a valve (Hans Rudolph, 2700, Kansas City, MO, USA) and respiratory gas exchange was determined using an automated open-circuit system (Metasys, Brainware, La Valette, France). Oxygen (O_2) content, carbon dioxide (CO_2) content, and air flow rate were recorded breath by breath. The Metasys system currently recorded HR during the same period. Prior to each trial, the system was calibrated using a known composition mixture of O_2 and CO_2 (O_2 15%, CO_2 5%, N_2 balanced) (Carburos Metálicos, Barcelona, Spain) and ambient air. Participants were monitored continuously via a 12-lead electrocardiogram (CardioScan v.4.0, DM Software, Stateline, Nevada, USA).

Testing took place in a well-ventilated lab with a room temperature of 23 ºC and relative humidity of 48%, with minimal variations of no more than 1 ºC in temperature and 10% in relative humidity. Participants carried out the test at least 3 h after a light meal, and without previously practicing vigorous physical activity for 72 h (Balagué et al., 2016).

Data analysis

Firstly, data series of the selected cardiorespiratory variables (expired fraction of oxygen 'FeO_2', expired fraction of carbon dioxide '$FeCO_2$', HR and VE) were divided into incremental and recovery phases. Other cardiorespiratory variables commonly used in CPET (e.g., respiratory exchange ratio, oxygen pulse, VO_2, systolic volume, etc.) were excluded from the analysis due to their mathematical relation with the previous ones (Balagué et al., 2016).

Principal component analysis

PCA was then performed on the selected cardiorespiratory variables for each phase separately. Prior to perform PCA, Barlett's sphericity test and Kaiser-Meyer-Olkin index (KMO) were computed for each participant to assess the suitability of applying PCA (Jolliffe, 2002). The number of PCs was determined using the Kaiser-Gutmann criterion, treating PCs with eigenvalues $\lambda \geq 1.00$ as significant (Jolliffe, 2002). The optimal parsimony solution of the extracted PCs was obtained through Varimax orthogonal rotation (Meglen, 1991).

Given the interest in studying CRC during exercise recovery, two groups were distinguished based on the number of PCs in the recovery phase: participants with 1PC (1PC group; $n = 6$) and participants with 2 PCs (2PCs group; $n = 9$).

Information entropy analysis

To quantify the degree of coordination among the involved cardiorespiratory subsystems of each participant during both phases, the information entropy measure was calculated as follows:

$$H \pm \sum [1/2 \ln (\lambda) + 1/2 \ln (\pi) + 1/2]$$

Where H is is the information entropy of the system, λ is the PC's eigenvalue and π is the Ludolph's number. This sum included all PC's eigenvalues of the CPET (e.g., in a test with 2PCs, the sum was conducted over two eigenvalues belonging to PC_1 and PC_2, respectively).

Comparison of incremental and recovery phases

To compare the PC_1 eigenvalues and information entropy between the incremental and recovery phases of the test, Mann-Whitney U test and matched pairs t-test were used, respectively. PC_1 was chosen due to containing the largest proportion of data variance. Additionally, differences in both outcomes between 1PC and 2PCs groups during the recovery phase were assessed using Mann-Whitney U test and independent t-test, respectively. Standardized differences were demonstrated through Cohen's d, considering medium and large effect sizes ($d \geq 0.5$ and $d \geq 0.8$, respectively, Cohen, 1988).

Orthogonal projections of PC_1 during the recovery phase between 1PC and 2PCs groups

A comparison of PC_1 projections of all variables between 1PC and 2PCs groups during the recovery phase was carried out using Mann-Whitney U test and effect sizes (Cohen's d).

Psychobiological recovery efficacy and performance between 1PC and 2PCs groups

The values of HR, VE, VO_2 and RPE at the end of the recovery phase and the entire test were compared between 1PC and 2PCs groups through Mann-Whitney test and effect sizes (Cohen's d).

All statistical analyses were performed using RStudio (RStudio, Inc., 2023), and the predetermined significance level was set at $p < .05$.

Results

PCA and information entropy of cardiorespiratory variables during incremental and recovery phases

Barlett's sphericity test presented a highly significant result ($p < .001$), confirming the suitability of PCA data. The Kaiser-Meyer-Olkin (KMO) index indicated satisfactory sampling adequacy in both the incremental phase (0.60 ± 0.07) and the recovery phase for both groups: 1PC (0.69 ± 0.06) and 2PCs (0.52 ± 0.07).

During the recovery phase, the percentage of participants exhibiting one PC evidenced an increase of 228% compared to the incremental phase, as shown in Figure 2.

Figure 2

Percentage of participants with one and two principal components between incremental and recovery phases.

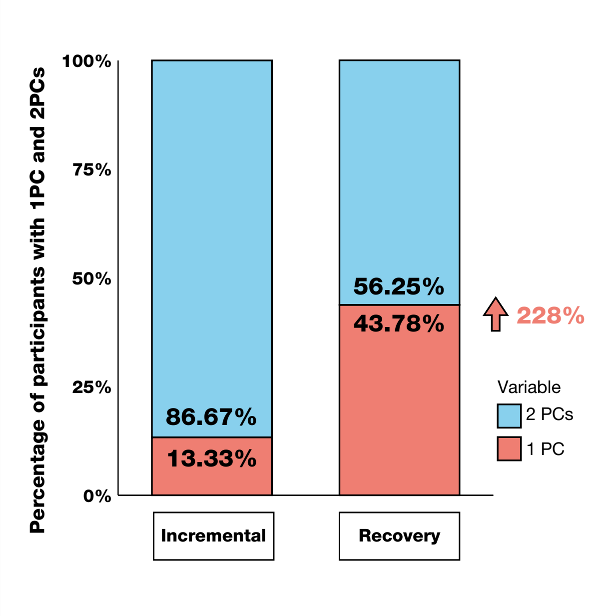


Figure 3 illustrates that the eigenvalues of PC_1, representing the predominant portion of data variance, were slightly greater in the incremental phase (2.57 ± 0.18) than in the recovery phase (2.28 ± 0.51) ($d = -0.76$). Furthermore, information entropy was also significantly higher during the incremental phase (2.54 ± 0.39) compared to the recovery phase (2.20 ± 0.54) ($t = -2.67$; $p < .01$; $d = -0.72$).

Figure 3
*Comparison of (a) average PC_1 eigenvalue (λ) and (b) average information entropy (H) between the incremental and recovery phases (*p < .05).*

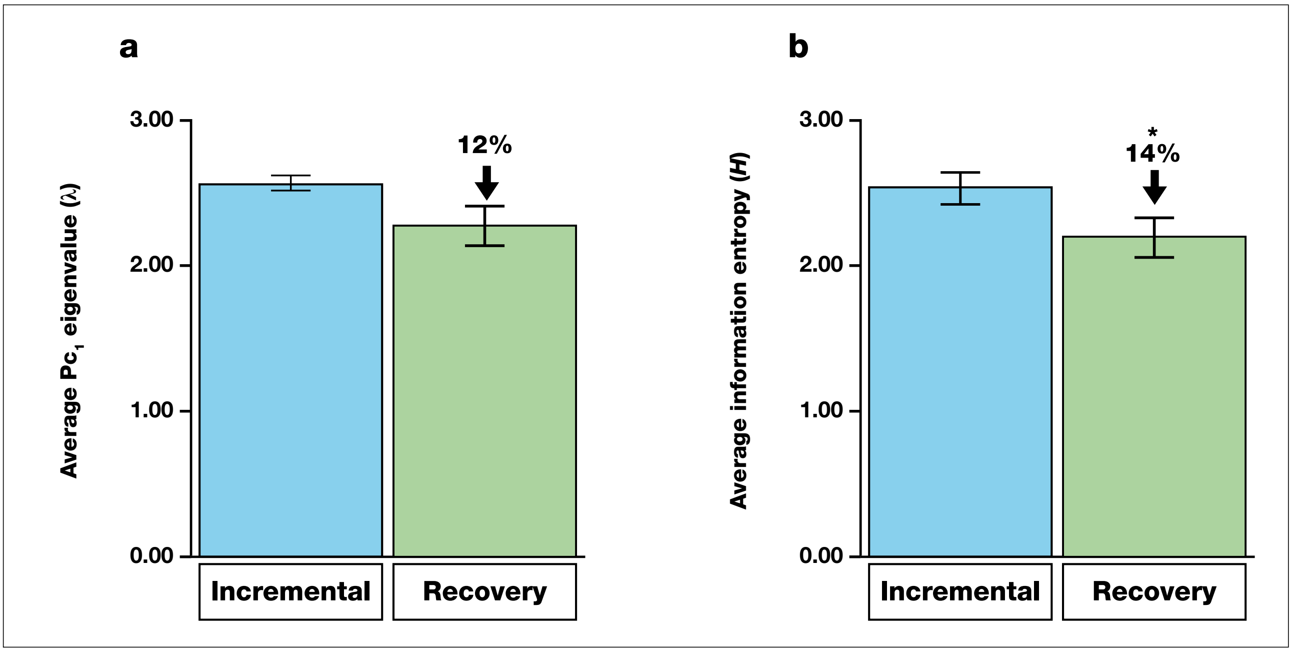
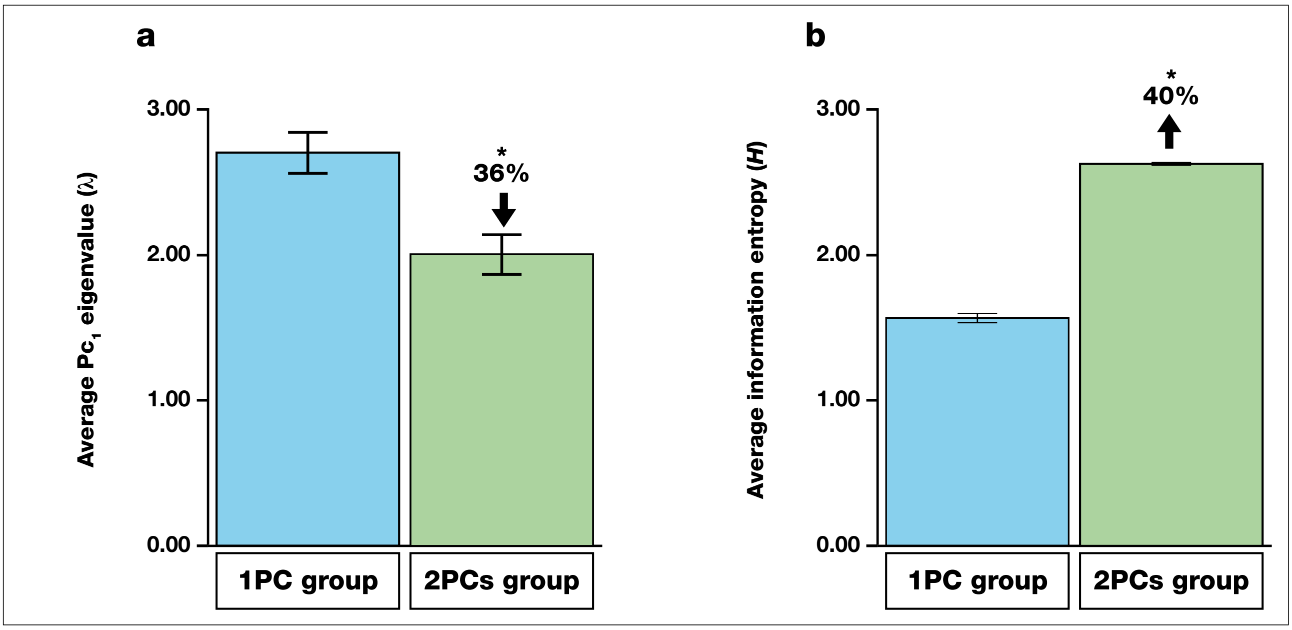


Figure 4
*Comparison of (a) average PC_1 eigenvalue (λ) and (b) average information entropy (H) between 1PC and 2PCs groups during the recovery phase (*p < .05).*



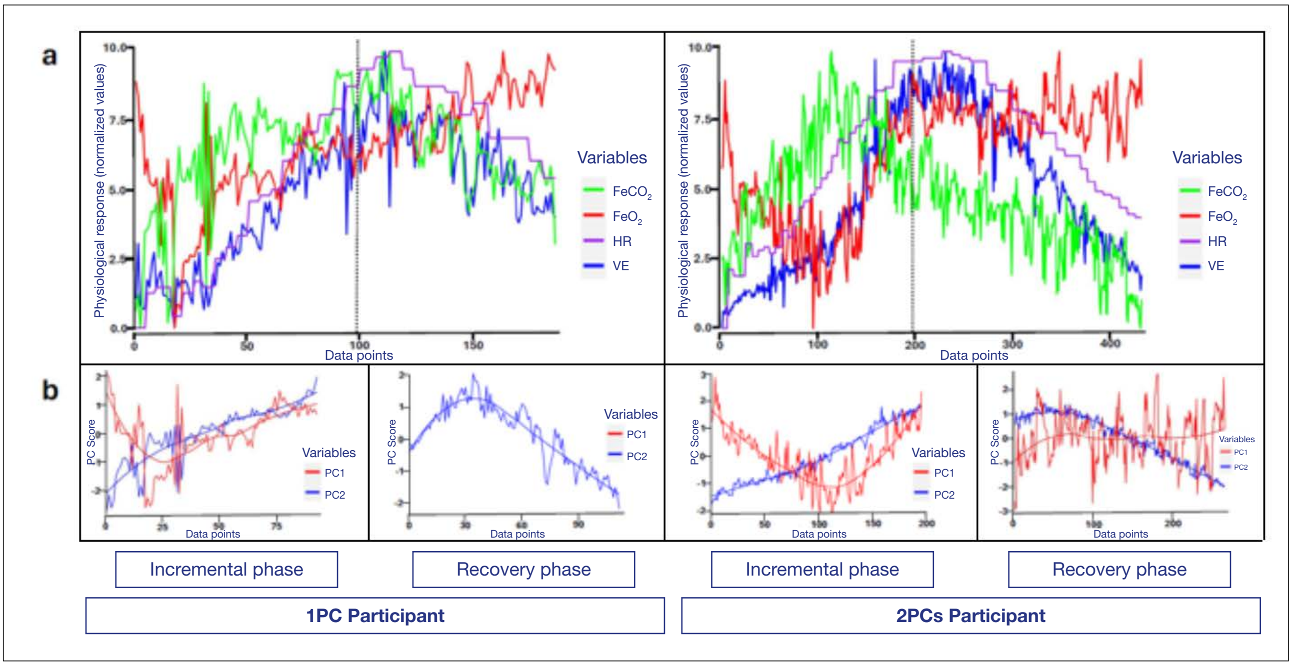
When comparing the two groups within the recovery phase, PC_1 eigenvalues were significantly higher in the 1PC group (2.71 ± 0.32) compared to the 2PCs group (1.99 ± 0.39) ($t = 3.756$; $p < .01$; $d = 2.09$). In the same phase, the 1PC group displayed markedly lower information entropy (1.57 ± 0.06) compared to the 2PCs group (2.62 ± 0.07) ($U = 0.00$; $p < .01$; $d = 15.83$) (see Figure 4).

Table 1
Orthogonal projections of variables onto PC_1 for participants in both groups during the recovery phase.

	1PC group					2PCs group			
ID	FeO_2	$FeCO_2$	HR	VE	ID	FeO_2	$FeCO_2$	HR	VE
1	–0.80	0.87	0.92	0.88	7	–0.26	–0.21	0.89	–0.21
2	–0.82	0.72	0.77	–0.66	8	–0.84	0.84	0.08	–0.05
3	–0.86	0.89	0.90	0.81	9	–0.35	0.44	0.83	0.87
4	–0.70	0.81	0.94	0.89	10	0.47	0.09	0.95	–0.96
5	–0.71	0.89	0.75	0.76	11	0.14	0.20	0.96	0.96
6	–0.70	0.87	0.92	0.84	12	0.03	0.50	0.96	0.96
					13	–0.06	0.84	0.98	0.98
					14	0.93	–0.94	–0.08	0.11
					15	0.23	0.39	0.96	0.95
Median	**–0.78***	**0.87***	**0.91**	**0.83**	**Median**	**0.03***	**0.39***	**0.95**	**0.87**
IQR	**0.11**	**0.06**	**0.12**	**0.10**	**IQR**	**0.49**	**0.41**	**0.13**	**1.01**

Note: *$p < .05$; FeO_2, expired fraction of O_2; $FeCO_2$, expired fraction of CO_2; HR, heart rate; VE, expired minute volume.

Figure 5
Example of the transformation of cardiorespiratory variables to PCs in 1PC and 2PCs groups. (a) Original time series of the four selected cardiorespiratory variables in both groups during incremental and recovery phases. (b) Time series of PC scores (standardized z-values in the space spanned by PCs) for both groups in both phases. The four-time series were condensed to one or two time series through the dimension reduction of PCs. Blue and red lines represent the average trend of both PCs, calculated through the weighted least squares method. Data points on the x-axis correspond to the number of measurements recorded during the test.



Orthogonal projections of PC_1 during the recovery phase between 1PC and 2PCs groups

Table 1 reveals that participants in the 1PC group presented relative uniform physiological responses during the recovery phase. Specifically, three cardiorespiratory variables ($FeCO_2$, HR and VE) displayed high positive projections/values on PC_1, while FeO_2 exhibited negative values. Notably, FeO_2 and $FeCO_2$ projections onto PC_1 were significantly higher in the 1PC group compared to the 2PCs group (FeO_2: $U = 5.00$; $p < .01$; $d = 1.99$, $FeCO_2$: $d = 1.66$). In contrast, participants in the 2PCs group did not present uniform cardiorespiratory projections on PC_1.

Figure 5 illustrates the differences between the results of 1PC and 2PCs groups in CRC. During the incremental phase, both groups demonstrated similar outcomes, with their variables ($FeCO_2$, HR, and VE) displaying a higher degree of co-linearity with PC_1, while FeO_2 predominantly aligned with PC_2. However, in the recovery phase, the variance of the four cardiorespiratory variables in the 1PC group was encapsulated by a singular PC_1, whereas the 2PCs group showed three variables (FeO_2 or $FeCO_2$, HR, and VE) with PC_1 and $FeCO_2$ or $FeCO_2$ with PC_2.

Table 2
Comparison of median and Interquartile Range (IQR) Final Values of HR, VE, VO_2 and RPE between groups.

	HR ($b \cdot min^{-1}$)	VE ($l \cdot min^{-1}$)	VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	RPE (Borg's 6-to-20 scale)
1PC group				
Median	†107.00**	31.22*	12.15	6.00*
IQR	14.50	9.82	2.17	3.25
2PCs group				
	HR ($b \cdot min^{-1}$)	VE ($l \cdot min^{-1}$)	VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	RPE (Borg's 6-to-20 scale)
Median	†116.00**	40.72*	12.43	9.50*
IQR	24.00	26.20	3.99	6.13

Note: †p < .05; d = intermediate (*) and large (**) effect; HR = heart rate; VE = expired minute volume; VO_2 = oxygen consumption; RPE = rating of perceived exertion.

Psychobiological recovery efficacy and performance between 1PC and 2PCs groups

Table 2 shows the values for both groups of HR, VE, VO_2 and RPE at the end of the recovery phase. In comparison to the 2PCs group, the 1PC group presented lower values across all studied variables, with statistically significant differences in HR (U = 7.50; p = .03). Effect sizes indicated intermediate to large magnitudes for HR, VE and RPE (d = 1.21; d = 0.57; d = 0.71, respectively). Furthermore, the total duration of the entire tests by the 1PC group (968.17 ± 179.66), including both incremental and recovery phases, was significantly longer than that of those performed by the 2PCs group (848.22 ± 234.75) (U = 0; p < .01; d = 0.56).

Discussion

The main findings of this study were that: a) CRC increased during the recovery phase of a pyramidal CPET, b) participants with 1PC in the recovery phase displayed higher PC_1 eigenvalues and lower information entropy compared to those with 2PCs, and c) HR, VE and RPE values recorded at the end of the CPET were lower in the 1PC group compared to the 2PCs group.

The reduction in the number of PCs and information entropy during the recovery (decremental) phase, in comparison to the incremental phase of the pyramidal test, suggests a more efficient CRC when the workload decreases. Although this may seem contradictory to previous findings, which indicated impaired CRC after previous exertion (Garcia-Retortillo et al., 2017), the current results can be elucidated by a heightened involvement of anaerobic metabolism during the incremental phase as opposed to the recovery phase. During the incremental phase, the inertia of aerobic metabolism, counterbalanced by the activation of lactic metabolic pathways, produced hyperventilation (Binder et al., 2008; Molkov et al., 2014). This response, which is attributed to the production of non-metabolic CO_2, was plausibly responsible for increasing the number of PCs during the incremental phase, even though the same workloads were performed in the recovery phase.

Montull et al., (2020) also reported a lack of symmetry in cardiorespiratory values between the incremental and recovery phases of a pyramidal exercise test, with higher values during recovery (decremental phase) for the same workload. In contrast, CRC in this study showed a higher efficiency during the active recovery. These findings confirm the interest of complementing the results of current CPET, such as cardiac reserve and cardiorespiratory fitness, with CRC parameters (i.e., number of PCs and information entropy) (Garcia-Retortillo et al., 2017).

The higher PC_1 eigenvalues and lower information entropy observed in the 1PC group during the recovery phase, in comparison with the 2PCs group, signifies a higher order, synchronization, efficiency, and adaptability in the cardiorespiratory response (Balagué et al., 2016; Garcia-Retortillo et al., 2017). This implies a more trained cardiorespiratory system and may extend to other interrelated and embedded physiological processes, for example, chemical-sensitive receptors, limbic-hypothalamic system, sympathetic/parasympathetic activity or muscle activity, operating at different timescales to ensure adaptation to workload demands (Garcia-Retortillo & Ivanov, 2022; Kairiukstiene et al., 2020; Pocock et al., 2013; Qammar et al., 2022; Velicka et al., 2019).

During the recovery phase, the 1PC group demonstrated similar covariation across the four cardiorespiratory variables, with FeO_2 showing elevated values that inversely correlated with $FeCO_2$, HR, and VE. This sustained elevation in FeO_2, while other variables were recovering, suggests a delayed oxygen demand response (Bahr & Sejersted, 1991). Despite this delay, the 1PC group did not form a new PC, likely due to their superior performance, which resulted in a lower frequency of cardiorespiratory values (i.e., impacting fewer data points) compared to the 2PCs group (Balagué et al., 2016).

In contrast, some participants in the 2PCs group contributed to the formation of PC_2 primarily through FeO_2, likely attributed to heightened hyperventilation at the onset of the recovery phase, indicating less efficient gas exchange. Others in the 2PCs group formed PC_2 through $FeCO_2$, which suggests they surpassed their ventilatory anaerobic threshold, resulting in substantial hyperventilation induced by excess non-metabolic CO_2 (Binder et al., 2008; Molkov et al., 2014).

The 1PC group exhibited lower quantitative values of HR, VE and RPE at the end of the recovery phase compared to the 2PCs group, despite undergoing a longer test duration, indicating potentially better workload tolerance. This suggests that participants with superior performance demonstrated not only greater efficiency but also more efficacy in the recovery of the cardiorespiratory system during pyramidal workloads. Indeed, the increased information entropy in the 2PCs group highlights potential dysfunctions in the feedforward and feedback mechanisms mediated by chemoreceptors to regulate ventilation (Zebrowska et al., 2020). This inefficiency may contribute to a more pronounced impairment in the control and regulation of cardiorespiratory function, ultimately leading to earlier exhaustion and higher quantitative values of psychobiological variables.

The CRC assessment of exercise recovery using pyramidal protocols has relevant clinical implications in CPET. This emphasis on evaluating exercise recovery with gradual changes in workloads provides valuable insights into post-exercise cardiorespiratory regulation, offering information about the internal load stress provoked by the preceding exercise (Bartels et al., 2018; Romero et al., 2017). The application of PCA and information entropy notably demonstrated the potential to inform about the efficiency and efficacy of the cardiorespiratory system in front of both workload increase and decrease, which reinforces these measures as a valuable objective assessment of individuals' cardiorespiratory fitness during exercise (Balagué et al., 2016; Garcia-Retortillo et al., 2017). This approach introduces new possibilities for the diagnosis and prediction of health and performance states in CPET, including the identification of physiological disorders or pathologies and, most importantly, the prevention of cardiac arrest (Kairiukstiene et al., 2020; Velicka et al., 2019).

Dimensional compression techniques, such as PCA, reduce the high dimensionality of time-series data into a few components, offering a more comprehensive understanding of individual dynamics (Denis, 2016). This approach aligns with the perspective that such analyses are more integrative and realistic compared to traditional physiological measures relying on isolated and static quantitative values (Balagué et al., 2020; Garcia-Retortillo et al., 2017). Moreover, it is worth noting that submaximal pyramidal exercises offer a highly relevant information about the state of the cardiorespiratory system and allow avoiding maximal tests, which may pose certain risks, especially in adult and inactive populations.

This work presented certain methodological limitations and future perspectives of research. The strict inclusion criteria of including only inactive and healthy adults in the sample size limited the statistical significance of the results. Future investigations are warranted to increase this sample size and investigate diverse age groups and varying fitness and health statuses to validate these preliminary findings. Secondly, considering that this study established the workloads based only on RPE, future research should add other objective measurements such as HR or predetermined workloads. Finally, future studies should consider incorporating systolic and diastolic arterial blood pressure into PCA, alongside other cardiorespiratory variables to integrate more relevant variables.

Lastly, although PCA as a linear dimension technique is validated as a valuable and sensitive tool for detecting cardiorespiratory changes during CPET (Garcia-Retortillo et al., 2017), further data analysis techniques should be explored to capture the nonlinear dynamics of CRC. In this sense, not only nonlinear PCA methods (Tenenbaum et al., 2000) may be interesting, but also other analyses promoted by Network Physiology of Exercise (Garcia-Retortillo et al., 2020; Garcia-Retortillo & Ivanov, 2022; Garcia-Retortillo et al., 2024; Montull et al., 2023; Vázquez et al., 2016).

Conclusion

This study demonstrated that cardiorespiratory coordination in healthy inactive adults increased during exercise recovery. Participants with fewer number of principal components in this phase exhibited greater recovery efficiency and efficacy of the cardiorespiratory system. Hence, cardiorespiratory coordination is reinforced as a valuable biological variable for providing integrative and sensitive insights into cardiopulmonary exercise testing and, accordingly, the fitness status. Additionally, the submaximal pyramidal exercise protocol appears to be a suitable tool for assessing adult populations and identifying potential cardiorespiratory dysregulation.

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Predictors and reasons for dropping out of long-distance mountain races

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Laura Kluge fighting for the puck in the match between Germany and Hungary during the Eishockey Deutschland Cup, in Landshut, Germany, on November 9, 2024
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Abstract

Interest in long-distance mountain races has been steadily increasing. Many varying factors other than physiological aspects must be considered in order to overcome these challenges, such as mental and strategic factors. The need to juggle so many factors at once may explain the high rate of race withdrawals or dropouts. The main aim of this study was to analyze the predictors of dropping out of long-distance mountain races and to discover participants' reasons for withdrawing from the Canfranc-Canfranc Ultratrail (2023) and Val d'Aran by UTMB races (2023). The participant dropout rate was 32.7%. The resulting predictors were negative sensations prior to the race and competing in the longest distance. After analyzing these predictors, the main reasons for dropping out were adverse weather, onset of debilitating fatigue, injury during the race, other performance-related factors, and illness and gastrointestinal distress. Our results demonstrate the importance of preserving health as an essential factor in dropping out of long-distance mountain races.

Keywords: drop out, endurance sports, survival, ultra trail.

Introduction

With the growing trail running trend (Venero, 2007), increasing interest in long-distance events has been observed recently among both amateur and professional athletes (Cejka et al., 2014). These challenging events (Scheer, 2019) attract athletes who want to test their mental and physical limits (Belval et al., 2019) as well as their strategic planning capabilities. These mental, physical, and strategic skills, however, are not always sufficient to endure the full gamut of challenges presented during these races, and many participants end up dropping out. Studying the reasons and factors involved in dropping out is essential to delving into the complex experiences of runners and their performance in these types of races.

These types of races and their specific characteristics are a growing concern to the industry professionals who are responsible for ensuring the safety of race participants (Glick et al., 2015). With that in mind, there is a need for a comprehensive approach (Lepers & Cattagni, 2012) that studies the physical, mental, and strategic aspects associated with successfully completing these races (Balducci et al., 2017). On that topic, Millet et al. (2012) state that it is essential to maximize aerobic capacity, plan strategically, develop mental toughness, manage recovery, and adapt to the weather and terrain conditions. According to Méndez-Alonso et al. (2021), individuals who participate in long-distance races tend to present mental toughness, resilience, and non-obsessive passion. Similarly, participants must have excellent cardiovascular, musculoskeletal, and mental fitness, an elevated awareness of their own body, and well-studied race preparation and strategy.

According to Philippe et al. (2016), dropping out of long-distance races is a common occurrence. Their study identified seven representative stages that lead up to dropping out: feeling pain, giving meaning to those feelings, adjusting running style, attempting to overcome the problem, other runners' influences, assessing the situation, and finally, deciding to drop out. The same authors (2017) later analyzed when these sequences occur during a race: 46.2% at resupply points, 35.6% during ascents, and less than 20% during descents. They also associated the most difficult terrain with more dropouts.

Along the same lines, Bordás and Fruchart (2023) offered an interesting view on decision-making models in adverse circumstances in mountain races. They found that athletes' real-time perceptions of effort and pleasure influenced their decisions to reduce, increase, or maintain pace. These perceptions could be key to understanding the reasons behind deciding to drop out of a race.

As far as factors related to dropping out, we highlight psychological factors, health-related factors, and those related to vitality states. From a psychological perspective, Méndez-Alonso et al. (2021) observed that aspects such as mental toughness, resilience, and passion for the sport were positively related to race completion. This aligns with the results of Corrion et al. (2018), who found that self-efficacy and coping strategies based on seeking social support contributed to protecting against dropout, whereas avoidance-based coping strategies were positively related to race dropout.

Another key factor to explain dropout is associated with health preservation. In terms of health, if health-seeking is one of the foundational reasons for participating in a race, the absence of this motivation, or fear of health declining during the race, could lead to deciding to drop out. This relationship between risk and health highlights the complexities of decision-making under these circumstances (Chambers & Poidomani, 2022).

Additionally, Rochat et al. (2017) examined vitality states during mountain races. Vitality states are the different conditions that runners experience. There are three main states: vitality preservation, vitality loss, and vitality revival. The authors observed significant differences in how these states evolved throughout a race between runners who completed the race and those who withdrew. Based on those observations, they pointed out the importance of knowing how to adapt and modify these states in order to complete the race.

Previous research has mainly used qualitative methodology to study the factors of dropping out of mountain races and provided a detailed understanding of participants' experiences in these competitive events. However, to supplement that research, we need to conduct studies that analyze the factors involved in the likelihood of dropping out and that quantify the main reasons for race withdrawal. With that in mind, the primary objective of this study was to analyze the predictors of dropping out of long-distance mountain races. In addition, the secondary objective was to determine why participants dropped out of the races, differentiating between races with three different distances.

Method

Participants

The study sample included a total of 211 participants (M_{age} = 44.5 years, *SD* = 8.7; 88.6% male) in the Val d'Aran by UTMB (*n* = 80) and Canfranc-Canfranc (*n* = 131) races. The participants competed in either the amateur (*n* = 164; 77.7%) or semi-professional (*n* = 47; 22.3%) category and had been competing for an average of 7.5 full seasons (*DE* = 5.1) in mountain races. In the Val d'Aran by UTMB race, we analyzed three distances: short (55 km with 3,700 m+), medium (110 km with 6,400 m+) and long (163 km with 10,000 m+). The same applied to the Canfranc-Canfranc race: short (45 km with 3,700 m+), medium (70 km with 6,100 m+) and long (100 km with 8,848 m+). All the above are considered long-distance races. The participants were distributed among the race distances as follows: short distance *n* = 88 (41.7%), medium distance *n* = 56 (26.5%), and long distance *n* = 67 (31.8%).

Instruments

We developed an ad hoc instrument to collect data on the predictors and reasons for dropping out of mountain races. This was a questionnaire to collect information on the participants' characteristics (i.e., sex, age, athletic level), their preparation (i.e., hours of training, injuries during the season), and their experience in mountain races (i.e., years practicing the sport, competition category, races run during the season, prior races from which they had withdrawn). The participants were asked if they had dropped out of the race and, if they answered positively, the reason or reasons that led to their decision. The participants completed the questionnaire virtually via Google Forms.

Procedure

The procedure used in the study of predictors and reasons for dropping out of mountain races was divided into three stages. First, the study was designed according to the principles of the Declaration of Helsinki and was approved by the Ethics Comittee of the Arnau de Vilanova Hospital in Catalonia (1665). Next, we contacted the organizational committees of the Val d'Aran by UTMB and Canfranc-Canfranc races to explain the aim of the study and to coordinate data collection. Contact was made three months prior to when each race was scheduled to be held. Once the organizations had granted approval, it was agreed that the research group would send a reminder email one week before each race. Lastly, runners who ran in both races in the previously stated distances were invited to participate in the study. After the races, the organizations sent emails to those participants with a brief introduction about the aims of the study and instructions on how to fill out the questionnaires. The first page of the questionnaire included an informed consent form. One week after this initial contact between the organization and the runners another email reminder was sent encouraging anyone who had not yet participated to do so.

Data analysis

The data were analyzed according to a three-step process and using the SPSS v. 26 statistics software. We first analyzed the data descriptively, with means and standard deviations for the quantitative variables and frequencies and percentages for the categorical variables. This preliminary analysis also enabled us to analyze lost values.

Secondly, to address the primary objective of the study and determine the predictors of dropping out of the races, we analyzed possible differences between participants who dropped out of the race and those who did not using χ^2 (categorical variables) and t-tests (continuous variables). The variables that differed significantly at a bivariate level ($p < .05$) between the runners who dropped out and those who did not were plugged into a logistic regression model to identify the factors independently associated with the likelihood of dropping out of the race. The binary logistic regression analysis was carried out using a forward stepwise procedure (entry criterion $p < .05$, elimination criterion $p > .10$).

Third, and lastly, to satisfy the secondary objective, we analyzed the reasons for dropping out. To that end, we classified the different reasons based on responses to the open-ended questions and obtained the following categories: Weather conditions, Injury during the race, Pre-race injury, Fatigue, Mental factors, Performance, and Illness and gastrointestinal distress. We then obtained the frequencies and percentages for each type of reason for dropping out. We also analyzed the frequency and percentage of each reason for the three race modalities: short distance, medium distance, and long distance.

Results

Primary objective: predictors of withdrawal

Comparison between participants who do and do not drop out

The preliminary data analysis revealed the percentage of lost values was less than 5% for all variables, and thus had no impact on the subsequent analyses. Out of the total number of participants, 69 runners dropped out of the race (32.7%). As seen in Table 1, we found statistically significant differences between the runners who dropped out of the race and those who did not for three variables. In that regard, a higher number of participants who dropped out of the race reported not having positive sensations at the starting line (23.2% vs. 12.0% for those who did not drop out), were mainly competing in the longest distance (53.6% vs. 21.1% for those who did not drop out), and had been competing for more years in mountain races (8.6 vs. 7.0 for those who did not drop out).

Table 1
Comparisons between individuals who do and do not drop out of races.

Variable	Participants who do not drop out	Participants who do drop out	Comparison (χ^2 or T-test)
Sex, n (%)			
Male	127 (89.4 %)	60 (87 %)	NS
Female	15 (10.6 %)	9 (13 %)	
Competition category, n (%)			
Amateur	111 (78.2 %)	53 (76.8 %)	NS
Semi-professional	31 (21.8 %)	16 (23.2 %)	
Positive sensations prior to the race, n (%)			
No	17 (12 %)	16 (23.2 %)	$p = .044$
Yes	125 (88 %)	53 (76.8 %)	
Race distance, n (%)			
Short	73 (51.4 %)	15 (21.7 %)	$p < .001$
Medium	39 (27.5 %)	17 (24.6 %)	
Long	30 (21.1 %)	37 (53.6 %)	
Injuries during the year, n (%)			
No	91 (64.1 %)	46 (66.7 %)	NS
Yes	51 (35.9 %)	23 (33.3 %)	
Drops out in previous races this year, n (%)			
No	118 (83.1 %)	50 (72.5 %)	$p = .072$
Yes	24 (16.9 %)	72.5 (27.5 %)	
Age, *M* (SD)	44.3 (8.5)	44.8 (9)	NS
Years competing in mountain races, *M* (SD)	7.0 (4.8)	8.6 (5.5)	$p = .032$
Number of previous races this year, *M* (SD)	4.5 (3.7)	4 (3.1)	NS
Weekly hours of training, *M* (SD)	8.1 (4.1)	8.9 (4.4)	NS

Note. NS = Not significant ($p > .05$)

Predictors of dropping out

The three variables from the previous stage that presented significant differences between runners who did and did not drop out of the race were plugged into the binary logistic regression model as predictors of dropping out. Withdrawal from previous races that year was also added as a predictive variable, with a value of p = .072 in the bivariate comparison. As seen in Table 2, the statistically significant predictors in the binary logistic regression (Hosmer–Lemeshow test: $\chi^2(3)$ = 0.955, p = .812; Nagelkerke's R^2 = .189) were, positively, lack of positive sensations before the race (OR = 2.645; 95 % CI = 1.154 – 6.061) and negatively, competing in the short distance (OR = 0.154; 95% CI = 0.072 – 0.328) and in the medium distance (OR = 0.364; 95% CI = 0.171 – 0.774) races compared to the longest distance.

Supplementary aim: comparing the reasons for dropping out among runners

As seen in Table 3, weather conditions (37.7%) were the main reason for dropping out for both the general sample and for the participants in the medium and long-distance races. As for participants in the shorter distance races, the main reason for dropping out was related to illness and gastrointestinal distress. Some of the other most stated reasons included suffering an injury during the race (23.2%), the effects of fatigue (20.3%), and performance-related reasons (17.4%), such as not making cut-off times or dissatisfaction with one's own performance.

Discussion

This study analyzed the predictors for dropping out of long-distance mountain races and the reasons that lead runners to decide to drop out. Our results show that a lack of positive sensations at the start of the race and competing in the longest distance modalities are predictors of race dropout. The study also highlights how adverse weather conditions, illness and gastrointestinal distress, injuries during the race, the effects of fatigue, and performance-related aspects play additional, key roles in dropping out of races with these characteristics. As a whole, our results allowed us to delve into the phenomenon of mountain race dropouts, enabling us to quantify predictors and motives and to identify health preservation as a key aspect of dropping out of these types of events.

Table 2
Predictors for dropping out of the mountain race.

	B	Wald χ^2	p	OR	95 % IC
Positive sensations prior to the race	0.973	5.285	.022	2.645	1.154 - 6.061
Short distance (versus long)	–1.870	23.527	0	0.154	0.072 - 0.328
Medium distance (versus long)	–1.011	6.883	.009	0.364	0.171 - 0.774
Constant	0.063	0.061	.805	1.065	

Nota. OR = Odds ratio; CI= Confidence interval for the OR.

Table 3
Description of the reasons for dropping out.

Reason for dropping out	Full sample	Short distance	Medium distance	Long distance
Weather	26 (37.7 %)	2 (13.3 %)	8 (47.1 %)	16 (43.2 %)
Injury during the race	16 (23.2 %)	3 (20 %)	4 (23.5 %)	9 (24.3 %)
Pre-race injury	5 (7.2 %)	1 (6.7 %)	0 (0 %)	4 (10.8 %)
Fatigue	14 (20.3 %)	3 (20 %)	1 (5.9 %)	10 (27 %)
Mental factors	3 (4.3 %)	2 (13.3 %)	1 (5.9 %)	0 (0 %)
Performance	12 (17.4 %)	3 (20 %)	3 (17.6 %)	6 (16.2 %)
Illness and gastrointestinal distress	9 (13 %)	4 (26.7 %)	3 (17.6 %)	2 (5.4 %)

Note. NS = Not significant (p > .05)

Health preservation seems to play a fundamental role as a predictor of withdrawal in relation to the lack of positive sensations prior to the race and as a reason for dropping out. Despite the considerable numbers of runners (who may or may not be sufficiently prepared) willing to sign up for long-distance races to test themselves in an athletic challenge, it can be inferred from our study that the decision to drop out is related to avoiding situations that could result in worsening health. In that regard, prior research has highlighted the importance of maintaining a balance between athletic challenge and health preservation (Chambers & Poidomani, 2022). Similarly, this result is closely related to the paradigm shift taking place within sports activities in recent years. While focus has traditionally been placed on performance, today many studies prioritize analyzing factors associated with athletes' overall well-being (Thuany et al., 2023; Le Goff et al., 2021). This is even more true in the case of long-distance races (in which participation only continues to increase), as runners expose themselves to highly demanding (Jaenes et al., 2022; Rose et al., 2023), and very likely unhealthy situations (Scheer et al. 2021) that contribute to the onset of injury (Hoffman & Krishnan, 2014).

Predictors for dropping out of long-distance mountain races

Sensations at the start of a race seem to play a fundamental role in the process of deciding to drop out of a race. These sensations are highly personal and involve assessing both non-specific (e.g., evaluating expectations) and specific aspects (e.g., presence vs absence of discomfort). These results may help complete the succession of sequences described by Philippe et al. (2016) by adding the importance of sensations felt prior to starting a race. Our results can also be associated with the vitality states experienced during the race as described by Rochat et al. (2017). Therefore, it is possible that a lack of positive pre-race sensations could be related to states of vitality loss that are associated with dropping out. Likewise, it is possible that race expectations may impact the how participants feel prior to the race. The connection between these results and those from our study suggest that an analysis of the reality that fits the situation, proper identification of which indicators enable us to adequately evaluate pre-race sensations, and putting those sensations into perspective could help minimize the impact of negative feelings on the likelihood of dropping out.

As for race distance, we observed that dropout rates increased with longer distances. This could be due to the increased duration and cognitive, motivational, and emotional demands required in races of this kind, as well as runners' own perceptions of greater effort and level of fatigue (Berger et al., 2024). On the other hand, psychological factors such as perfectionism have been associated with long-distance runners and one could associate dropping out of a race with self-protection strategies to avoid social and personal failure (Curtis & Hutchinson, 2022) when runners feel they are not performing up to their expected level.

Reasons for dropping out of long-distance mountain races

Based on our results, health preservation was also directly or indirectly linked to many of the reasons for dropping out as stated by the race participants. The main reason for dropping out was adverse weather conditions. At the physiological level, adverse conditions can present a risk to health (e.g., increases or decreases in body temperature, changes in blood pressure). In terms of emotional and cognitive aspects, poor conditions can lead to more fatigue and may hasten decision-making, such as deciding to drop out (Peng et al., 2023; Próchniak & Próchniak, 2020; Wagner et al., 2019).

Our results show that injuries prior to or during the race were another important reason for dropping out. In that regard, Hespanhol et al. (2017) reported a mean prevalence of trail running-related injuries with a higher prevalence for overuse injuries than for acute injuries. We can deduce from our results the importance of designing injury prevention programs that look out for the health of race participants (e.g., Vincent et al., 2022). Our results also indicate a higher prevalence of injury-related reasons for dropping out in longer distances. In relation to this result, it is important to consider the study from Hoffman and Fogard (2011) that highlights that the incidence of injury is not directly related to race distance but is related to the general sport of ultra running and the elevated number of training hours.

Fatigue is another health-related reason for dropping out. One study by Temesi et al. (2021) supports the hypothesis that central fatigue plays a crucial role in decreased performance among runners, particularly in longer distance events. However, a Hoffman and Fogard study (2011) indicates that exhaustion influences runners' performance but does not register as a primary cause of withdrawal. As the evidence is not clear-cut, we think it is important for future studies to delve deeper into what triggers the onset of perceived fatigue. For example, it is known that inadequate food and water intake strategies during these races can lead to the onset of fatigue and worsening performance (Hargreaves et al., 2004; Jeukendrup et al. 2011; King et al., 2018), which could lead to dropping out.

Practical applications

In terms of practical applications, on the one hand our study allowed us to identify the main factors and reasons related to dropping out of long-distance mountain races. Professionals in different scientific fields related to this sport (physiology, psychology, nutrition) can use these results to design and implement prevention and intervention protocols that holistically address all the reasons identified. On the other hand, our study shows that the health variable plays a fundamental role, both directly and indirectly, in deciding to drop out of a race with these characteristics. We believe these results could be of particular interest when organizing mountain race events and courses as they focus on finding a balance between the inherent challenge that these races present and preserving the health and safety of the participating individuals.

Limitations and future research

Despite the results this study offers, we must highlight two main limitations. On the one hand, the reasons for dropping out were coded according to an open-ended question. While asking the question in this manner allowed participants to provide more detailed explanations of their reasons for dropping out of the race, this meant that the research team was responsible for classifying those reasons into the categories that were later analyzed. Second, we must point out the situational nature of the sample analyzed. It represents a portion of the total number of participants who dropped out of the Val d'Aran by UTMB and Canfranc-Canfranc races, and the data collected could have been influenced by the specific characteristics of these competitive events (e.g., type of terrain, topographic profile, conditions on the day of the event). Therefore, we encourage future research to analyze the predictors and reasons for dropping out during events with different characteristics in order to complement the results of this study.

We would also like to propose two future lines of complementary research. First, we propose analyzing individual differences between runners, contextualizing the problem from a comprehensive point of view. For example, in terms of psychology, emotional regulation, personality, and mental toughness could be included since previous studies have stated that these could be deciding factors (De la Vega et al., 2011). It may also be interesting to analyze perceived race quality, which would involve assessing factors like perceived value, logistical infrastructure, or supplementary services (Madruga-Vicente et al., 2021). Second, we believe that studying race dropout could benefit from a methodological approach that tracks runners' experiences during the race. Wearable technology like physiological and performance monitoring devices could be very useful for gaining objective information about factors involved in effort management, race strategy, and decision-making.

Conclusion

As far as we know, this is the first study to analyze the predictors of dropping out of long-distance mountain races. Specifically, our research shows how races with longer distances and more elevation gain, as well as a lack of positive sensations prior to the race, are related to a higher likelihood of dropping out of a race. Our results also highlight weather conditions, injuries, fatigue, and under par performance as reasons for dropping out of mountain races. Based on our study, we can infer the importance of balancing athletic challenge with health prevention in order to optimize experiences during long-distance races and to encourage safe and sustainable participation in these types of sports events.

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Impact of the ludotechnical model on motivational variables in elementary school: perceptions and gender differences

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Laura Kluge fighting for the puck in the match between Germany and Hungary during the Eishockey Deutschland Cup, in Landshut, Germany, on November 9, 2024
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Abstract

The aims of the present study were: 1) to analyse the effects of the ludotechnical model (LTM) on the students' perceived interpersonal style of autonomy support teaching (SAS), performance in athletics events, fun and intention to continue practicing athletics and gender differences, and 2) to know the teacher's and students' perception of this methodology after the intervention. A quasi-experimental design was applied to a sample of 59 students (30 girls and 29 boys) with a mean age of 11-13 years. The results showed significant differences in favour of boys in the LTM group (M = 3.78) compared to the traditional methodology (M = 4.19) at the end of the intervention on the SAS (p = .0020). In terms of athletic test performance, significant improvements were obtained over time in both groups in the 10 x 10 m sprint and javelin throw tests. Specifically, the LTM group showed improvements in the 10 x 10 m test for boys (M pretest = 32.25 and M posttest = 31.44; p = .005) and girls (M pretest 33.78 and M posttest 33.07; p = .019) and for boys in the javelin throw (M pretest = 9.22 and M posttest = 10.27; p = .027). For the traditional group, the significant improvements in the 10 x 10 m sprint test were for girls (M pretest 34.43 and M posttest 33.33; p < .001) and in the javelin throw for girls as well (mean pretest 6.88 and mean posttest 8.18; p = .007). In the traditional group, significant improvements were obtained in the triple jump for girls (pretest mean = 3.85 and posttest mean = 4.10; p = .017). Both the teacher and the students perceived the LTM as more motivating for the young people; however, these results could not be supported by the questionnaire on fun and intention for future athletics practice. The use of LTM in the initiation of athletics in physical education is suggested, since students acquire motor skills in the same way as with traditional methodologies, but both students and teachers prefer LTM because of its greater support for autonomy and its potential positive physical and psychosocial consequences, although further and longer studies are needed to contrast these ideas and the possible differences according to gender.

Keywords: individual sport, interpersonal style, motivation, pedagogical models, physical education.

Introduction

A decrease in physical activity in children and adolescents leads to negative physical, cognitive and psychosocial consequences (Guthold et al., 2020; Tapia-Serrano et al., 2022), and the main reasons for sport dropout are lack of fun and a feeling of low motor competence (Crane & Temple, 2015).

Physical education has great potential for the acquisition of a wide range of goals, values and competences, and contributes to the physical, cognitive, affective and social development (Bayley et al., 2009; Kirk, 2013), with sport content being of particular relevance in this subject. However, this potential is undermined if the orientation of sport is not educational and is more performance or competition oriented. For this reason, different forms of sports teaching are proposed, in order to maximise the positive results that can be provided to students (Guijaro & González-Víllora, 2023).

Following these ideas, authors such as Haerens et al. (2011) approach the term "pedagogical models" with the idea of providing relevant, interesting and enjoyable activities that help to promote an active and healthy lifestyle. Pedagogical models are theoretical structures for teachers to develop practical teaching units in order to provide a comprehensive and coherent teaching plan for the achievement of specific learning objectives in relation to a specific context and content (Fernández-Río et al., 2021).

In the educational context, physical education teachers are using teaching models such as comprehensive teaching and sports education for the teaching of collective sports (Fernández-Río & Iglesias, 2024). These methodologies make it possible to achieve higher levels of self-determined motivation and increased satisfaction, as well as a wide range of positive consequences such as fun, learning, intention to be physically active, etc. (Merino-Barrero et al., 2020; Pérez-González et al., 2019; Vasconcellos et al., 2020) thanks to a structured session plan and methodological strategies systematised over a medium- and long-term implementation (Fernández-Río & Iglesias, 2024).

In individual sports such as athletics, teachers who continue to adopt a traditional methodology (TM) tend to perfect technique through repetition of technical gestures during childhood (Calderón et al., 2014), which leads to boredom among children (Murrie, 1997) and a way of teaching based on direct instruction with little support for autonomy (Metzler, 2017).

In response to this approach, new proposals have emerged for the teaching of athletics, such as the ludotechnical model (LTM) (Valero-Valenzuela & Conde-Caveda, 2003), which uses modified forms of play and games that include rules that allow them to acquire athletic technique (Valero-Valenzuela et al., 2019). Previous research has shown evidence of benefits in technique and performance (Valero-Valenzuela et al., 2012), higher intrinsic motivation values (Valero-Valenzuela et al., 2009) and increased fun (Sánchez-Morales et al., 2016).

In terms of gender, research has revealed differences in perceptions and beliefs held, with boys more likely to hold beliefs of greater ability and success, while girls tend to feel more competent and interested in tasks traditionally perceived as feminine such as dancing and gymnastics (Lee et al., 1999; Shen et al., 2003). However, Xiang et al. (2006) showed that racing content, which is not as stereotyped as football or dance, did not reveal gender differences. For men, fun is the main variable predicting task orientation, as it is for women, although effort is another relevant variable for the latter (Abraldes et al., 2013). On the other hand, authors such as Sánchez-Hernández et al. (2018; 2022) focus more on how the content is presented and the way it is taught than on the content itself, with the aim of approaching PE from a gender perspective and making gender stereotypes visible, due to the strong presence of performance discourse and androcentrism in PE sessions.

The main objectives of this study were: 1) to find out the effects of LTM versus TM on students' perception of the teacher's autonomy-supportive style, fun, intention to be physically active and performance in the different events of the "Playing athletics" competition, as well as by gender, and 2) to find out the teacher's and students' perception of LTM as a new methodology for initiation into athletics.

Methodology

Research design

This is a quasi-experimental (Thyer, 2012) repeated-measures study with a mixed-method research approach based on a predominantly quantitative integrated design (Castañer Balcells et al., 2013).

Participants

The study population consisted of schoolchildren from a public primary school located in the rural area of the province of Zaragoza, Spain. The teacher who took part in the study taught Physical Education in 4 groups (2 in 5th and 2 in 6th grade). He was a 41-year-old permanent staff member with more than 14 years of teaching experience. He had previously used other active methodologies. The sample of students was selected on the basis of accessibility and convenience, and finally consisted of a total of 59 students (30 girls and 29 boys) aged between 11 and 13 years. Of these participants, 29 were in the traditional group (13 boys and 16 girls) and 30 in the experimental group (16 boys and 14 girls). The teacher randomly assigned which was the experimental group and which was the control group.

Measurements and instruments

Fidelity of implementation

(1) Checklist for assessing the implementation of the LTM. To analyse whether the LTM sessions were reproduced as per the established model, a checklist was used where the items to be assessed were based on the strategies that LTM has throughout a session (Valero-Valenzuela et al., 2012). Subsequently, an outsider familiarised with the use of the LTM was trained in the use of the checklist. This person then analysed two randomly selected sessions (one from the TM and one from the LTM) and these same sessions were analysed again. The quality of the recording was assessed by calculating intra-observer reliability concordance using Cohen's kappa coefficient (Cohen, 1960). A value of .813 was obtained for the traditional session and .852 for the LTM session.

Technical skills

Several of the physical tests from the "Playing athletics" battery were used to assess the different motor skills of the students.

- *10 x 10 m race*: timed race over a distance of 10 m, to be run 10 times. The distance was delimited by cones that had to be circled from behind to turn around. Time was measured in seconds.

- *Soft javelin throw*: from a standing position, without previous run. Two attempts where only the best scored. It was not considered invalid if one foot went over the line after throwing. Distance was measured in metres.

- *Triple jump from a standing position*: behind the starting line and with the feet parallel, three consecutive jumps were performed, alternately landing on each foot without interruption and landing mandatorily on both feet. Distance was measured in metres.

- *Forward medicine ball throw*: with a 2 kg ball, overhead forward throw, standing upright. Two attempts where only the best scored. Distance was measured in metres.

- *Lateral jumping with a low obstacle*: continuous jumps with feet together on either side of a foam rubber or cardboard obstacle (approximately 20 cm high) were performed in 20 seconds, with both feet necessarily having to pass over the obstacle in all jumps. Each participant made one attempt. The number of jumps made was recorded.

Psychosocial variables

A questionnaire was used to assess different psychosocial variables. Different scales were provided in the presence of the principal researcher and the PE teacher in the computer room, in a calm atmosphere and lasting between 20 and 35 minutes.

(1) Scale of Autonomy Support (SAS) in Physical Education: instrument validated by Moreno-Murcia et al. (2020). It consists of 11 items that participants have to answer about the teacher's or trainer's style in the classroom (e.g., "With his/her explanations, he/she helps us to understand what the activities we do are for"). This is expressed on a Likert scale from 1 (Strongly disagree) to 5 (Strongly agree). The scale showed the following internal consistency values: $\alpha = .85$ pretest and $\alpha = .78$ posttest.

(2) Fun: the 8-item athletics fun questionnaire validated by Valero-Valenzuela et al. (2004) was included. This is expressed on a Likert scale from 1 (Very much) to 4 (Not at all), e.g. "I usually have fun when I do athletics". The scale showed the following internal consistency values: $\alpha = .80$ pretest and $\alpha = .82$ posttest.

(3) Intention to be Physically Active (IPA): the Spanish validated version of the 5-item questionnaire by Arias et al. (2013) was included. This is expressed on a Likert scale from 1 (Strongly disagree) to 7 (Strongly agree) preceded by the sentence: "Regarding your intention to practice any physical-sports activity...". The internal consistency for Cronbach's alpha was .77 at pretest and .73 at posttest.

Participants' perceptions

Semistructured interviews were used to assess participants' (students' and teacher's) perceptions of the intervention programme.

(1) Semistructured interviews with students. The tutors in each group interviewed their students ($n = 13$) in their reference classroom, lasting around 10-15 minutes. The interview questions covered different topics: (a) opinion on

the development of the sessions (e.g. How did you enjoy the sessions? How would you describe them?); (b) improvement in the "Playing athletics" competition (e.g. Do you think the sessions have helped you improve in "Playing athletics"?); and (c) lessons learnt (e.g. What did you learn about the phases of the tests?).

(2) Semistructured teacher interview. Once the study was completed, a member of the research team met with the teacher to get his impressions of the students' evolution throughout the implementation of the LTM, both in physical and psychosocial variables. The interview lasted approximately 45 minutes. The questions were structured in different sections: a) impact of the intervention on physical and psychosocial variables (e.g. Do you think there have been changes in the marks obtained and in the psychosocial variables after the sessions applied to one group and the other?); b) comparison between the traditional and the ludotechnical group (e.g. Do you think there were differences between the group that followed a traditional methodology and the group that followed the LTM?); c) training and support during the intervention (e.g. Did you feel the need for any support or feedback about whether you were implementing the LTM correctly?); d) duration of the intervention (e.g., Do you think that 5 sessions were enough to see changes between the LTM and the traditional one in the variables under study?); e) weaknesses and difficulties in the implementation (e.g., What weaknesses or difficulties did you find during the intervention?); and f) proposals for improvement and future-oriented proposals (e.g., What would you change in this study? Would you implement the LTM in the future? Why?).

Procedure

The study was approved by the Ethics Committee of the University of Murcia (code 4325/2022). The teacher conducted one session for the traditional group and another one for the ludotechnical group. Both sessions were filmed and analysed through observational analysis, evaluating the implementation of the pedagogical model and complementing it with the interpretation of the teacher's and students' perception at the end of the intervention through semistructured interviews. Informed consent was requested from the families after explaining the study to be carried out and a message was sent via Tockapp explaining how the recorded images would be used.

Data collection

The data collection process was carried out at different points during the intervention. Prior to the intervention, one session was devoted to carry out the pretest, consisting of the physical tests, followed by the administration of the questionnaires. The physical tests were carried out by all the students in the same order in which the "Playing athletics" tests would be carried out later, i.e. 10 x 10 metre run, javelin throw, triple jump and side jumping, medicine ball throw, obstacle course and Grand Prix. The students had previous experience with this type of tests, as it is an activity that 4th, 5th and 6th grade students do every year, but there was no attempt prior to the data collection. Once completed, the students, during the tutoring hour, filled in the questionnaires online in the computer room. In the posttest, the same physical tests and questionnaires were repeated, with the addition of the teacher and student interviews. In the case of the students, the interviews were conducted by their respective tutors during break time and lasted approximately 10 minutes. As for the teacher, the interview was conducted online by one of the researchers of this study, once the intervention and the posttest data collection had been completed.

Intervention programme

TM and LTM were implemented during 5 sessions of 50 minutes. In each session, priority was given to one test of the "Playing athletics" competition in this order: 10 x 10 metres race, javelin throw, triple jump and side jumping, medicine ball throw and, finally, the obstacle course and Grand Prix. The contents of this section are related to block A, dimension 1 according to the primary curriculum in Aragon (Order ECD/1112/2022, of 18 July).

As for the ludotechnical group sessions, they had the characteristics of LTM (Valero-Valenzuela, 2007; Valero-Valenzuela & Conde-Caveda, 2003), i.e., the session was divided into 4 parts: 1- Challenge question; 2- Ludotechnical proposals; 3- Overall proposal; 4- Debriefing. In the debriefing, the challenge question was answered; then the technical actions that made up the gesture and the key elements learned were recalled. Table 1 specifies the content and technical actions, as well as the challenge question. Furthermore, for this table, an equivalent exercise between the LTM session and the TM has been chosen.

The traditional group sessions were structured as follows: (a) a warm-up phase; (b) a main part characterised by a direct command and task assignment teaching style; and (c) a cooldown phase (Valero-Valenzuela, 2006). This approach promoted high teacher control of the session and low student autonomy, limiting their cognitive involvement (Metzler, 2017). Analytical exercises aimed at improving performance technique and a final competition situation were used (Valero-Valenzuela, 2006).

Table 1
Description of the sessions implemented in the experimental group.

		Ludotechnical model				Traditional methodology		
		Example of an activity				Example of an activity		
Session	Content and phases	Challenge question	Ludotechnical proposal	Overall proposal	Sharing	Warm-up	Main part	Cooldown
1	Triple jump and lateral jumping - Technical action 1: Take-off: assume a tandem position. - Technical action 2: Flight: the body tucks in, aiming to form a C shape. - Technical action 3: Landing: initial contact with both feet at the same height.	What are the movements of a jumper in the air used for? Which part of the foot is used during the take-off?	Log jumping: the first player will lie down. The second jumps with one leg over him/her and lies down. The third player jumps over the first and second players and lies down, and so on.	Triple jump competition.	To balance oneself. With the entire sole.	Joint mobility + game (crossing the river).	Jumping between markers at different distances. Stairs.	Stretching and reflection.
2	Javelin throw - Technical action 1: Starting position: javelin parallel to the ground and supporting leg in front and the same of the throwing hand behind. - Technical action 2: Final throwing action: extension of the throwing arm and advancement of the leg of the throwing arm, with both feet on the ground. - Technical action 3: Recovery: throwing leg comes forward to stop the body's forward movement.	Is the throw performed with one or two feet on the ground, or with feet in the air?	Clay target: In pairs. A player standing behind a line in a throwing position shouts "Pull!", at which point his/her team-mate, standing in front of him/her at a given distance, throws upwards a cardboard which must be hit with a ball by the team-mate who is in the throwing position.	Javelin throwing competition trying to make it land on the tip.	The throw is performed with both feet on the ground to anchor the body and transmit all the speed to the javelin. The trunk is flexed to slow down the forward movement of the body and avoid fouling.	Joint mobility + game (cleaning my house).	Placed in the arm preparation phase, throwing with the wrist only, elbow + wrist, shoulder + elbow + wrist.	Stretching and reflection.

Table 1 (Continued)
Description of the sessions implemented in the experimental group.

		Ludotechnical model				Traditional methodology		
		Example of an activity				Example of an activity		
Session	Content and phases	Challenge question	Ludotechnical proposal	Overall proposal	Sharing	Warm-up	Main part	Cooldown
3	Medicine ball - Technical action 1: Starting position: standing with the back turned, the ball close to the ground, knees slightly bent, trunk leaning forward, and arms not fully extended. - Technical action 2: Stretching: the knees are extended and the trunk is lifted, taking advantage of the start of the upright position to move both arms at the same time, using all the energy of the kinetic chain (legs-trunk-arms). - Technical action 3: Final release action: the ball is released when it is at its maximum height. - Technical action 4: Recovery: the thrower will move his arms to regain his/her balance and even tilt his/her trunk forward.	Why do we move our arms at the end of the throw?	Aim... fire! With a foam rubber ball ready above the head, stand upright, throw the ball and try to get it to land in front of your partner, who will stand facing away from you (the throwing distance will be varied).	Throwing competition.	The arm movement is aimed at being able to regain balance.	Joint mobility + game (the triple of champions).	Positioning to throw as high as possible. Contrasts: sitting, kneeling, standing. Forward, chest, backward, twist. Trajectories: descending, ascending, flat, parabolic.	Stretching and reflection.

Table 1 (Continued)
Description of the sessions implemented in the experimental group.

		Ludotechnical model				Traditional methodology		
		Example of an activity				Example of an activity		
Session	Content and phases	Challenge question	Ludotechnical proposal	Overall proposal	Sharing	Warm-up	Main part	Cooldown
4	10 x 10 m - Technical action 1: Starting position: metatarsal contact. - Technical action 2: Propulsion in tandem position. - Technical action 3 Upper body: trunk upright, slightly bent forward, elbows at 90°. - Technical action 4: Coordination: lower and upper body.	Why do long-distance runners step on their heels?	The technical rider: In pairs, one partner will wrap a 3-metre rubber band around his/her partner's waist and stand behind him/her. The partner acting as the 'horse' will perform skipping in front, aided by intensive arm movement and keeping their gaze forward, until the band becomes taut. At that point, the 'rider' will begin faster skipping in front.	10 x 10 competition.	The tension generated in the calf area does not allow this gesture to be prolonged for more than a few minutes.	Joint mobility + game (crazy relays).	Within 5 m (mark with cones): - Start with heels to buttocks and trunk forward. - Take the minimum number of strides. - Changes of direction between cones.	Stretching and reflection.
5	Relays - Technical action 1: Recipient: waits with one leg forward and one leg back, runs at full speed as his/her partner passes by the signal and extends his/her arm on hearing his/her signal. - Technical Action 2: Wearer: Gives the "go" signal at a distance of 2.5 meters. - Technical Action 3: Exchange: Up-down and down-up motions.	Who is responsible for the exchange in the 4 x 100 and 4 x 400 race? Why?	Free delivery. Light jogging around the area (semicircle). Those who carry the baton must pass it to a teammate without a baton in less than 10".	Relay race without obstacles and with a low hurdle.	In the 4 x 400 race, the recipient, due to accumulated wearer fatigue.	Joint mobility + game (the 4 corners).	Baton relay: A participant moves to the end of the line and hands the baton to a teammate from behind.	Stretching and reflection.

Statistical Analysis

The IBM SPSS 28.0 statistical programme was used for the analysis of the variables. Descriptive statistics were obtained for all the dimensions under study and internal consistency was assessed with Cronbach's alpha coefficient. The vast majority of the coefficients exceeded the reliability values of .70 that are considered acceptable for psychological scales, and a few were around .60, also considered acceptable according to Hu and Bentler (1999). To determine the effect of implementation, a repeated-measures multivariate analysis (MANOVA) was carried out on the different variables according to time (pre-post) and group (TM vs. LTM). In addition, gender was taken into account as a variable that could influence participants' responses. A significance level of $p < .05$ was established.

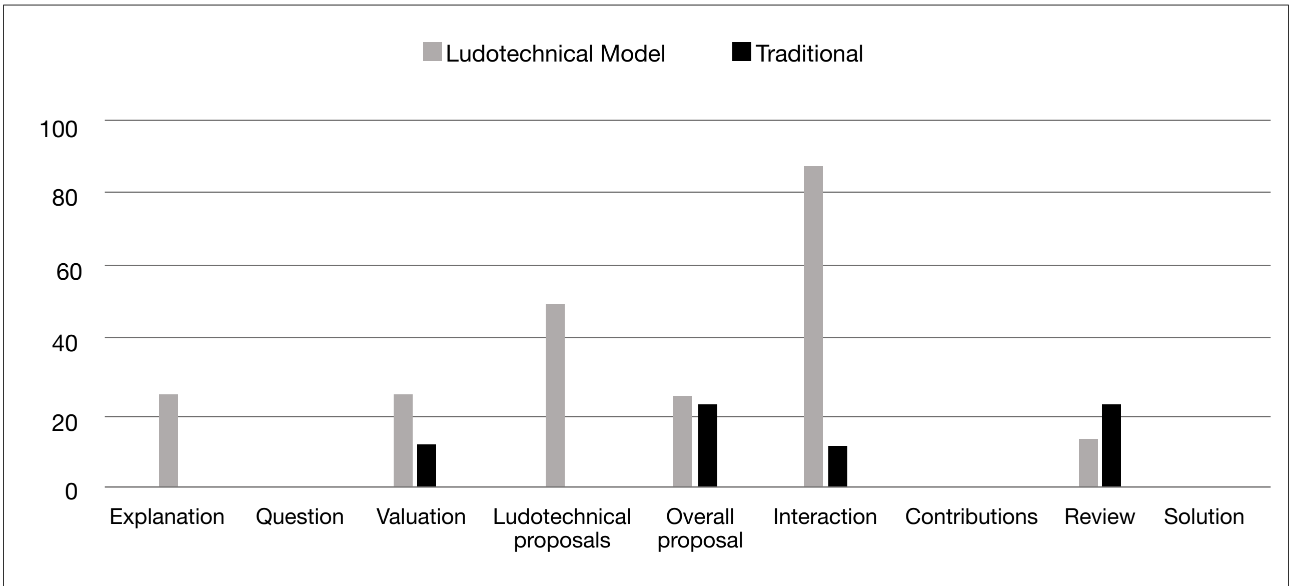
The analysis of the qualitative data was carried out following the stages of thematic analysis proposed by Braun and Clarke (2006), a process that allowed the researchers to explore participants' perceptions of the intervention programme in greater depth. The process was led by the second author and supervised by the fourth one. Before starting the analysis, the interviews, which had previously been audio-recorded, were transcribed verbatim. The analysis process began with the second author immersing himself in the data, reading and re-reading the interview transcripts. This initial familiarisation step allowed the researchers to identify recurring patterns and relevant aspects in the answers. Subsequently, in the initial coding phase, the second author highlighted segments of text that represented key aspects related to the participants' experience. Codes such as "perceived fun", "phased learning" and "motivation" were identified and served as a basis for the creation of broader themes. In the next phase, the search for themes began, grouping the codes into thematic categories that captured the shared experiences of the participants. Emerging themes were reviewed for internal consistency and refined to ensure that they accurately reflected student and teacher perceptions. Finally, these themes were defined and named in an interpretative and reflexive way, seeking an authentic and meaningful representation of the qualitative data, and clear connections were made to the quantitative results of the study.

Results

Fidelity of implementation results

The frequency of occurrence of each item, differentiated by model (LTM vs. TM), is presented in Figure 1. Throughout the 9 items that make up the checklist, the frequencies observed were always higher for the LTM session, except for the item "the technical aspects learnt have been reviewed" (12.5% vs. 22.2%) in favour of the TM. Another item with a very similar score was "At least one overall proposal has been made" (25% for LTM vs. 22.2% for TM). In addition, the lack of frequency of occurrence of the item question, input and solution stands out with 0% in both the ludotechnical and traditional groups.

Figure 1
Frequency of the different strategies specific to the ludotechnical model applied in the traditional and ludotechnical group.



Quantitative results of the inferential analysis

The results show that there are significant differences in the intraparticipant time factor (Wilks' lambda = 0.45, F [7.32] = 8, *p* = .001) and in the interparticipant gender factor (Wilks' lambda = 0.55, F [4.83] = 8, p = .001). These results were then analysed at the univariate level to see which variables showed significant differences. As for the time factor, the 10 x 10 m race (F = 29.499, *p* = .001), the javelin throw (F = 13.364, *p* = .001) and the lateral jumping (F = 5.048, p = .001) were the ones with significant differences. With respect to the time-group interaction, significant differences were only found for the lateral jumping (F = 6.754, *p* = .012).

Table 2 shows the means and standard deviations of the differences between the pre- and posttest, according to group and gender. Also included are the values of *p* values obtained by comparing these estimated means (using the Bonferroni correction). Focusing on the significant differences at the gender level, in boys, the group that received LTM obtained better values at the end of the intervention in the javelin throw (*p* = .027) and in the 10 x 10 m test (*p* = .005), and worse in the lateral jumping (*p* = .007). In contrast, the girls' results were different, with more physical variables showing significant differences (race, throw and triple jump) in the TM group compared to the LTM group, where there were only significant improvements in the race (*p* = .019) and, again, a lower performance in the lateral jumping (*p* = .040), just as happened with the boys. While assessing the differences between groups (TM vs. LTM), in the javelin throw it was found that the boys started from different values (*p* = .025) and ended with similar values (*p* = .146), and in the SAS, after the intervention, the LTM group showed higher values compared to the TM group (*p* = .02).

Table 2
Pre- and posttest differences by gender and group.

		PRETEST		POSTTEST		Pre- and posttest differences	
		Boys	Girls	Boys	Girls	Boys	Girls
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Value of *p*	Value of *p*
10 x 10 (s)	Control	31.86 (3.08)	34.43 (2.86)	31.34 (2.98)	33.33 (3.26)	.097	**.001*** **
	Experimental	32.25 (3.13)	33.78 (3.98)	31.44 (3.12)	33.07 (3.89)	**.005** **	**.019***
	Value of *p*	.752	.595	.940	.832		
Javelin throw (m)	Control	11.54 (2.76)	6.88 (2.01)	1.79 (2.14)	8.18 (2.73)	.622	**.007** **
	Experimental	9.22 (3.65)	6.94 (1.83)	10.27 (3.44)	7.87 (2.37)	**.027***	.065
	Value of *p*	**.025***	.950	.146	.760		
Triple jump (m)	Control	4.31 (0.46)	3.85 (0.88)	4.40 (0.57)	4.10 (0.69)	.485	**.017***
	Experimental	4.15 (0.74)	3.71 (0.54)	4.10 (0.90)	3.70 (0.72)	.587	.910
	Value of *p*	.537	.587	.296	.150		
Medicine ball throw (m)	Control	5.18 (1.46)	4.00 (0.86)	5.63 (1.56)	4.20 (0.83)	.164	.503
	Experimental	5.36 (1.18)	4.21 (1.28)	4.96 (1.28)	4.13 (1.36)	.170	.792
	Value of *p*	.681	.643	.166	.878		
Lateral jumping (rep.)	Control	28.15 (9.15)	24.44 (8.82)	27.77 (9.20)	25.31 (8.73)	.796	.514
	Experimental	24.81 (9.93)	26.57 (8.73)	21.06 (13.07)	23.57 (11.20)	**.007** **	**.040***
	Value of *p*	.334	.528	.100	.660		
SAS	Control	3.97 (0.52)	4.11 (0.77)	3.78 (0.48)	4.23 (0.47)	.249	.417
	Experimental	4.08 (0.57)	4.17 (0.52)	4.19 (0.44)	4.30 (0.45)	.463	.409
	Value of *p*	.622	.806	**.020***	.697		
IPA	Control	4.15 (0.69)	4.24 (0.58)	4.18 (0.77)	4.11 (0.60)	.882	.503
	Experimental	4.34 (0.70)	4.01 (0.75)	4.46 (0.60)	4.30 (0.50)	.503	.155
	Value of *p*	.473	.374	.234	.411		
Fun	Control	4.13 (0.68)	3.83 (0.67)	4.10 (0.73)	4.10 (0.71)	.857	.170
	Experimental	4.20 (0.67)	3.95 (0.79)	4.24 (0.56)	4.20 (0.84)	.839	.243
	Value of *p*	.796	.645	.585	.717		

Note: rep. = repetitions; m = metres; SAS = interpersonal style of autonomy support; IPA = intention to be physically active
*p < .05; **p < .01; ***p < .001

Qualitative results of the thematic analysis

From the thematic analysis, 5 themes were developed that provide an in-depth interpretation of participants' experiences throughout the intervention: (1) play as a driver of motivation and fun; (2) fragmented versus meaningful learning; (3) the paradox of perceived learning and physical performance; (4) the classroom as a space of connection; and (5) perceived weaknesses and the roads ahead.

Play as a driving force for motivation and fun. This theme explores how the LTM sessions generated enthusiasm among the students. The answers reflected that LTM activities were perceived as more engaging, dynamic and motivating than TM ones. One LTM student described the sessions as "a lot of fun", while another TM student said that "at times they were boring while waiting in line". This is evidence that the play component of the LTM not only kept the students physically active, but also captured their interest and desire to participate. In turn, the teacher corroborated this perception, stating that the LTM exercises "were more dynamic" and that "the students were more motivated" with this model because "they enjoyed it a lot more".

Fragmented versus meaningful learning. This theme highlights how LTM promoted deeper and more structured learning by breaking down athletic techniques into specific phases to enable students to better understand each of the components of athletic movement. The LTM students stated that they had learned the technique "in phases", suggesting that this methodology helped to consolidate technical knowledge in a more effective and meaningful way. In contrast, TM students did not recall learning the phases of the technique, reflecting that the repetitive and analytical approach of this methodology may have limited learning retention. The students' responses were in line with the perception of the teacher, who stated that "those who have worked with the traditional method will have to start all over again", referring to the fact that this methodology does not generate significant learning. The difference between the approaches led the teacher to perceive greater strengths in LTM, highlighting that it is "very appropriate for working on the technique in the world of education because it adapts much more to the characteristics of the students and humanises the learning of the technique, which has usually been worked on using traditional methodologies and analytical strategies".

The paradox of perceived learning and physical performance. This theme addresses the difference between perceptions of improvement and actual performance results. Although the LTM students enjoyed the sessions more and perceived significant learning, the differences in the physical test results were not as evident. This creates a paradox, as the feeling of improvement (perceived satisfaction) does not always translate into higher performance in physical tests (measurable results). The teacher mentioned that, although the LTM was more motivating, "I don't know which ones have actually improved a lot". While there were improvements in both groups, performance in physical tests was comparable between the two, raising the question of whether a more playful methodology can balance, or even overcome, traditional approaches when it comes to physical improvement and technical teaching.

The classroom as a space for connection. This theme refers to how the classroom climate was transformed into a more positive and collaborative space in the group that followed the LTM. The teacher mentioned: "I think the classroom climate is more positive", suggesting that the play methodology not only benefited individual performance, but also interpersonal relationships between students. By placing the student at the heart of the learning process, LTM promotes an environment where students felt more comfortable and connected, which contrasted with the more controlled and rigid environment of TM. The classroom climate facilitated by LTM contributed to the teacher feeling more comfortable with this approach: "I feel more comfortable with the ludotechnical model, which is more related to humanising..."

Perceived weaknesses and roads ahead. This theme addresses the weaknesses and difficulties that emerged during the intervention, as well as the roads ahead for future research to improve study design and development. The teacher identified that time constraints could significantly affect the potential impact of LTM on students. He explicitly mentioned that "five sessions may not have been enough to bring about significant changes". This reflection highlights one of the main limitations of the study, namely the brevity of the intervention. Although students showed increased enjoyment and motivation during the LTM sessions, the time spent on each test and phase was too short to produce profound and lasting effects. The teacher himself pointed out: "We would have needed perhaps two or three sessions for each of the tests". This observation suggests that a longer duration would have allowed the different stages of technical learning to be worked through in more detail, thus allowing for greater consolidation of knowledge.

Another challenge identified was the lack of continuous feedback during the application of the LTM. The teacher expressed that it would have been useful to receive external support: "Having feedback would have been interesting in order to improve". This lack of feedback prevented adjustments in real time, which would have optimised the implementation of the sessions and improved the adaptation of the activities to the level of the students. The introduction of a rigorous observation process by experts, with continuous feedback on the implementation of the LTM, would have made it possible to adapt the methodology according to the needs and responses of the students, as well as to avoid some of the difficulties experienced. Another issue that emerged as a difficulty was the lack of coordination and time in the design of the study. According to the teacher, the planning of the LTM was rushed, resulting in sessions that did not always meet pedagogical expectations. Some activities were not aligned with the technical objectives of the tests and, in some cases, were received by the teacher "the afternoon or evening before being put into practice". This may have affected not only the quality of the sessions, but also the teacher's confidence in applying the methodology, as he himself pointed out: "I did not feel completely at ease". This lack of preparedness may have affected the ability to maximise the potential of the LTM.

Discussion

This study examined the effects of LTM versus TM on the athletic performance of both male and female students in various sporting events. The results indicate that, while the LTM participants showed improvements in their performance in the specific 10 x 10 m test, this improvement was parallel to that observed in the TM group, where significant gains were only recorded among the males in the same test. In the javelin test, improvements were seen in the girls under TM, and in the LTM it was the boys who showed progress. However, only in the TM and the triple jump were improvements reported exclusively for girls. These observations suggest that both methodologies have comparable effectiveness in terms of physical performance, which corroborates findings from previous studies (Valero-Valenzuela et al., 2005, 2012).

In addition, a positive impact of LTM on the teacher's interpersonal style of autonomy support was detected, particularly in boys. This finding is consistent with the cross-sectional study carried out by Valero-Valenzuela et al. (2019), which analysed the profiles of more than 250 young people practising athletics in terms of their level of motivation. In this study, it was observed that those with a higher self-determined motivation perceived a more autonomy-supportive style from their coach and had a higher intention to continue playing athletics. The study by Abraldes et al. (2013) indicated that it was men who showed higher levels of autonomy support, because fun was the variable that best predicted the task orientation of male lifesavers.

In relation to the improvement of fun, although the questionnaires have not reported improvements, the statements made by both teacher and students do show indications of increased satisfaction through the use of the LTM. These results are consistent with previous research that showed benefits of LTM on the satisfaction of primary school students who were learning different athletic disciplines (Valero-Valenzuela et al., 2009).

The intention to be physically active did not vary between students in the two groups. It is striking that, despite the association between autonomy-supportive style and intentions to be physically active (Valero-Valenzuela et al., 2019), this association was not found in this study. This could be attributed, in part, to the limited number of sessions conducted (only 5), in contrast to other studies that reported increases in intention to be physically active (Merino-Barrero et al., 2020). In addition, the partial implementation of LTM strategies, as evidenced by the non-application of some of them (e.g. question, input and solution) and the similar application of strategies in both groups (e.g. overall proposals and review), may have contributed to the absence of differences. Previous research has discussed various ways of applying the pedagogical models (Curtner-Smith et al., 2008), and the "watered-down" version of the model may be one of the reasons for the partial results obtained in terms of fun and intention to be physically active. The lack of ongoing training to complement initial training possibly prevented teachers from identifying and effectively applying LTM strategies in their teaching practice (Lee & Choi, 2015).

In relation to the second objective, qualitative results reveal the impact of LTM on students' motivation and perceived fun. However, the quantitative results related to the variable of fun and intention to practice in the future failed to capture this perceived difference. This discrepancy may be due to several factors such as the short duration of the intervention, which may have been insufficient for the observed psychosocial improvements to be consolidated into measurable outcomes through questionnaires (Rubio-Castillo & Gómez-Mármol, 2016). In addition, the questionnaires may not have accurately captured the immediate and dynamic experiences that the students experienced during the sessions. These findings underline the importance of using measurement tools that can more sensitively capture the subjective experience of students (Bautista, 2022), especially in short-term interventions.

The dissonance between immediate subjective experience and measurable outcomes was also present in other variables such as perceived technical learning and athletic performance outcomes, as although students reported a greater acquisition of knowledge of athletic technique, this did not translate into superior performance in the physical tests. These findings suggest that LTM enhances technical learning and does not compromise physical performance against TM. Despite this, it is necessary to take into account factors that may have influenced the results, such as the short intervention period, which may have influenced the development of physical skills and abilities that play a key role in physical test performance (Valero-Valenzuela et al., 2012). These findings also have important implications, as they show that it is possible to acquire greater technical knowledge and balance physical performance with a more playful and motivating approach, a combination that could be particularly valuable for teaching sports at an early age, when fun and enjoyment are key to sport adherence. In the absence of previous studies in athletics, other works such as sailing and team sports indicate greater knowledge when active methodologies such as comprehensive sport teaching were used (Hortigüela Alcalá & Hernando Garijo, 2017; Morales-Belando & Arias-Estero, 2017). Research in physical education didactics suggests that pedagogical models, such as LTM, can promote deeper and more meaningful learning (Valero-Valenzuela et al., 2012), but this type of learning may not always translate immediately into measurable improvements in physical tests.

Another qualitative highlight was the transformation of the classroom climate into a space for connection and interaction. This finding suggests that LTM not only has an impact on technical learning or motivation, but also positively affects interpersonal relationships and group dynamics. Although this variable was not measured quantitatively, participants' perceptions suggest that LTM contributes to a more humanised learning environment, facilitating collaboration and reducing the individualistic competition characteristic of more traditional pedagogical approaches. This observation is consistent with the findings of Valero-Valenzuela et al. (2009), whose teachers perceived LTM as creating a better classroom climate. By adopting a more humanised and student-centred approach, LTM appears to have the potential to foster a more positive and collaborative environment. This positive climate could be a precursor to improvements in other psychosocial variables (Manzano-Sánchez et al., 2021) which, over time, could have shown significant differences in terms of motivation or intention to continue with sport practice. The student-centred approach and the collaborative environment promoted by LTM were determining factors for the teacher to show a greater preference for this pedagogical model for the technical teaching of athletics. However, the teacher also expressed weaknesses throughout the intervention, such as the need for more pedagogical support during LTM implementation to increase their confidence in applying the model, which links to Hastie and Casey's (2014) recommendations and the need for ongoing training (Lee & Choi, 2015).

As for the limitations of the study, it is important to highlight the importance of implementing the pedagogical models over a longer period of time in order to obtain the expected results with the use of these methodologies. Furthermore, the absence of feedback to improve the loyalty rate in the implementation of the LTM may have led to a watered-down or *à la carte* use of the model's strategies. Another limitation might be that the same teacher implemented the two methodologies in different groups, which could have sometimes led to interference between one methodology and the other, making it difficult at times to distinguish which type of tasks to apply with one group of students and not with the other. Important strategies such as the challenge question, the evaluation of the session and the solution to the challenge question were not carried out in the session analysed with the LTM. Other interesting variables to assess in future studies would be motivation, satisfaction of basic psychological needs or classroom climate. Although certain opinions have been collected about these concepts in the teacher and student interviews, they could be measured by means of validated questionnaires.

Conclusion

The study revealed that LTM induced beneficial effects on students' perceptions, especially in boys, of the teacher's interpersonal style of autonomy support in primary school athletics teaching. This methodology is comparable to TM in terms of athletic performance improvements, and also promotes increased student motivation, a more positive classroom environment and greater enjoyment of the activities. Despite these benefits, confirmation of these results is beyond the scope of this study, possibly due to the comparable effectiveness of both methodologies or the need for a larger number of sessions for changes to be detectable through the self-assessment instruments used. In light of these findings, it is suggested that physical educators consider the use of playful pedagogical strategies such as LTM for teaching individual sports such as athletics, given its ability to foster a motivational style of teaching that supports student autonomy and its potential positive effects on motivation and intention to continue sport practice in the future.

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Passing behaviour patterns in UEFA Champions League finals (2018-2022)

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Laura Kluge fighting for the puck in the match between Germany and Hungary during the Eishockey Deutschland Cup, in Landshut, Germany, on November 9, 2024
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Abstract

The aim of this study was to analyse the behavioural patterns of passes made in UEFA Champions League finals played between 2018 and 2022, and to identify the situational (field position, opponent pressure) and behavioural (passing technique, decision making) factors associated with successful passes. Successful passes are those that result in the loss of possession by the opponent, or culminate in a goal or a shot. The study was carried out on a one-off, nomothetic and multidimensional basis: it was based on the observation of a specific moment without continuous time tracking, the comparison of behaviours of seven teams, and the analysis of various levels of response with an observation instrument. To this end, an observation instrument was constructed and validated through expert review, pilot testing, and reliability and validity analysis, therefore ensuring accuracy in coding. The participants of the study were professional teams playing in the UEFA Champions League finals. In total, 4,658 passes were recorded and coded. Preliminary results indicate that passes from the offensive zone (third quarter into the opponent's half) are more likely to lead to a goal or a shot, while passes from a greater distance are associated with a loss of possession. These findings suggest that timing, location on the field and passing distance are key factors in the success or failure of plays.

Keywords: observational methodology, playing time, polar coordinates, score, zones of the field.

Introduction

Research into team sports has become increasingly important from physical, technical and tactical perspectives. This has enabled teams to make informed decisions in different situations, backed by scientific evidence (Rennie et al., 2018; Young et al., 2019). In this sense, it has become increasingly important in recent years to validate instruments that allow the assessment of competence in professional football, using data providers such as WyScout (Sánchez-López et al., 2023). Furthermore, possession transitions has been studied to better understand the probability of success in specific plays (Castellano-Paulis et al., 2009).

Observational methodology has been essential to this advancement, especially in the evaluation of behaviours in invasive team sports. Specifically in the field of football, studies have addressed technical-tactical actions, the evolution of goals in world competitions and ball circulation in various categories (Gréhaigne et al., 2010; Iván-Baragaño et al., 2022 Mićović et al., 2022; Muriarte Solana et al., 2023; Ortega-Toro, 2019). These approaches have provided valuable information on game development, effectiveness in offensive phases and optimisation of game strategies.

Observational methodology, in addition to being widely used, has paved the way for the implementation of various data analysis techniques in the study of team sports (Barreira et al., 2020). Among these techniques, polar coordinates (PC) have been fundamental, as they allow the estimation of relationships between a specific behaviour and other observed behaviours. Pedagogical proposals and the evaluation of performance indicators have been utilised in the analysis of offensive play (Flores-Rodríguez, 2020; Maneiro et al., 2018).

In the specific context of football, passing network analysis has been a valuable resource for defining team characteristics and explaining team success on the field (Buldú et al., 2019; Castañer et al., 2016; Maneiro et al., 2018; Zeng & Zhang, 2022). These studies have provided parameters such as the offensive behaviour index and the game control index, crucial for detecting the degree of a team's control over the opponent.

In addition to the overall analysis, the importance of examining the effectiveness of possession units has been noted. These segments of play, defined by ball control, are crucial to analysing the quality, effectiveness and distribution of possession. Factors such as total number of passes, passing accuracy and other aspects have been shown to be closely related to the success of these units (Collet, 2012; Hewitt et al., 2016; Zeng & Zhang, 2022). These studies have provided valuable information on the relationship between different parameters and success in the game.

In relation to passing and scoring, the relationship between the number of passes and scoring success has been found to present some contradictions. For example, while it is suggested that fewer passes per action increases the probability of scoring a goal, it has been observed that 80% of possession units that end in a goal involve more than three passes (Aguado-Méndez et al., 2020; Alves et al., 2023; Taha & Ali, 2023). These discrepancies emphasise the importance of defining the type of attack and the role of counter-attacking actions in the context of the game (Chmura et al., 2021).

The incidence of passing errors is a key element to consider, given that the majority of possession units do not result in goals. It has been observed that short passes can reduce losses and thus improve the chances of successful play (Chmura et al., 2021).

On the other hand, analysis of ball recovery zones has revealed that recovering the ball close to the opponent's goal is associated with an increase in the probability of scoring. Furthermore, counter-attacks generated in the central channel have shown a correlation with successful play (Mendes & Morante, 2011). These findings underline the relevance of recovery strategies and their impact on the development of play.

Finally, it is essential to consider the influence of situational variables on the performance and behaviour of players. Elements such as the location of the match, the level of the opponent and the match status have been shown to have both physical and tactical effects (Mackenzie & Cushion, 2013; Taylor et al., 2008). These variables have been shown to influence aspects such as time of possession, type of pass and possession success rate, and have varied significantly between the first and second halves of matches (Maneiro et al., 2021).

Based on the current state of the evidence, the aim of this research was to analyse the passing behaviour patterns in the UEFA Champions League finals played between 2018 and 2022. Specifically, passes that ended in a shot and passes that ended in loss of ball possession were studied according to time of play, score, type of pass made and zones of the field where the passes were made and received.

Method

Materials

For this research, an *ad hoc* observation instrument was designed to record relevant behaviours in relation to the objective of the study. The construction and validation of the instrument was carried out in three main phases: initial design based on the literature, pilot testing and adjustment through expert judgement. The observer training process and the reliability and validity analyses were prescriptive to ensure the accuracy and utility of the instrument.

Observational design

The research was conducted using a one-off, nomothetic and multidimensional observational design (Anguera & Hernández-Mendo, 2013). One-off, because the matches observed correspond to specific moments without continuous time tracking; nomothetic, because different units of analysis were compared—in this case, the behaviours of seven different teams; and multidimensional, because several levels of response, collected through the observation instrument, were studied.

Participants

Data were collected from five different UEFA Champions League finals (Table 1), all played on neutral ground, between 2018 and 2022. In total, seven different teams from three different European leagues were analysed.

In accordance with the Belmont Report (1978), it was not necessary to obtain informed consent or review by the relevant ethics committee because: (a) the study involved the observation of individuals in a public setting (football stadium); (b) the teams observed had no expectation of privacy as the matches were broadcast worldwide; and (c) the study did not involve direct intervention or interaction of the researchers with the athletes studied.

The units of observation were all passes made by the different teams with the exception of those made by resuming the game (for example, goal kicks, free kicks, fouls, corners, throw-ins, etc.).

Instruments

An *ad hoc* observation instrument was designed to record relevant behaviours in relation to the research objective. The construction of the observation instrument consisted of three phases, based on the work of Aguado-Méndez et al. (2020).

First phase. Two doctors in Physical Activity and Sport Sciences, with previous experience in observational studies, designed an initial version based on the available literature. In this first stage, we opted for a combination of the field format of Aguado-Méndez et al. (2020) with a system of categories. The playing field format was divided into a grid of 24 rectangular zones, organised into four rows and six columns, labelled with the prefix "Zone" followed by a number from 1 to 24. The field grid numbering started in the upper left corner of the field with "Zone 1" and proceeded from left to right and from top to bottom, ending in the lower right corner with "Zone 24". Zones 1 to 12 were configured as the home camp, while zones 13 to 24 belonged to the opposing camp. This combination made it possible to take advantage of both the flexibility of the field format and the theoretical consistency of the category system (Anguera & Hernández-Mendo, 2013).

Second phase. The instrument was subjected to a precautionary test (Anguera, 2003), consisting of the recording of several matches not included in the sample. The precautionary test served to modify the initial design of the research instrument by adding and deleting different criteria and categories. The test was considered as finished when, during the recording of the non-sampled matches, no behaviour was detected that could not be recorded with the research instrument.

Table 1
Finals analysed.

Year	Team 1	Team 2
2018	Real Madrid	Liverpool
2019	Tottenham	Liverpool
2020	PSG	Bayern Munich
2021	Manchester City	Chelsea
2022	Liverpool	Real Madrid

Third phase. The instrument was assessed by three experts, doctors and university lecturers in Physical Activity and Sport Sciences, who marked their agreement or disagreement with each of the categories and criteria of the instrument. Ultimately, all the criteria and categories that made up the final version of the instrument obtained a percentage of agreement of over 80%. The final instrument used for the observation is indicated in Table 2.

After the tool design was finalised, it was implemented in Microsoft Excel for recording and coding the actions; it therefore functioned as a recording instrument. Polar coordinate analysis was applied with the HOISAN 1.2 software (Hernández-Mendo et al., 2012). Prior to the calculation of polar coordinates and as a requirement, sequential delay analysis was performed using the GSEQ 5.1 software (Bakeman & Quera, 2011). Finally, after polar coordinate analysis, the significant associations were represented with the program Snowflake.

Table 2
Observation instrument.

Criterion	Category	Code	Description
Minute (MIN)	Minute 0 to 15	T01	The pass is made between minutes 0 and 15.
	Minute 16 to 30	T02	The pass is made between minutes 16 and 30.
	Minute 31 to 45	T03	The pass is made between minutes 31 and 45.
	Minute 45 to 60	T04	The pass is made between minutes 45 and 60.
	Minute 61 to 75	T05	The pass is made between minutes 60 and 75.
	Minute 76 to 90	T06	The pass is made between minutes 75 and 90.
	Extra time 1st half	ET1	The pass is made in the extra time of the first half.
	Extra time 2nd half	ET2	The pass is made in extra time of the second half.
Score (SCO)	Draw	DRA	The team is drawing at the time of the pass.
	Losing	LOS	The team is losing at the time of the pass.
	Winning	WIN	The team is winning at the time of the pass.
Attacking team (ATT)	Man. City	MAN	The pass is made by a Manchester City player.
	Chelsea	CHE	The pass is made by a Chelsea player.
	PSG	PSG	The pass is made by a PSG player.
	Bayern Munich	BAY	The pass is made by a Bayern player.
	Liverpool	LIV	The pass is made by a Liverpool player.
	Real Madrid	MAD	The pass is made by a Real Madrid player.
	Tottenham	TOT	The pass is made by a Tottenham player.
Pass initiation zone (PIZ)	Zone 1	I01	The pass starts in Zone 1.
	Zone 2	I02	The pass starts in Zone 2.
	Zone 3	I03	The pass starts in Zone 3.
	…		
	Zone 24	I24	The pass starts in Zone 24.
Pass reception zone (PRZ)	Zone 1	R01	The pass is received in Zone 1.
	Zone 2	R02	The pass is received in Zone 2.
	Zone 3	R03	The pass is received in Zone 3.
	…		
	Zone 24	R24	The pass is received in Zone 24.
Type of pass (TPM)	Short	STP	The pass does not cross any zones.
	Medium	MTP	The pass crosses one zone, but not two.
	Long	LTP	The pass crosses two or more zones.
Progresses (PRO)	Yes	PYE	The pass advances play.
	No	PNO	The pass does not advance play.
Outcome of pass (OOP)	Teammate receives	TMR	A teammate of the player who made the pass receives the ball.
	Team loses ball	TLB	The pass results in loss of possession of the ball.
	Teammate shoots	TMS	A teammate of the player who made the pass receives the ball and shoots without scoring a goal.
	Goal assist	GAS	A teammate of the player who made the pass receives the ball, shoots and scores a goal.
Pass number (PSN)	Pass No. 1	001	Pass No. 1 made by the team in the match.
	Pass No. 2	002	Pass No. 2 made by the team in the match.
	Pass No. X	00X	Pass No. X made by the team in the match.

Procedure

The nature of the research, based on observations at football matches and the analysis of existing data, did not involve manipulation of participants or direct intervention in their physical or emotional integrity, thus avoiding the need for a bioethics committee for approval.

The recording of the actions was carried out by an observer, who participated in the design of the observation instrument.To optimise the reliability of the recordings, the observer participated in a training process, which consisted of recording matches not included in the sample. The training process was concluded when values equal to or greater than .8 were obtained for Cohen's Kappa statistic at the intra-observer level, a near-perfect result (Landis & Koch, 1977). Once the training process was completed, the matches that made up the study sample were recorded.

Lastly, the results of these analyses were reviewed and the instrument was adjusted accordingly to ensure its accuracy and usefulness in measuring the desired constructs. This systematic approach ensures that the observation instrument is both reliable and valid for use in future research.

Data analysis

The observational data were analysed using the polar coordinate technique, which allows the graphical representation of the activation or inhibition relationships between the analysed behaviours. This technique has been used in the study of different team sports, such as football (Castañer et al., 2016) or handball (Flores-Rodríguez & Alvite-de-Pablo, 2023). In this analysis, one of the behaviours assumes the role of focal behaviour, since it is considered to be the generator of the relationships with the rest of the behaviours that participate in the analysis, which assume the role of conditioned behaviours.

As a prerequisite, it is necessary to perform the sequential analysis of positive lags, which will inform about the prospective perspective, and of negative lags, to learn about the retrospective perspective (Sackett, 1980). Once the sequential analysis has been performed, the Zsum statistic performs the integration of the two, and values are obtained that can have a positive or negative sign. The results were represented in one of four possible quadrants, depending on the combination of signs obtained in each Zsum.

As established in previous research (*e.g.*, Anguera et al., 2011; Camerino et al., 2019), the graphical combination allows us to explain how to interpret the associations between the focal behaviour, located in the centre of the figure, and the conditioning behaviours in each quadrant. The association is shown both quantitatively (vector length) and qualitatively in quadrants I, II, III or IV. If the relationship is located in quadrant I, it indicates a mutual activation relationship between the focal behaviour and the conditioned behaviour. Conversely, when the representation is in quadrant III, it indicates the existence of a mutually inhibiting relationship between the focal behaviour and the conditioned behaviour. The representation in quadrant II indicates that the conditioned behaviour triggers the occurrence of the focal behaviour while being inhibited by it. Lastly, placement in quadrant IV indicates that the focal behaviour inhibits the conditioned behaviour while being activated by it.

By presenting the analysis described above, the aim was to analyse the behavioural patterns of passes made in UEFA Champions League finals played between 2018 and 2022, identifying the situational (field position, opponent pressure) and behavioural (passing technique, decision making) factors associated with successful passes.

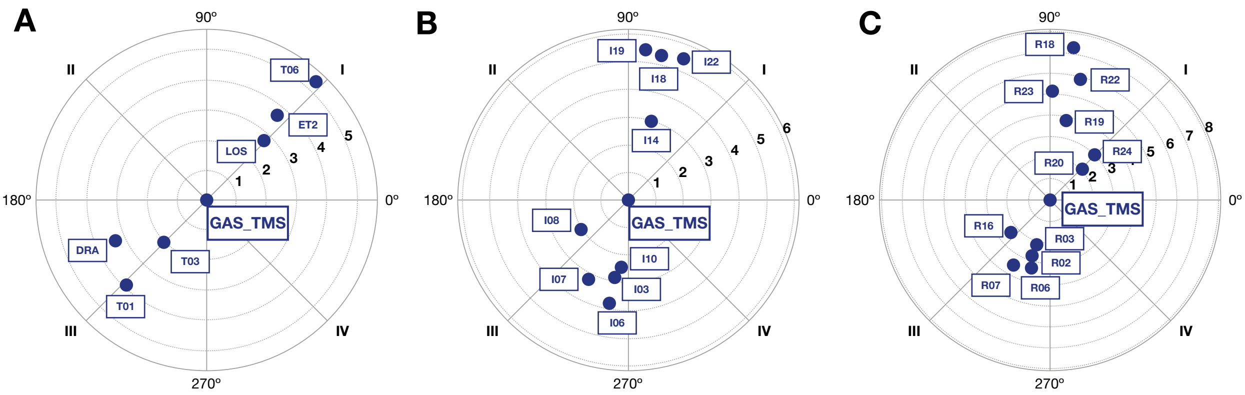
Results

Significant associations are represented below: those with a radius greater than 1.96 ($p < .05$), identified between the focal behaviour and the conditioned behaviours located in quadrants I and III. Placement in quadrant I indicates a mutually activating relationship, while representation in quadrant III expresses mutual inhibition. To facilitate the understanding of the results, they are presented in two subsections: in the first one, the passes that preceded a shot as focal behaviour; and in the second one, the role of focal behaviour is assumed by the passes that ended in a loss of ball possession.

Passes preceding a shot

To understand the behavioural patterns related to passes that preceded a shot, the combination of the categories GAS (passes made just before a shot that ended in a goal) and TMS (passes made just before a shot that did not end in a goal) was used as the focal behaviour. In Figure 1 (Graphs A, B and C), the categories belonging to the criteria of minute (MIN), score (SCO), and type of pass (TPM) assumed the role of conditioned behaviours in Graph A. On the other hand, in Graph B the conditioned behaviours were the categories of the criterion of pass initiation zone (PIZ); and in Graph C, the categories of the criterion of pass reception zone (PRZ) were considered as conditioned behaviours.

Figure 1
Passes that preceded shots per time in the match, score and type of pass made (A), the zone of the field in which they were made (B), and the zone of the field in which they were received (C)

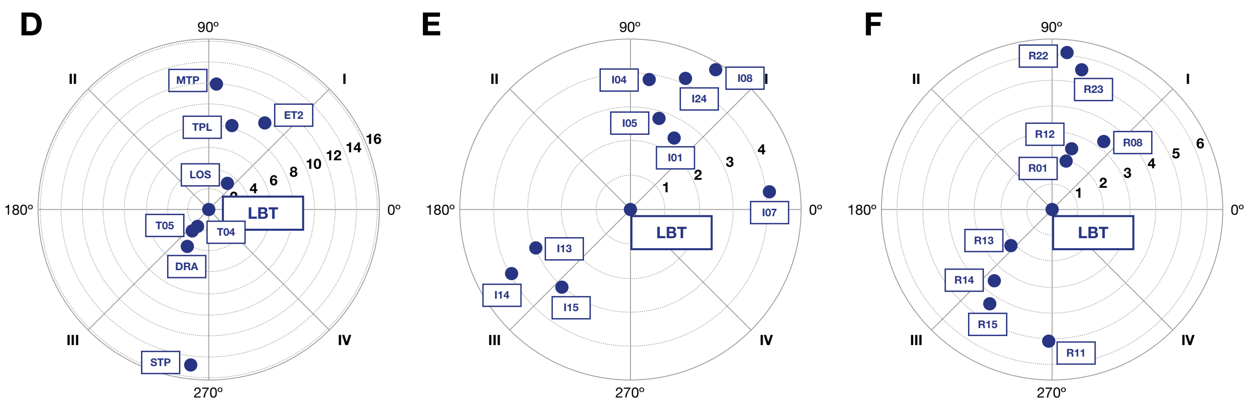


	Criterion	Category	Radius	Angle	Quadrant
GRAPH A	Time in the match	T01	3.92	226.94	III
		T03	2.03	225.33	III
		T06	5.42	47.79	I
		ET2	3.71	50.77	I
	Score	DRA	3.28	204.52	III
		LOS	2.77	46.61	I
GRAPH B	Pass initiation zone	I03	2.81	260.13	III
		I06	3.76	259.75	III
		I07	3.17	243.07	III
		I08	1.98	213.40	III
		I10	2.41	265.62	III
		I14	2.96	74.04	I
		I18	5.32	77.01	I
		I19	5.43	82.87	I
		I22	5.43	68.66	I
GRAPH C	Pass reception zone	R02	2.74	252.13	III
		R03	2.20	253.75	III
		R06	3.33	254.92	III
		R07	3.52	240.43	III
		R16	2.40	219.48	III
		R18	7.37	80.89	I
		R19	3.90	**78.21**	I
		R20	2.17	45.00	I
		R22	5.98	76.01	I
		R23	5.23	88.75	I
		R24	3.08	45.54	I

NB. Time of pass: T01 = Minute 0 to 15; T03 = Minute 31 to 45; T06 = Minute 75 to 90; ET2 = Extra time of second half; Team situation: DRA = Drawing; LOS = Losing; Pass initiation zones: I03; I06; I07; I08; I10; I14; I18; I19; I22; Pass reception zones: R02; R03; R06; R07; R16; R18; R19; R20; R22; R23; R24.

Figure 2

Passes that ended in loss of the ball according to the time period in the match, the score and the type of pass made (D), the zone of the field in which they were made (E), and the zone of the field in which they were received (F)



	Criterion	Category	Radius	Angle	Quadrant
GRAPH D	Time in the match	T04	2.04	235.10	III
		T05	2.55	230.91	III
		ET2	9.80	58.10	I
		DRA	4.09	238.44	III
	Score	LOS	3.06	55.00	I
		STP	15.02	263.27	III
	Pass type	MTP	12.11	86.56	I
		LTP	8.48	75.54	I
		LOS	2.77	46.61	I
GRAPH E	Pass initiation zone	I13	3.01	202.40	III
		I14	3.98	208.43	III
		I15	3.05	228.26	III
		I01	2.42	58.64	I
		I04	3.83	82.04	I
		I05	2.78	73.03	I
		I07	4.08	7.01	I
		I08	4.74	58.60	I
		I24	4.13	67.42	I
GRAPH F	Pass reception zone	R11	5.04	268.33	III
		R13	2.09	221.05	III
		R14	3.52	230.03	III
		R15	4.33	236.15	III
		R01	1.98	74.59	I
		R08	3.31	53.29	I
		R12	2.48	**72.19**	I
		R22	6.11	84.52	I
		R23	5.54	78.05	I

NB. Time of pass: T04 = Minute 45 to 60; T05 = Minute 60 to 75; ET2 = Extra time of second half; Team situation: DRA = Drawing; LOS = Losing; Pass Trajectory: STP = No zone crossed; MTP = One zone crossed-; LTP = Two or more zones crossed; Pass initiation zones: I01; I04; I05; I07; I08; I13; I14; I15; I24; Pass reception zones: R01; R08; R11; R12; R13; R14; R15; R22; R23.

With regard to the minute criterion (MIN), it can be observed that the passes that preceded the shots presented a mutual activation relationship with the period T06, the period of play between the 75th and 90th minute, and with the period ET2, extra time in the second half. On the other hand, there is a relationship of mutual inhibition with the passes made between minutes zero and 15 (T01) and with those made between minutes 31 and 45 (T03). In relation to the behaviours belonging to the criterion of match score (SCO), a relationship of mutual activation can be seen with the LOS behaviour (the team that makes the pass is losing), and a relationship of mutual inhibition with the DRA behaviour (the team that makes the pass is drawing). Finally, no significant relationships were found between passes that preceded a shot and behaviours corresponding to the type of pass made (TPM).

In turn, the significant associations found between passes that preceded a shot and behaviours related to the pass initiation zone (PIZ) are depicted. A mutual activation relationship was found with field zones I14, I18, I19 and I22, and a mutual inhibition relationship with the following zones: I03, I06, I07, I08 and I10.

Significant relationships between passes that preceded a shot and the pass reception zone (PRZ) have also been reflected. Mutual activation relationships with zones R18, R19, R20, R22, R23 and R24 stand out. In contrast, mutual inhibition was found within zones R02, R03, R06 and R07.

Passing that resulted in loss of possession

The LBT category was used as the focal behaviour to identify behavioural patterns related to passes that ended in a loss of ball possession. In Figure 2 (Graphs D, E and F), the conditioned behaviours in Graph D were those belonging to the criteria of minute (MIN), score (SCO), and type of pass (TPM). In Graph E, the categories of the criterion of pass initiation zone (PIZ) assumed the role of conditioned behaviours. In Graph F, those categories corresponding to the criterion of pass reception zone (PRZ) were considered as conditioned behaviours.

In relation to the time criterion, it can be seen that the passes that preceded shots presented a mutual activation relationship with the ET2 period (extra time in the second half). A mutual inhibition relationship can also be observed with passes made between the 45th and 50th minute (T04) and those made between the 60th and 75th minute (T05). With respect to the behaviours belonging to the criterion of score (SCO), the results indicate a mutual activation relationship with the LOS behaviour (the passing team is losing), and a mutual inhibition relationship with the DRA behaviour (the passing team is drawing). Lastly, regarding the type of pass made (TPM), mutual activation was found with MTP (the pass crosses only one zone) and LTP (the pass crosses more than one zone), and a mutual inhibition relationship with STP (the pass does not cross any zone).

Similarly, the significant associations found between the focal and the conditioned behaviours belonging to the criterion PIZ (the pass initiation zone), are shown. Mutual activation was found with I01, I04, I05, I07, I08, I24, and mutual inhibition with the following: I13, I14 and I15.

In turn, the relationships found with the behaviours corresponding to the criterion PRZ (the pass reception zone), are represented. In relation to the following categories, a relationship of mutual activation was observed: R01, R08, R12, R22 and R23.

Discussion

The aim of this research was to analyse the passing behaviour patterns in the UEFA Champions League finals played between 2018 and 2022. Specifically, passes that ended in shots and passes that ended in loss of possession were studied according to time of play, score, type of pass made, and the zones of the field where the passes were made and received. After analysis of the data collected through the polar coordinate technique, each of the variables was arranged in one of the four quadrants of the polar coordinate map, which allowed us to describe the relationship of the variable with the focal behaviour.

As for the study of passes ending in shots, the focal behaviours TMS and GAS were analysed by collecting both behaviours where a shot occurred. In this respect, in terms of the "Minute" dimension, our results show a relationship of activation of these behaviours with ET2 and T06, marking a tendency towards the appearance of shots in the last minutes of the match. This is probably related to periods in the match when the players are more physically and mentally exhausted. In contrast, in the first minutes of the match, when exhaustion should be less, there is a relationship of mutual inhibition as reflected in the data of T01 and T03. The "Result" dimension reflects a mutual activation relationship between TMS/GAS and LOS, as well as inhibition with the variable DRA, which is contrary to the findings of Maneiro et al. (2021), where the highest percentages of successful possessions were related to teams that were winning or drawing. Regarding the dimension of "Pass initiation zone", there are mutual activation relationships with variables I14, I18, I19 and I22, areas of the field where the aim is to create spaces between lines to create advantageous situations in which passes can be made to areas closer to the goal for shots to take place. These results are in line with those reported by Immler et al. (2021) in terms of the involvement of midfielders with successful possessions, who tend to participate within the reflected zones, as well as that described by Maneiro et al. (2020) on passes made in the last 30 metres by the winning teams. However, mutual inhibition relationships are established with the variables I02, I03, I06, I07 and I16, zones related to the initiation of play, which is consistent with the findings of Chmura et al. (2021) on the involvement of defenders in unsuccessful possessions, as they are zones related to the positioning of defenders. The dimension of "Pass reception zone" indicates mutual activation relationships with the variables R18, R19, R20, R22, R23 and R24; zones in the opposite field related to shots. In contrast, inhibition relationships occur with the variables R02, R03, R06, R07 and R16, areas of play initiation, as we have noted above.

As for the EPB focal behaviour, the analysis of the "Minute" dimension highlights a mutual inhibition relationship with T04 and T05, periods in the second half where teams are likely to take fewer risks in their passing as they seek to avoid losing situations that allow the opponent to create scoring opportunities. On the contrary, a mutual activation relationship is established with ET2, the final minutes where teams risk more as they seek to generate scoring opportunities, as previously reflected in the TMS and GAS analysis. The dimension "Result" points to a mutual activation relationship with LOS, reflecting the higher risk taken by losing teams. In contrast, a mutual inhibition relationship is generated with the variable DRA, probably for similar reasons to those expressed above in the results of T04 and T05. The dimension "Pass initiation zone" shows mutual activation relationships with zones I01, I04, I05, I07, I08 and I24, which correspond to the initial phase of the game and the central channel. In this area, ball losses are particularly dangerous, as they can generate counterattacks by the opposing team (Gómez et al., 2012; Mendes & Morante, 2011). Moreover, these zones are associated with the defenders, who, according to Chmura et al. (2021), are involved in unsuccessful possessions. The I24 zone is an advanced position on the field where there is usually a low density of attacking players, which makes it difficult to pass to close teammates. On the other hand, mutual inhibition relationships are observed with zones I13, I14 and I15, which are usually occupied by midfielders. These players, according to Immler et al. (2021), are frequently involved in successful possessions. The analysis of the pass reception zone variable produces mutual activation relationships of the EPB focal behaviour with R01, R08, R12, R22 and R23. These variables point to zones in the home half of the field related to the initiation of play and where error can lead to counter-attacking situations, as described above, and forward areas of the field, which in many cases involve more risky passes that make mistakes more common. In contrast, inhibition relationships occur with R11, R13, R14 and R15, which, as mentioned above, are areas related to the construction of the play and which involve the midfielders more, which Immler et al. (2021) relate to successes in possession.

Finally, the analysis of the dimension "Type of pass" reflects mutual activation with MTP and LTP, passes in which the distances are greater, which increases the probability of error and interception by the opponent. On the other hand, there is a mutual inhibition relationship with STP, reflecting how shorter distance passes allow for greater accuracy and safety, as pointed out by Chmura et al. (2021), and relates to those teams that are winning (Praça et al., 2019).

Practical recommendations

The observation instrument that was developed proved useful in analysing passing performance and the influence of the match situation on passing decisions. The findings showed an increase in passes leading to goals in the final minutes of the match and a higher incidence of ball losses at these times, suggesting that teams take more risks in search of scoring opportunities. The importance of passing in the final third of the field, close to the opponent's goal, was emphasised to generate successful shots. Although passing distance is not directly related to creating shooting situations, short passes reduce ball losses, suggesting a more conservative and accurate strategy.

With these results, specific training sessions can be designed to improve technical skills and prepare players for various game situations. These training sessions could focus on three main factors: the match situation, the passing trajectories and the areas of the field where passes are initiated and received. Integrating these elements into task design can be beneficial. For example, game situations of reduced play in specific zones of the field could provide opportunities for these three conditioning factors to be worked on. In these situations, exercises in a reduced space can improve the precision of short passes, even in situations with high player density. Moreover, if these are set up with different spatial dimensions and in different zones of the field, they are likely to improve the ability to defend and attack effectively in those areas of play. Lastly, incorporating hypothetical scenarios in which the team is drawing or losing allows for practice under pressure and the development of quick and effective decision-making. Here, mental preparation is crucial to handle pressure and keep calm in critical moments, with the use of short passes being particularly beneficial, as they provide greater security.

Overall, the integration of these specific approaches could not only improve players' technical skills, but also develop their ability to cope with tactical and emotional challenges during a match, which may contribute to stronger and more cohesive performance on the field.

Conclusion

This study presents significant contributions to the analysis of performance in football, although it faces some limitations. The main one was the lack of access to videos of the finals and full data packages of the passes, which limited the depth of the analysis and the validation of the findings. Future research with access to these resources could provide a more comprehensive and accurate analysis.

Despite these limitations, the observational methodology used proved to be an extremely useful tool in the context of scientifically analysed football. This methodology allows for a detailed assessment of player behaviour in real game situations. In particular, polar coordinate analysis was effective in identifying patterns of behaviour and relationships between variables, and provided a comprehensive view of performance in the field.

These findings can be of great use to top-level teams, especially in preparation for the final rounds of elite competitions such as the UEFA Champions League. The implementation of these evidence-based strategies allows for the development of more effective game plans tailored to the specific circumstances of the match. Understanding passing patterns and their relationship to successful play will allow for better tactical preparation, optimisation of ball possession and increased goal scoring opportunities.

Therefore, we believe that this work contributes to the field of performance analysis in football by providing a deeper understanding of how passing patterns influence game outcomes, which will help to devise more effective tactics. The validation of the observation instrument and the application of polar coordinate analysis offer robust analytical tools for future studies and sport professionals. In addition, the findings can influence training methodologies, improving passing accuracy and decision making, especially at critical moments of the game.

Finally, coaches can use these findings to improve the performance of their teams, making strategic and data-driven use of observations and analyses. This observational methodology provides a sound basis for informed decision-making and continuous improvement of team performance, and offers a significant competitive advantage in the elite football field.

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SPORT TRAINING

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A pilot study of ten sessions of overspeed training with motorized towing system: a methodological proposal

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Laura Kluge fighting for the puck in the match between Germany and Hungary during the Eishockey Deutschland Cup, in Landshut, Germany, on November 9, 2024
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Abstract

The current motorized towing system devices are highly precise when selecting loads and achieving results. An increased use could expand the theoretical body on the effects of overspeed methods. Our objectives were to analyze the results of an overspeed intervention with a motorized towing system on the maximum running speed (MRS), the step length and rate, the flight and contact time, and the distance to the first support from the vertical projection of the center of masses, as well as to make a methodological proposal. Six young athletes (age: 16.71 ± 2.00 years) performed ten overspeed sessions with the assistance of 5.05 ± 0.53% of body weight at 105.83 ± 1.79% of maximum running speed, using the 1080 Sprint device. After the intervention, non-significant ($p > .05$) increases of 2.94% (95% CI: 0.25 – 5.62) of the voluntary maximum running speed were obtained with a large effect size (r_B: 0.71; 95% CI: 0.00 – 0.95). The distance to the first support from the vertical projection of the center of masses presented significant differences ($p < .05$; dr_B: 1; 95% CI: 1 – 1). The non-significant maximum running speed increases cannot be neglected in high-level competition, where small differences in performance separate athletes. To choose the appropriate training load is key, and so a standardized methodology allowing the comparison of results is necessary.

Keywords: assisted sprint, ecological approach, effect size, individualization, responders.

Introduction

In the field of sports training, overspeed (OS) is widely used by coaches (Schiffer, 2011) for the improvement of maximum running speed (MRS). One of the most widely used methods to generate OS stimuli is the towing system (TS), which consists of pulling the athlete from the front, both with non-motorized (Clark et al., 2009; Kristensen et al., 2006; Mero & Komi, 1985; Stoyanov, 2019) and motorized devices (Cecilia-Gallego et al., 2022a; Clark et al., 2021; Mero et al., 1987; Sugiura & Aoki, 2008; Van den Tillaar, 2021). Among the motorized TS devices currently available on the market, we highlight the 1080 Sprint (1080 motion, Lidingö, Sweden; https://www.1080motion.com/products/sprint2) and the Dynaspeed (Ergotest Technology AS, Langesund, Norway; https://www.musclelabsystem.com/dynaspeed/), which allow the loads to be selected through an electromechanical system, based on an electric motor controlled by its software, which gives us clear and immediate results (Cecilia-Gallego et al., 2022a; Clark et al., 2021; Lahti et al., 2020; Van den Tillaar, 2021).

There is currently little scientific evidence in this field of study that allows determining the real validity of OS training with TS for the improvement of the MRS. Most of the available studies offer acute data on OS exposure in athletes (Cecilia-Gallego et al., 2022b), and the main conclusions are: 1) these effects are principally due to the action of the athlete's forward pulling system (Gleadhill et al., 2024), and 2) many more studies with intervention periods are needed to determine whether OS training with TS produces adaptations that allow to improve the MRS or not. In addition, these studies present great methodological variability in the TS used, in the participants, in their athletic level, age, sex, or grade of familiarity with the devices, as well as in the scale and expression of the training load. Among the rare studies found that include a training period for OS with TS are those by Majdell and Alexander (1991) with American football players, Kristensen et al. (2006) with physical education students, Lahti et al. (2020) with rugby players, or Stoyanov (2019) with young sprinters.

An important concept provided by the study by Lahti et al. (2020) is the response capacity of athletes to OS training with TS. The concept of responders, or participants that respond to training in the expected sense, has been widely studied (Mann et al., 2014; Pickering & Kiely, 2017; Pickering & Kiely, 2019) and one of the main conclusions reached is that the problem does not lie in the existence of responders (or high-responders) and non-responders (or low-responders) (Pickering & Kiely, 2019), but in the training load used and its dosage (Mann et al., 2014). In other words, if an athlete does not respond to a certain training, it is possibly due to a poor choice and dosage of the training load (Pickering & Kiely, 2019). The parameters should then be adjusted until finding those that produce changes in performance, and the individualization of the training load must be sought (Pickering & Kiely, 2017).

Currently, some studies propose an ecological approach to training, further removed from laboratory conditions (Araújo et al., 2006; Torrents, 2005), and introducing OS training into the global planning of athletes (Lahti et al., 2020; Stoyanov, 2019). It should be noted that the existing literature on OS does not particularly recommend overspeed training in young or inexperienced athletes, mainly due to the risk of injury and the possibility of not having a stable technical pattern that could be negatively modified (Schiffer, 2011). Therefore, it is necessary to know the maturity status of the participants (Mirwald et al., 2002), as well as to ensure familiarity with the devices and OS conditions.

Seeking an ecological approach, it was decided to carry out a pilot study, with an intervention within the overall training planning, of 10 OS sessions using the 1080 Sprint device. The main objective of the study was to analyze the effects of OS training with TS on the MRS of the participants and other kinematic and biomechanical variables that could explain the effects produced. The proposed hypothesis was that the intervention would produce an increase in the MRS of the participants, although with different effects depending on their characteristics. In addition, we understand this pilot study as a proposal for a training methodology that can be replicated to compare results and establish broader conclusions about OS training with motorized TS.

Materials and Methods

Participants

A convenience sample of eight young athletes was recruited. Two of them did not finish due to muscular problems, so in the end six athletes were included in the study (2 males / 4 females). Anthropometric data were recorded by an International Society for Advancement of Kinanthropometry (ISAK) Level 1 certified evaluator (Esparza-Ros et al., 2019) following the ISAK protocol. The calculation of the maturity status of the participants was carried out by collecting anthropometric data following the protocol proposed by Mirwald et al. (2002). The characteristics of the sample can be consulted in Table 1.

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the University of the Basque Country (protocol code M10_2021_191). Informed consent and assent were obtained from all participants and their parents when the participants were minors.

Table 1
Participants characteristics and % of body weight of every assisted load.

Athletes	Chronological Age (y)	Years to PHV	Years of training	Height (cm)	Weight (kg)	% Body Fat	% BW 2 kg	% BW 4 kg	% BW 5.25 kg	PB 60 m (s)
F1	19.5	+ 5.8	7	170.0	63.4	16.7	3.2	6.3	8.3	8.33
F2	18.7	+ 4.3	5	150.4	57.8	22.6	3.5	6.9	9.1	8.94
M1	16.7	+ 2.9	6	179.6	65.8	7.6	3.0	6.1	8.0	7.69
F3	15.5	+ 3.4	4	166.0	56.7	12.3	3.5	7.1	9.3	8.13
F4	15.1	+ 2.0	5	151.3	39.4	11.6	5.1	10.2	13.3	8.35
M2	14.7	+ 1.6	4	176.7	60.2	7.3	3.3	6.7	8.7	7.63
Mean ± SD	16.71 ± 2.00	3.33 ± 1.54	5.17 ± 1.17	165.6 ± 12.45	57.2 ± 9.38	13.0 ± 5.83	3.6 ± 0.75	7.2 ± 1.50	9.4 ± 1.97	8.18 ± 0.48

Note. PHV: peak height velocity; % BW: percentage of body weight of every overspeed load; F: female; M: male; PB: personal best for 60 m-dash; SD: standard deviation.

Table 2
Weekly training schedule during the intervention.

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Week -1			Fam 1 / Anth 1	Rest	Fam 2 / Anth 2	Rest	Rest
Week 1	Pre-Test	ST & TT	OS S1	TT	OS S2	Rest	Rest
Week 2	OS S3	ST & TT	OS S4	TT	OS S5	Rest	Rest
Week 3	OS S6	ST & TT	OS S7	Rest	OS S8	Rest	Rest
Week 4	OS S9	ST & TT	OS S10	Rest	TT	Rest	Rest
Week 5	ST & TT	Rest	Post-Test				

Note. Fam: familiarization session with 1080 Sprint; Anth: anthropometric measures; ST: strength training; TT: technical training; OS S: overspeed sessions.

Design

Following a within-participant design, 10 OS training sessions were performed with a motorized TS. The time variables in a 5-m flying sprint (T5 m), MRS in a 5-m flying sprint (V5 m), step length (SL), step rate (SR), contact time (CT), flight time (FT) and horizontal distance from the first contact of the support on the ground to the vertical projection of the center of masses (HD) were recorded in a maximum unassisted sprint and three assisted sprints with different loads. The results obtained in the different conditions, before and after training, were compared to assess their effect. The results between conditions at each moment were also compared to determine the effect of each OS load on the different variables concerning the MRS. The intervention took place during the mesocycle before the indoor competitions. Table 2 shows the schedule for the entire intervention period.

Procedures

The athletes carried out two familiarization sessions with the motorized TS before the intervention. Anthropometric data collection was also conducted during these sessions. From these sessions on, the loads chosen for the pre-test were those that could produce approximately 3-5% increases over the athletes' MRS (Cecilia-Gallego et al., 2022a).

On the pre-test and post-test data collection days, the athletes performed a standardized warm-up similar to that of Clark et al. (2021). Then, they performed one maximal unassisted sprint and three assisted sprints with progressively higher loads (2 kg, 4 kg, and 5.25 kg). Recovery time between repetitions was 8–10 minutes. The % of the loads concerning the body weight of each participant is shown in Table 1.

Table 3
Intervention parameters.

Athlete	ΔVel OS1 (%)	ΔVel OS2 (%)	ΔVel OS3 (%)	Load S1 (kg)	Sessions (n)	OS runs (n)	Exp Time (s)	Mean Load (kg)	% BW Load	Mean Time (s)	Mean Velocity (m/s)
F1	0.11	4.12	5.86	3	10	64	228.99	2.99	4.7	3.58	8.39
F2	5.90	6.33	6.19	2	10	63	242.42	2.81	4.9	3.85	7.80
M1	2.87	2.65	3.72	5	10	63	208.75	3.68	5.6	3.31	9.06
F3	6.45	4.15	15.09	3	10	63	216.79	2.63	4.6	3.44	8.72
F4	3.23	11.40	10.93	2.5	10	58	214.38	2.30	5.8	3.70	8.11
M2	-2.44	2.78	8.42	4	10	61	201.89	2.78	4.6	3.31	9.07
Mean	2.69	5.24	8.37	3.25		62.00	218.87	2.87	5.05	3.53	8.52
± SD	3.40	3.30	4.11	1.08		2.19	14.64	0.46	0.53	0.22	0.52

Note. F: female; M: male; SD: standard deviation; ΔVel OS: velocity increases for overspeed load (1: 2 kg; 2: 4 kg; 3: 5.25 kg); Load S1: load selected for session 1; OS runs: total runs of overspeed during the intervention; Exp Time: total time of exposure to overspeed conditions; Mean Load: mean load values of all overspeed runs; % BW Load: % body weight of mean load values; Mean Time: mean time values of all overspeed runs; Mean Velocity: mean velocity values of all overspeed runs.

From the pre-test on, individual loads were selected for the training sessions, and those that produced an approximate increase of 3–5% in the athlete's maximum speed were used (Cecilia-Gallego et al., 2022a; Clark et al., 2009; Sedlácek et al., 2015). However, the load used during the races of the training sessions could be modified depending on the result obtained in the MRS test for each one of them, increasing or decreasing it to adjust it to the objective of 103–105% in each race. In other words, the important element was not the load, but its result. This could be done thanks to the Quantum software (v3.9.9.5, 1080 motion, Lidingö, Sweden) that incorporates the device used, which immediately offers values of time and speed over the distance traveled. The average load of all the races performed by each athlete is shown in Table 3, expressed in absolute terms (kg) and as a percentage relative to the athlete's body weight.

The OS sessions were held on an outdoor synthetic running track and were planned as follows: 1) standardized warm-up (Clark et al., 2021) and; 2) main part of the training consisting of a race with the 1080 Sprint device and zero load as an initial test of the session, plus 6–8 assisted races with the selected load for each athlete with 8–10 minutes recovery time between races. The number of races for each athlete was individually adjusted according to fatigue and the % of MRS achieved. All athletes performed a total of 10 sessions. The number of races attended by each athlete and the total exposure time are shown in Table 3.

The assistance in the sprint was carried out using the 1080 Sprint device, which is provided with 90 m of cable that is mechanically rolled or unrolled by a servo motor (2,000 rpm G5 Series Motor; OMRON Corp. Kyoto, Japan) and is controlled by the Quantum software (1080 motion). The 1080 Sprint device was placed at a height of 80 cm so that the trajectory of the assistance was as horizontal as possible, and the athlete was attached with a belt and a carabiner to the device's fiber cable. In the Isotonic assisted mode, the device allows to adjust the load between 1 and 15 kg, with variations of 0.1 kg. This device allows choosing the times it should offer assistance. It was decided not to apply assistance during the first 20 meters of the race, so as not to affect the acceleration phase, but also taking into account that Van den Tillaar (2021) comments that he does not observe differences between MRS and supramaximum speed in the first acceleration phase. The athlete then received assistance for the next 30 meters. At meter 50, the device stopped offering assistance and the athlete progressively braked for approximately 20 meters until movement came to a complete stop. During the assisted 30 meters, the Quantum software provided time and speed data for that interval. These data were used to control the load based on the results of the pre-test and each of the races of the intervention sessions.

Assessments

The T5m (s) and V5m (m/s) variables were obtained with single-beam timing gates (www.chronojump.org/product-category/races/) (Vicens-Bordas et al., 2020), located at a height of 1 m and connected to a laptop (Toshiba Satellite Pro R50-B-10v) with the Chronojump software (version 1.9.0, www.chronojump.org/software/) and were recorded between meter number 40 and meter number 45 of each sprint (Padullés-Riu, 2011). To obtain the SL (cm), CT (s), FT (s) and HD (cm) variables, the attempts were recorded with a Casio Exilim F1 camera (http://arch.casio-intl.com/asia-mea/en/dc/ex_f1/) at 300 fps (Buscà et al., 2016) and analyzed twice in two consecutive steps, approximately between meter number 42.5 and meter number 47.5, with Kinovea 2D analysis software (stable version 0.8.15, www.kinovea.org/download.html) (Puig-Diví et al., 2017; Reinking et al., 2018). The values of these variables correspond to the average value of the two legs in two consecutive steps. The camera was placed perpendicular to meter number 45 of the race at a distance of 13 m from the race line and a height of 1.5 m. The Parallax effect was counteracted by putting references between meter number 40 and meter number 50, in the projection where athletes were shown on camera when they crossed that distance (Romero-Franco et al., 2017). Markers were placed on the femoral head and metatarsal of the right leg. The SR variable was calculated indirectly (number of steps/step time [CT + FT]).

Statistical analyses

The normality of the distribution of the data was checked using the Shapiro-Wilk test. To assess within-group changes from the pre-test to the post-test of the kinematic variables scores, Wilcoxon signed-rank test were used. To quantify within-group differences following the intervention, the matched rank biserial correlation (r_B) and the percentage change was computed. r_B values were interpreted as follow: < .1 = trivial; .1 - .3 = small; .3 - .5 = moderate; and > .5 = large (Cohen, 2013). The level of significance was set at .05 for all tests. All statistical analyses were performed using JASP for Mac (version 0.16.4; JASP Team (2021), University of Amsterdam, The Netherlands).

Results

The pre-test to post-test changes of the kinematic variables scores at different OS conditions are shown in Table 4. The plot with the ESs (effect sizes) of the kinematic variables at the V0 condition is shown in Figure 1. Pre-post changes of the V5m, SL, SR, CT, FT, and HD variables are shown in Figure 2.

Table 4
Pre-test to post-test changes of the kinematic variables scores at different overspeed conditions and percentage change at V0 condition after training period.

Variable	Pre	Post	r_B (95% CI)	Qualitative assessment	Percentage change (95% CI)
V0					
V5m (m/s)	8.10 ± 0.53	8.33 ± 0.57	0.71 (0, 0.95)	Large	+2.94 (0.26, 5.62)
SL (cm)	197.60 ± 13.40	198.33 ± 15.40	0.20 (–0.64, 0.82)	Small	+0.37 (–2.83, 3.56)
SR (steps·s^{-1})	4.27 ± 0.24	4.25 ± 0.19	–0.07 (–0.78, 0.72)	Trivial	–0.22 (–4.49, 4.04)
CT (s)	0.11 ± 0.01	0.11 ± 0	–0.60 (–0.93, 0.27)	Large	–2.98 (–7.46, 1.49)
FT (s)	0.12 ± 0.01	0.13 ± 0.01	0.57 (–0.24, 0.91)	Large	+2.81 (–0.98, 6.61)
HD (cm)	33.18 ± 4.24	36.55 ± 4.53*	1 (1, 1)	Large	+10.51 (3.36, 17.67)
OS1					
V5m (m/s)	8.31 ± 0.48	8.65 ± 0.50*	1 (1, 1)	Large	
SL (cm)	205.92 ± 14.81	207.32 ± 15.83	0.14 (–0.63, 0.78)	Small	
SR (steps·s^{-1})	4.28 ± 0.31	4.27 ± 0.21	–0.05 (–0.73, 0.69)	Trivial	
CT (s)	0.11 ± 0	0.10 ± 0*	–0.87 (–0.98, –0.34)	Large	
FT (s)	0.13 ± 0.02	0.13 ± 0.01	0.81 (0.23, 0.97)	Large	
HD (cm)	34.83 ± 3.51	36.78 ± 4.40	0.81 (0.23, 0.97)	Large	
OS2					
V5m (m/s)	8.52 ± 0.45	9.19 ± 0.53*	1 (1, 1)	Large	
SL (cm)	210.70 ± 17.46	220.37 ± 18.23	0.81 (0.23, 0.97)	Large	
SR (steps·s^{-1})	4.25 ± 0.29	4.23 ± 0.23	–0.05 (–0.73, 0.69)	Trivial	
CT (s)	0.11 ± 0	0.10 ± 0	–0.52 (–0.90, 0.30)	Large	
FT (s)	0.13 ± 0.02	0.13 ± 0.01	0.71 (5.55×10–3, 0.95)	Large	
HD (cm)	37.48 ± 3.88	40.50 ± 2.80*	0.90 (0.54, 0.98)	Large	

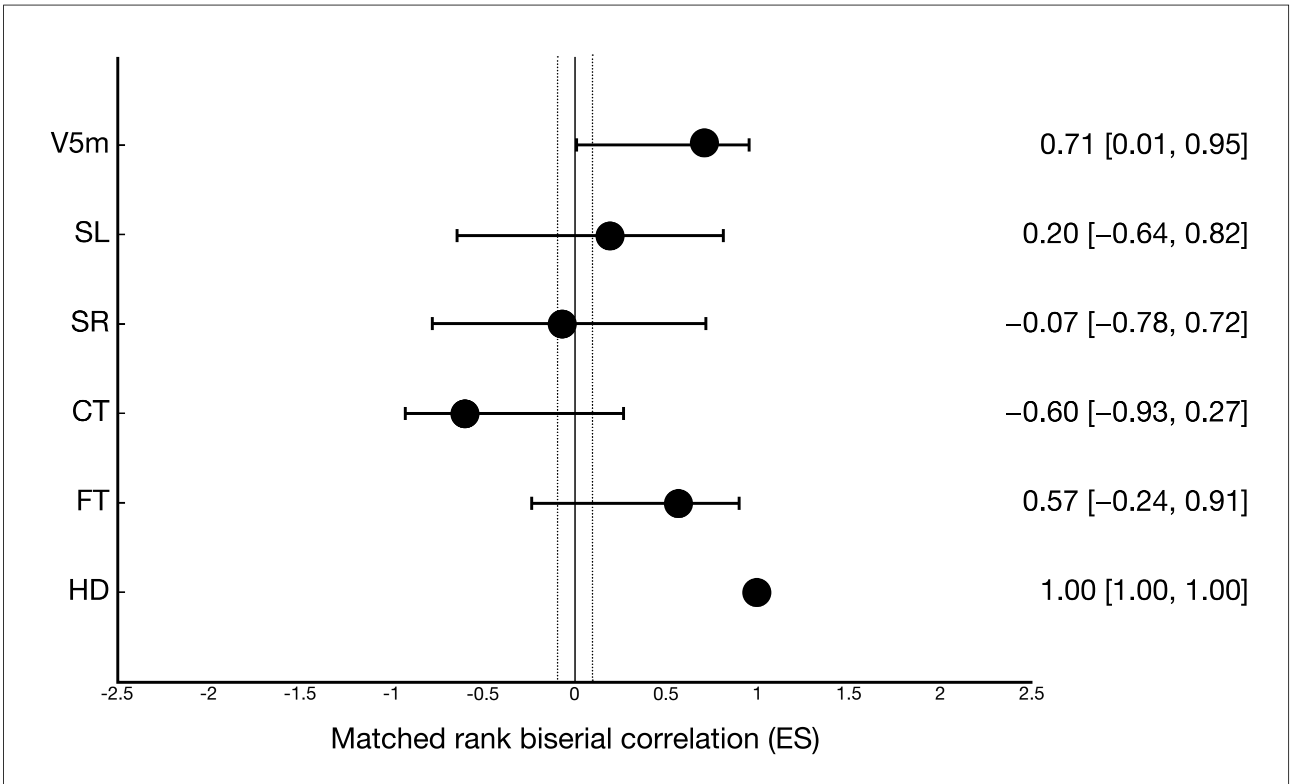
Note. Values are presented as mean ± standard deviation. V0: No overspeed load; OS: overspeed load (1: 2 kg; 2: 4 kg; 3: 5.25 kg); V5m: Mean velocity between 40-m and 45-m from a flying start; SL: Step length; SR: Step rate; CT: Contact time; FT: Flight time; HD: Horizontal distance between the first contact point and the vertical projection of center of masses. $r_{(B)}$: matched rank biserial correlation effect size. *: $p \leq .05$ different to pre-test values; CI: Confidence interval.

Table 4 (Continuation)
Pre-test to post-test changes of the kinematic variables scores at different overspeed conditions and percentage change at V0 condition after training period.

Variable	Pre	Post	r_B (95% CI)	Qualitative assessment	Percentage change (95% CI)
OS3					
V5m (m/s)	8.78 ± 0.66	9.09 ± 0.35	0.43 (–0.41, 0.87)	Moderate	
SL (cm)	219.10 ± 15.51	225.43 ± 16.74	0.52 (–0.30, 0.90)	Large	
SR (steps·s^{-1})	4.25 ± 0.27	4.25 ± 0.19	0.00 (–0.75, 0.75)	Trivial	
CT (s)	0.11 ± 0	0.10 ± 0	–0.71 (–0.95, –5.55×10–3)	Large	
FT (s)	0.13 ± 0.01	0.13 ± 0.01	0.52 (–0.30, 0.90)	Large	
HD (cm)	38.78 ± 4.21	41.53 ± 3.67*	1 (1, 1)	Large	

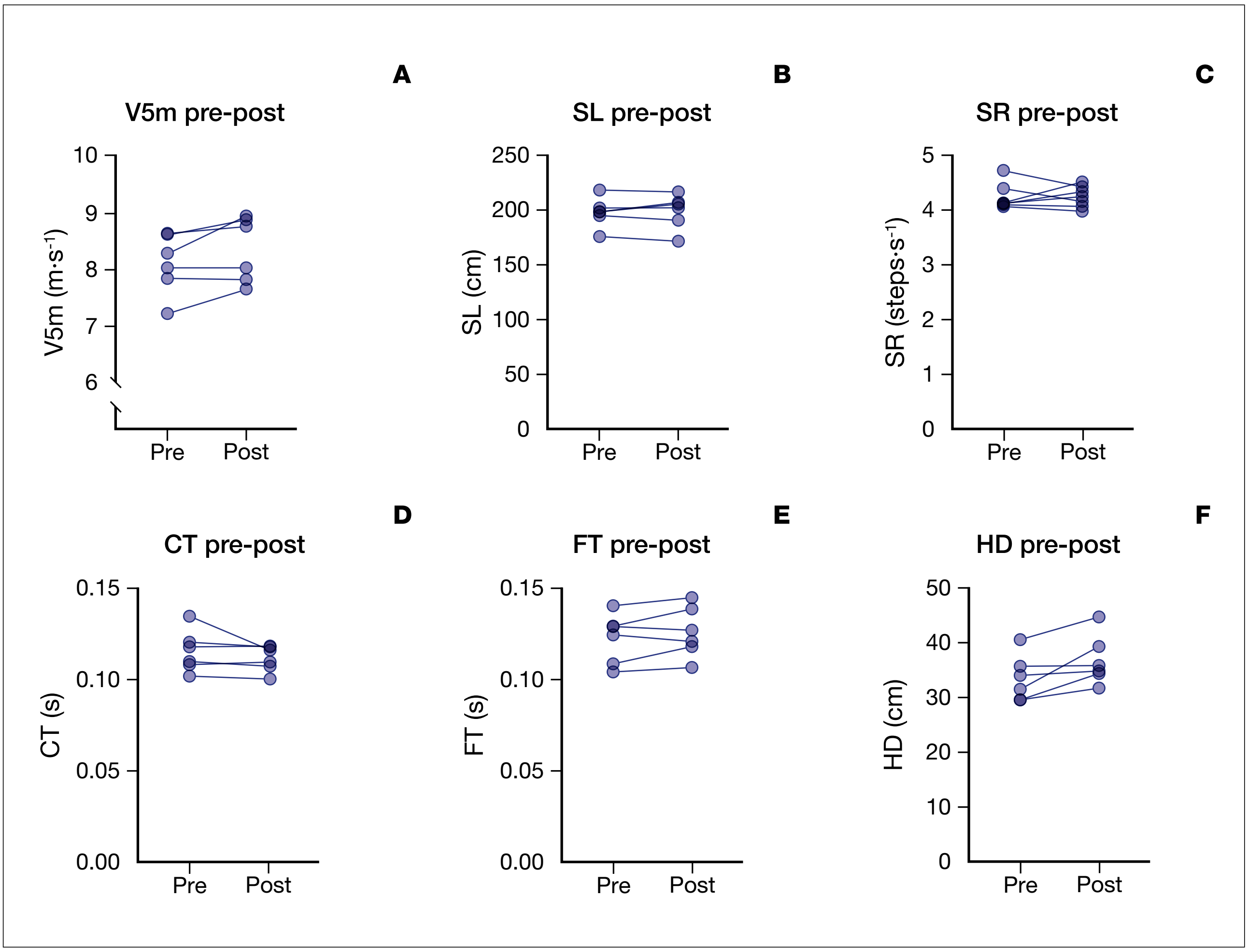
Note. Values are presented as mean ± standard deviation. V0: No overspeed load; OS: overspeed load (1: 2 kg; 2: 4 kg; 3: 5.25 kg); V5m: Mean velocity between 40-m and 45-m from a flying start; SL: Step length; SR: Step rate; CT: Contact time; FT: Flight time; HD: Horizontal distance between the first contact point and the vertical projection of center of masses. $r_{(B)}$: matched rank biserial correlation effect size. *: $p \leq .05$ different to pre-test values; CI: Confidence interval.

Figure 1
Plot with the effect sizes of the kinematic variables at V0 condition



Note. Black dashed lines delimit the trivial effect size magnitude (i.e., –0.1 to 0.1).

Figure 2
Pre-post change of each participant in the different variables.



Note. A) V5m variable; B) step length (SL), C) step rate (SR), D) contact time (CT), E) flight time (FT), and F) horizontal distance (HD) variables.

Discussion

After the intervention, improvements in the MRS (V5m) of the athletes were observed, although they were not statistically significant ($p > .05$). MRS changes should be observed from an individual perspective and keeping in mind that athletic performance is multi-factorial. For this reason, without being statistically significant, the small percentages of improvement found in some athletes could sometimes be decisive in the final result (Loturco, 2023), especially in sprint events in athletics (Loturco et al., 2022; Salo et al., 2011). In the unassisted MRS condition, significant differences ($p < .05$) were reported in HD with large ES (r_B: 1; 95% CI: 1–1), while in the other variables, the differences were not significant and the ESs were trivial or small (see Table 4), so the natural running pattern was not significantly affected.

In similar studies, increases in MRS appear after the intervention of OS with TS, although the methodological differences make it difficult to compare results. After 6 weeks of training, Majdell and Alexander (1991) obtained significant increases in MRS ($p < .05$) using motorized TS in varsity male football players (age: 23 ± 2.73 years) while Kristensen et al. (2006) also reported significant improvements in the MRS ($p < .05$) in physical education students (age: 22 ± 2.6 years) with non-motorized TS after the intervention. Neither of the two studies showed significant differences in the kinematic variables except for support time (Majdell & Alexander, 1991) and step time (Kristensen et al., 2006), so it can be stated that the technical pattern of the sprint was not affected. On the other hand, Lahti et al. (2020), after 12.5 ± 0.7 OS training sessions with the 1080 Sprint device in 10 male rugby players (age: 20.1 ± 1 years), observed significant increases in MRS of 3.40 ± 4.15% (p < .03; ES: 0.47; 95% CI:–0.38 – 1.32) although they point out that only 5 of the 10 members of the group respond positively in the expected direction after training, reinforcing the need for load individualization. It can therefore be argued that the possible changes in the MRS of the athletes are due to neural and coordination improvements within the early phase of training (Kristensen et al., 2006), hence studies with longer intervention periods would be necessary.

However, as mentioned, the methodological heterogeneity of the studies is so wide that it is not possible to conclude OS training with TS beyond the study sample itself. This heterogeneity affects many factors that are typical of the sample such as sex, age, sports specialty, and experience in training, but also the procedures used in the intervention in aspects such as the TS used, the loads, the distances, the intervention time, measurement instruments and procedures, variables analyzed, etc. Therefore, a second motivation of this study is to make some methodological proposals that can be replicated to broaden the knowledge about OS training with TS and its effects. We believe that the fact of having devices such as the 1080 Sprint used in this study should be exploited, especially when carrying out studies, due to their ability to monitor the training load and its effects in an individualized and immediate way (Cecilia-Gallego et al., 2022a; Clark et al., 2021; Lahti et al., 2020; Van den Tillaar, 2021), compared to other systems used, such as non-motorized TS (Kristensen et al., 2006) or elastic ropes (Stoyanov, 2019).

Studies similar to ours (Kristensen et al., 2006; Majdell & Alexander, 1991; Stoyanov, 2019) present differences in terms of age, sex, and experience in training, with the participants in our study being the youngest (see Table 1). Although there are some recommendations not to use OS training in young and inexperienced participants (Schiffer, 2011), our participants were in the post-PHV period (3.33 ± 1.54 years) (Mirwald et al., 2002), were enough experienced in speed training (5.17 ± 1.17 years) and were provided with 2 familiarization sessions with the device. These data indicate that the participants in the study, especially the girls, have largely overcome the PHV period, so their maturational, physiological and anthropometric characteristics now resemble those of adults. Furthermore, their experience in athletic training would allow these methods to be applied to them.

Normally, the selection of training loads has been made based on the increase produced over the MRS, recommending the use of those that take the athlete to speeds between 3% and 10% higher than the MRS (Clark et al., 2009; Mero & Komi, 1985; Sedlácek et al., 2015; Sugiura & Aoki, 2008). In the case of our study, we have worked with average loads of 5.05 ± 0.53% of body weight, which have produced average speeds of 105.71% of the MRS. For us, it is especially relevant to determine these values for further studies and their comparison. In addition, in our study the load was not fixed but was adjusted inter and intra-session, considering the effect produced, i.e., the objective of 103–105% of the MRS. This aspect is also taken into account in Stoyanov's study (2019) with elastic ropes, which sets its objectives in the resulting speed, from 102–103% to 108–110%, depending on the distance and athlete; and in that of Lahti et al. (2020), where the objective is to obtain speeds of 105% MRS, with a weekly adjustment of the loads.

The intervention carried out is based on an ecological approach (Araújo et al., 2006; Torrents, 2005) to the training of athletes (see Table 2), including it in their actual preparation for competition. We believe that these types of studies, although they are more difficult to control due to the high number of confounding variables that may appear, provide information with greater external validity than studies carried out in analytical or laboratory situations (Kristensen et al., 2006; Majdell & Alexander, 1991). This same line of ecological approach can be found in Stoyanov (2019), with young sprinters, and Lahti et al. (2020) with rugby players. In both studies, they provide us with the data of the intervention and the rest of the training content. Emphasis should also be placed on the need for studies with a control group that perform the same intervention in a more analytical situation, to allow the effectiveness of this type of intervention to be assessed.

A limitation of our study is the size of the final sample, where only 6 participants finished the intervention, out of the 8 who started it. This small sample does not provide enough statistical power to the results obtained, but we believe that is necessary to attend to the individuality of the results (Loturco et al., 2022) and the ES of the treatment, not focusing only on the statistical significance of the results (Hopkins et al., 2009; Swinton et al., 2022; Turner et al., 2021b, 2021a). We can see how in the study by Lahti et al. (2020) an ES of 0.47 (–0.38 – 1.32) is obtained with a p = .03 while in ours we obtained a higher ES (0.71 [–0.00 – 0.95]) but a non-significant p-value, due to the greater width of the confidence interval. If we look at the individual response, Lahti et al. (2020) report that 5 of the 10 participants do not respond in the expected direction, which they attribute to an inadequate training load, based on their initial strength-velocity profile, while in ours only 2 out of 6 do not improve their MRS after treatment (F1: –0.12%;

F4: –0.51%), while the rest of the athletes do improve, some considerably in percentage terms (F2: +5.87%; F3: +7.07%; M1: +1.48%; M2: +2.82%). Introducing follow-up tests for a few weeks could also provide us with more information about the effects of training (Bissas et al., 2022; Lahti et al., 2020), as well as taking into account the possible error in the measurement procedures, an aspect that is by no means negligible in research, and which can lead to possible false non-responder or vice versa (Mann et al., 2014; Pickering & Kiely, 2019). Pickering and Kiely (2019) argue that the most important aspect of training is the individual dosage of the training load and that the lack of response to the process may be because it was not adequate to its characteristics. According to these same authors, the terms "Responder" and "Non-responder" should stop being used and should be changed to "Did not respond", thus transferring the reason for the athlete's non-response to treatment. Finally, more studies are needed to be able to determine if there is a specificity of non-response to each type of exercise (Mann et al., 2014), in this case to OS.

Conclusions and practical applications

A period of adaptation or familiarization to the OS conditions generated by the TS is necessary to be able to run at supra-maximal speed in a controlled manner. The first repetitions generate insecurity and mistrust in athletes.

OS training with TS can be a good method to reduce CT values, a determining factor in performance for improving MRS since OS conditions imply a greater need for vertical ground reaction forces.

The management and dosage of the loads must be done on an individualized and daily basis, adapting the loads to the proposed objective.

Intervention periods of around 4–6 weeks may be insufficient; longer periods, between 8 and 12 weeks, would be recommended to be able to assess the results beyond the early phase of training.

In research, individual health data should be collected, both physiological and psychological or emotional, during the tests, to determine any possible influence on the results.

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Conflicts of interest

The authors declare no conflict of interest.

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Participants in popular mountain biking events in peri-urban protected areas: how many are too many?

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Abstract

In peri-urban settings, popular outdoor sporting events such as mountain biking and trail running frequently occur in natural and protected areas. While managers and researchers may perceive the number of participants as increasing pressure on these territories, visitors, users and other stakeholders often view these activities favourably and as environmentally friendly. Leveraging data from a popular mountain biking event held in Arrábida Natural Park, encompassing 4,464 participants across six editions, this research investigated the spatial dynamics between the participants and the event region to evaluate what additional pressure these events might exert on these territories. Findings showed that up to 70 % of participants originated from the park's vicinity, with only 15% travelling beyond 50 km to attend the event. Moreover, the majority self-identified as regular park users, having ridden within the area nearly weekly, contrasting with non-regular users who resided farther away and rode in the area approximately once every nine months on average. Comparative analysis with 148 other popular mountain biking events nationwide, totalling 35,147 participants, revelaed consistent distance patterns, albeit greater for events with larger participant numbers or held in less populated locales. When deciding whether or not to authorise these events, managers should always prioritise conservation and consider other factors such as seasonality and race routes. Nonetheless, these events could be harnessed to directly benefit the park's mission and activities, facilitating enhanced communication between managers and participants, most of whom are regular park users.

Keywords: management, MTB, outdoor activities, peri-urban parks, race events.

Introduction

Races and other sports events are common manifestations of popular outdoor activities such as cycling or running. The number of practitioners of a particular sport usually correlates with the number and magnitude of events (e.g., races or tournaments) (Farías Torbidoni, 2015; Segui Urbaneja & Farías Torbidoni, 2018) and is a good proxy of an event's popularity and success. Unlike elite national and international sports competitions, popular sports events or small-scale races (Mueller et al., 2018) are less demanding and open to anyone who regularly does physical activity.

Despite the competitive nature of these events, most participants frequently race within the open category. For these people, sports activity is a way of life (Sekot, 2012) shared with friends and relatives, usually without any ties to any club in particular (Dorado et al., 2022) and with a low level of federation membership (Quirante-Mañas et al., 2023). Unlike elite races or sports mega-events (Müller, 2015), these popular sports events attract more participants than spectators, similar to small-scale sports events (Gibson et al., 2012).

Outdoor recreational activities such as mountain biking and trail running, as well as the large sports events associated with them, take place close to nature, crossing into Protected Areas (PA) or Natura 2000 sites (Farias-Torbidoni et al., 2018; Nogueira Mendes et al., 2021a). In many cases, these territories welcome and encourage events and activities. For example, walking and cycling are frequently advertised by PA (Brown, 2016), and visitors and users perceive these activities as being environmentally friendly. These activities are generally considered good examples of eco- or nature and sustainable tourism, promoting respectful uses of the environment and increasing visitation. However, it is also common for PA mandates or management plans to include limits on visitor numbers and public use (Leung et al., 2018): it should not be forgotten that the primary missions of PA are to promote nature conservation and biodiversity, and to allow ecological cycles to take place undisrupted (European Commission, 2020; Maxwell et al., 2020).

Depending on how, when, where and by whom recreational activities are being carried out, strict conservation objectives can conflict with outdoor recreational uses due to environmental and social impacts. Negative impacts on soil, flora, and fauna are well acknowledged by many studies (Chiu & Kriwoken, 2003; Evju et al., 2021; Pickering et al., 2011; Salesa & Cerdà, 2020) as well as social impacts (Kleiner et al., 2022; Needham et al., 2004). Among these, massification is one of the most undesirable since it can push all impacts over acceptable limits (Gómez-Limón García & Martínez Alandi, 2016) and decrease visitor and user satisfaction.

For all these reasons, sports events are frequently seen by managers and researchers as resulting in massification and are often unwanted in PA (Newsome et al., 2011). Management plans generally include restrictions or zoning areas for such outdoor recreational uses, but due to the constant development of new activities or new trends, it is not uncommon for PA policies to become outdated (Thede et al., 2014) –as well as, at times, challenging to oversee. At the same time, stakeholders such as local municipalities and practitioners see these activities and events as crucial for showcasing and marketing their region and, thus, as an excellent opportunity to attract new visitors and users (Nogueira Mendes et al., 2021a). As mentioned by many authors, outdoor sports and recreation are also a meaningful way to ensure people's greater mental and physical well-being, connect them with nature, and raise awareness of environmental issues and sustainable development, currently a real concern also for popular and smaller sport events (Ulloa-Hernández et al., 2023).

Nogueira Mendes et al. (2023) found that regular practitioners of mountain biking in protected and recreational parks of Lisbon Metropolitan Area (LMA) are from the surroundings of the PA and parks in question. According to the same study, most riders generally target the same area but will also use other areas nearby, i.e., ones within cycling distance or no more than one hour away by car from their residence. Using their local parks and PA leads to a sense of ownership (Brown, 2016), resulting in users frequently reacting against implementing new regulations or restrictions (Ferse et al., 2010). Similar feelings of ownership are also common regarding popular sports events, which can further pressure natural areas already threatened by many other issues.

While crowding and massification are often discussed in the context of PA visitation management, for popular sporting events that has yet to be explored in the scientific literature. Knowing *how many* users there are is crucial for managers, but *who* these participants are should also play a significant role in deciding whether to allow a popular sports event to occur in peri-urban protected or natural areas or not. Additionally, the organising and hosting capacity of the event itself should also be considered.

Using a popular mountain biking event as a case study, this research aimed to evaluate the extent to which such events in a peri-urban context represent extra pressure compared to the regular use of the area, considering that many participants should be from the surroundings and already regular park users. We used a local-scale analysis to understand: (i) where participants came from and (ii) how often they rode in the area, and whether they considered themselves regular users or not of the area where the race was taking place. Finally, as proof of concept, (iii) we evaluated whether the spatial patterns were similar in other contexts by analysing where participants came from for similar popular sports events at a national scale.

Methodology

Philosophical underpinning

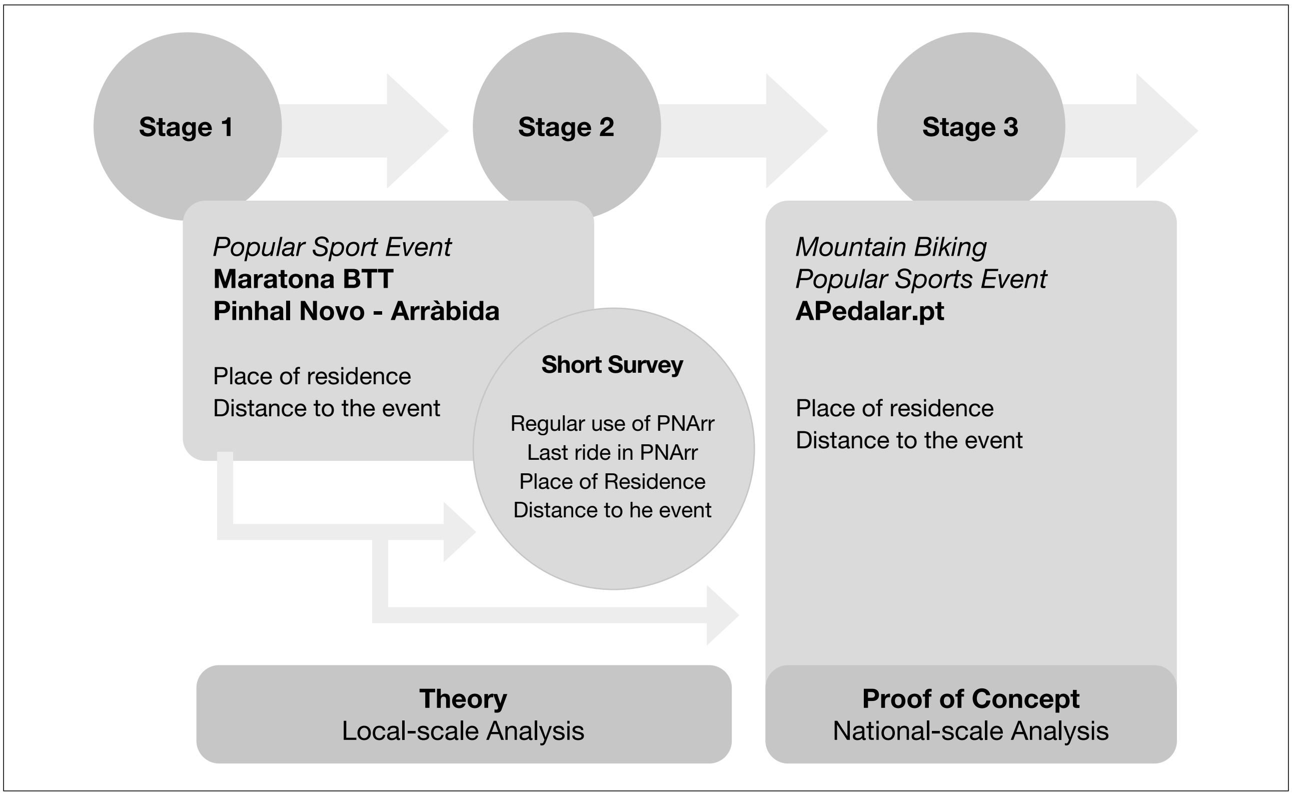
Based on a positivist paradigm, in which the search for universal patterns is emphasised and a convergent design based on quantitative and qualitative data, this research assessed how popular sporting events within protected areas in peri-urban contexts represent extra pressure relative to outdoor recreational uses. This is a question that has been difficult to answer comprehensively due to the growing demand for sports events within PA over the last decades and the quick change in outdoor practices. To advance in the analysis and resolution of this topic, following the epistemological continuum (Landi, 2023), this research followed the objectivism approach where the knowledge exists independently from the researcher.

Conceptual framework

A two-scale analysis, divided into three stages, was designed to evaluate the relationship between popular mountain biking events and participants' habits and places of residence (see the conceptual framework in Figure 1). The local-level analysis was conducted on Maratona BTT Pinhal Novo–Arrábida, the largest and most popular race event for Mountain Biking in Arrábida Natural Park (PNArr), within the LMA, Portugal. This annual event has taken place 12 times and is organised by a local association (BTTascaDuXico) with the support of Palmela Municipality and Pinhal Novo Parish. The race has two distances (a marathon and a half marathon) that cross into the natural park and a third minor, guided ride (typical in many popular race events) that does not reach the park's boundary. For proof of concept, popular mountain biking events co-organised at the national level by APedalar.pt (https://apedalar.pt/eventos/concluidos/2015), one of the leading timing companies in Portugal, were considered. According to Nogueira Mendes et al. (2021a), this company holds around a quarter of all popular mountain biking events in the country.

The dataset for Stage 1 was provided by the event organisers and exclusively included the place of residence (not their personal address) of the 4,464 participants from six consecutive editions of Maratona BTT Pinhal Novo–Arrábida held between 2010 and 2016 (from the 5th to the 10th editions; there was no event in 2014). Using Google Earth PRO, the place of residence of each participant (unavailable for 393 bikers) was geocoded, and the Euclidean distance from the place of residence of each participant to the event's start point and the park boundaries was measured using point distance within ArcGIS Desktop 10.7 from ESRI. Average and maximum distances were recorded, and distances were grouped in percentiles (25th, 50th, 60th, 70th, 75th, 80th, 90th, and 95th) for each race edition.

Figure 1
Conceptual framework and scale analysis dataset and study area.



The dataset for Stage 2 was collected via a short survey carried out at the 2016 and 2017 events. The organisers sent the request to participate in the survey to a random selection of 50 % of the event's participants. Data were anonymously collected using Kobotoolbox.org forms, where the study objectives were presented, reinforcing the voluntary nature of participation. The survey produced 219 valid answers, with a response rate of 31%, and it aimed to evaluate: (i) the participants' place of residence (for sample validation and comparison to the data used in stage 1); (ii) the last time they had ridden within the natural park and whether the participants considered themselves regular users of PNArr or not.

Stage 3, carried out at a national scale, included 148 of the 157 mountain biking events managed by Apedalar.pt in 2015, drawing 35,147 participants (the remaining nine events did not occur due to a lack of contestants). The start point of each event was gathered from Apedalar.pt or the event's social media or webpage. Distances from the place of residence (retrieved from the public lists of participants) to the event were measured using the same methods as for the local dataset. As with the previous stages, this dataset includes virtually all participants' places of residence, but no personal data were used or kept throughout this research.

Throughout the three stages, all data were analysed using description statistics, including average distances, percentiles, maxim and minimum values at all scale-analysis.

The location of Maratona BTT Pinhal Novo/Arrábida and the location of all events used for the national-level analysis are presented in Figure 2.

Results

Local-scale analysis

Stage 1 – Maratona BTT Pinhal Novo/Arrábida

Results from the local-scale analysis of the Stage 1 dataset are presented in Table 1. On average, for all race editions except for the 5th, the distance to the natural park is shorter than the distance to the event's starting point, although within the same value of magnitude–a pattern repeated up to the 60th percentile. Distances of more than 50 km to the event or PNArr are reached above the 85th percentile, except for the 8th and 10th editions (2013 and 2016, respectively). Both tendencies occur throughout the sub-dataset when all participants are analysed together.

Figure 2

Study area: (a) Arrábida Natural Park and race routes of the 10th Maratona BTT Pinhal Novo–Arrábida used for the local-level analysis; (b) Mainland Portugal and locations of the 148 mountain biking race events from Apeladar.pt used for the national-level analysis. (Map produced by the authors based on open data from dgterritorio.gov.pt, igeoe.pt and icnf.pt)

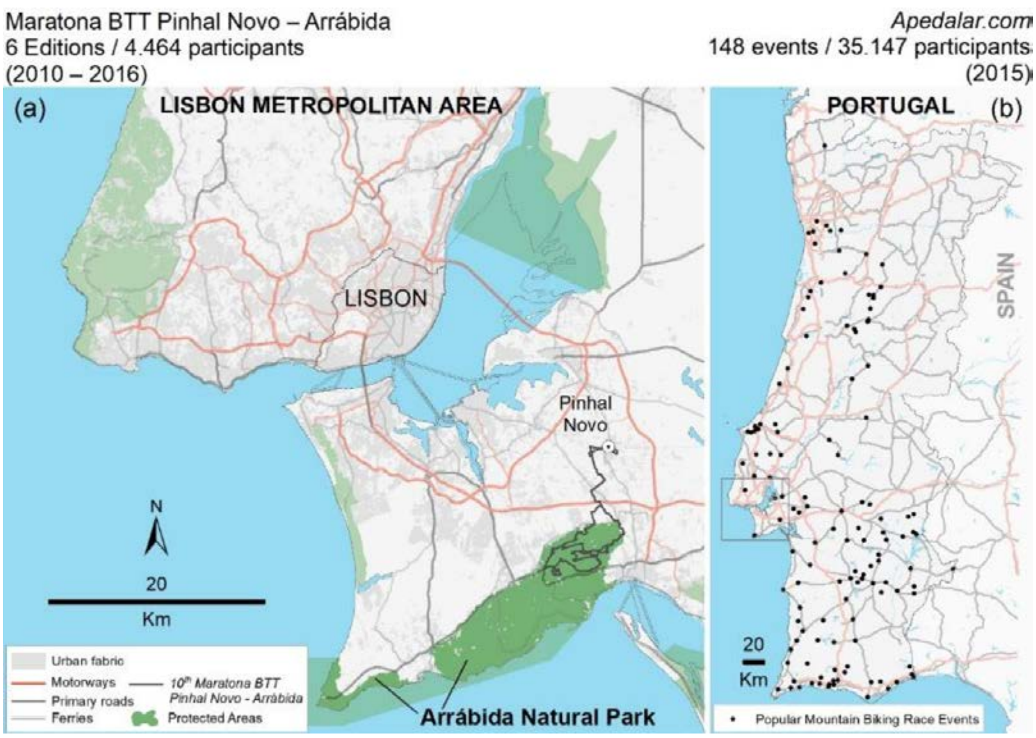


Table 1
Euclidian distances (km) from the residence place to the Maratona BTT Pinhal Novo/Arrábida start point and to the Arrábida Natural Park boundaries.

Edition (Year)	Riders	AVG	P25th	P50th	P60th	P70th	P75th	P80th	P85th	P90th	P95th	MAX
5th (2010)	703	28.92	12.04	21.62	28.69	31.67	35.90	41.10	45.53	51.84	87.45	276.47
PNArr		27.30	6.82	19.82	28.92	33.42	35.74	37.97	40.83	52.63	85.60	283.18
6th (2011)	644	26.27	9.75	16.30	21.79	28.71	31.45	35.12	43.92	50.50	87.45	323.33
PNArr		24.74	6.82	15.69	19.57	29.08	32.28	35.52	39.65	46.29	85.68	330.06
7th (2012)	811	28.46	12.04	18.82	21.77	28.84	31.18	36.70	44.57	69.52	87.45	301.82
PNArr		26.40	6.82	17.12	19.82	29.24	32.28	35.64	40.83	56.09	89.67	308.25
8th (2013)	845	32.75	12.04	21.20	26.36	30.60	34.75	41.17	59.40	87.45	114.19	323.33
PNArr		30.53	6.82	18.16	22.79	31.72	33.46	39.29	52.33	89.42	106.37	330.06
9th (2015)	760	32.32	12.04	21.20	26.66	31.45	35.05	39.78	46.74	70.18	104.49	985.41
PNArr		30.44	6.82	19.82	22.79	32.28	35.14	40.11	47.00	74.63	107.83	949.28
10th (2016)	701	35.57	12.04	21.20	26.36	31.50	36.34	41.54	59.87	85.86	117.75	985.41
PNArr		33.02	6.82	19.13	22.79	32.28	35.64	40.83	65.53	81.32	124.24	949.28
TOTAL	4,464	30.75	12.04	21.20	24.65	30.85	34.32	39.78	45.56	70.18	99.94	985.41
PNArr		28.76	6.82	18.27	22.79	31.72	34.01	37.97	43.39	76.29	101.15	949.28

Stage 2 – Short survey

Figure 3 presents the boxplot results of the short survey carried out with participants of the 10th and 11th editions of the Maratona. 56% of the participants considered themselves regular riders of PNArr. On average, they lived less than 12 km from the park limits, and the maximum distance to their residence was 42 km, which is less than the average distance to the park limits for those who did not consider themselves regular users. For both categories combined, results are in line with, and within the same range of values as, those found for Stage 1, except for the 75th percentile for non-regular users, which surpasses 50 km. It should also be noted that there were bikers living close to the PNArr who did not consider themselves regular users of the park.

Regarding the last time that participants in the Maratona had cycled in the PNArr (answered by nearly 82 % of the respondents), those who considered themselves regular riders had done so, on average, within the preceding five weeks, although the median fell within the last seven days before the questionnaire was completed. For the non-regular users, the average values rose to nine months and the median to the last seven months.

Figure 4 presents a geographical output of this case study's results, showing the place of residence of the Maratona participants. The map for the 10th edition also distinguishes between the places of residence for regular and non-regular users (results from the short survey).

Figure 3
Short survey dataset: (a) Boxplot distances from the place of residence to Pinhal Novo and PNArr; (b) Days since the last ride to PNArr. Boxes stand for the 2nd and 3rd quartiles, and black diamonds give average values. (Note: maximum values for (b) are outside the y-axis range.)

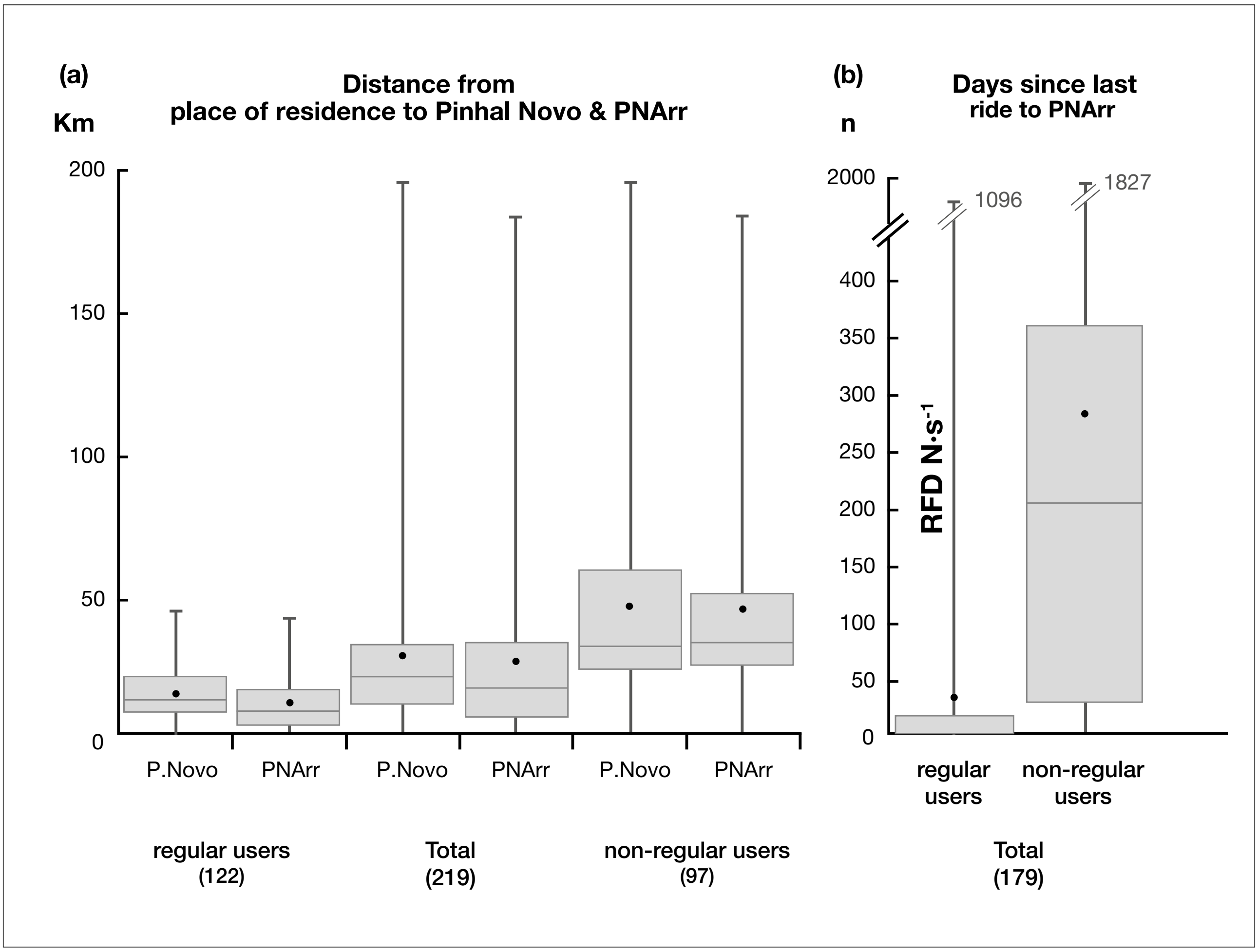


Figure 4
Place of residence and distance percentiles from the Maratona BTT Pinhal Novo/Arrábida for the six editions analysed.

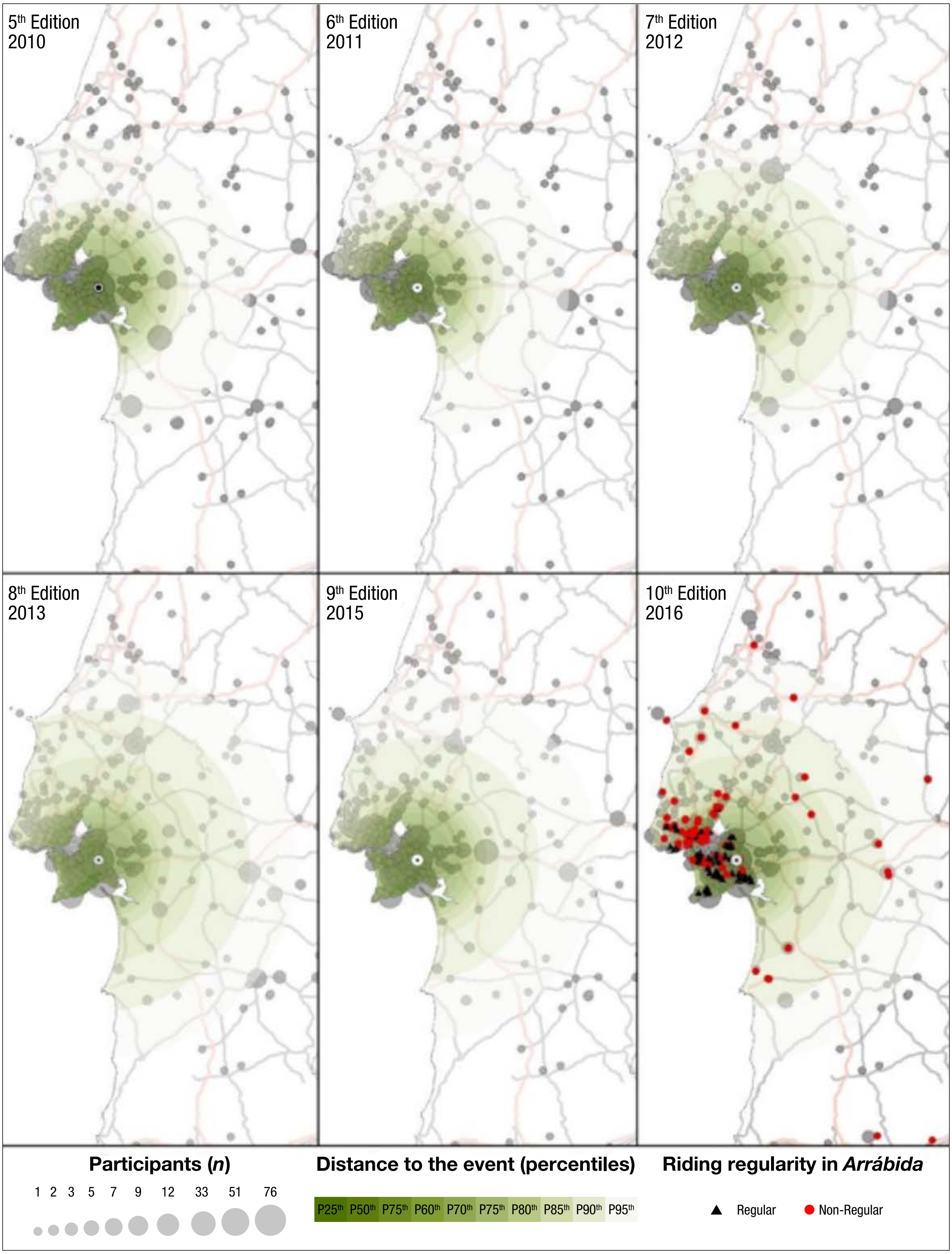
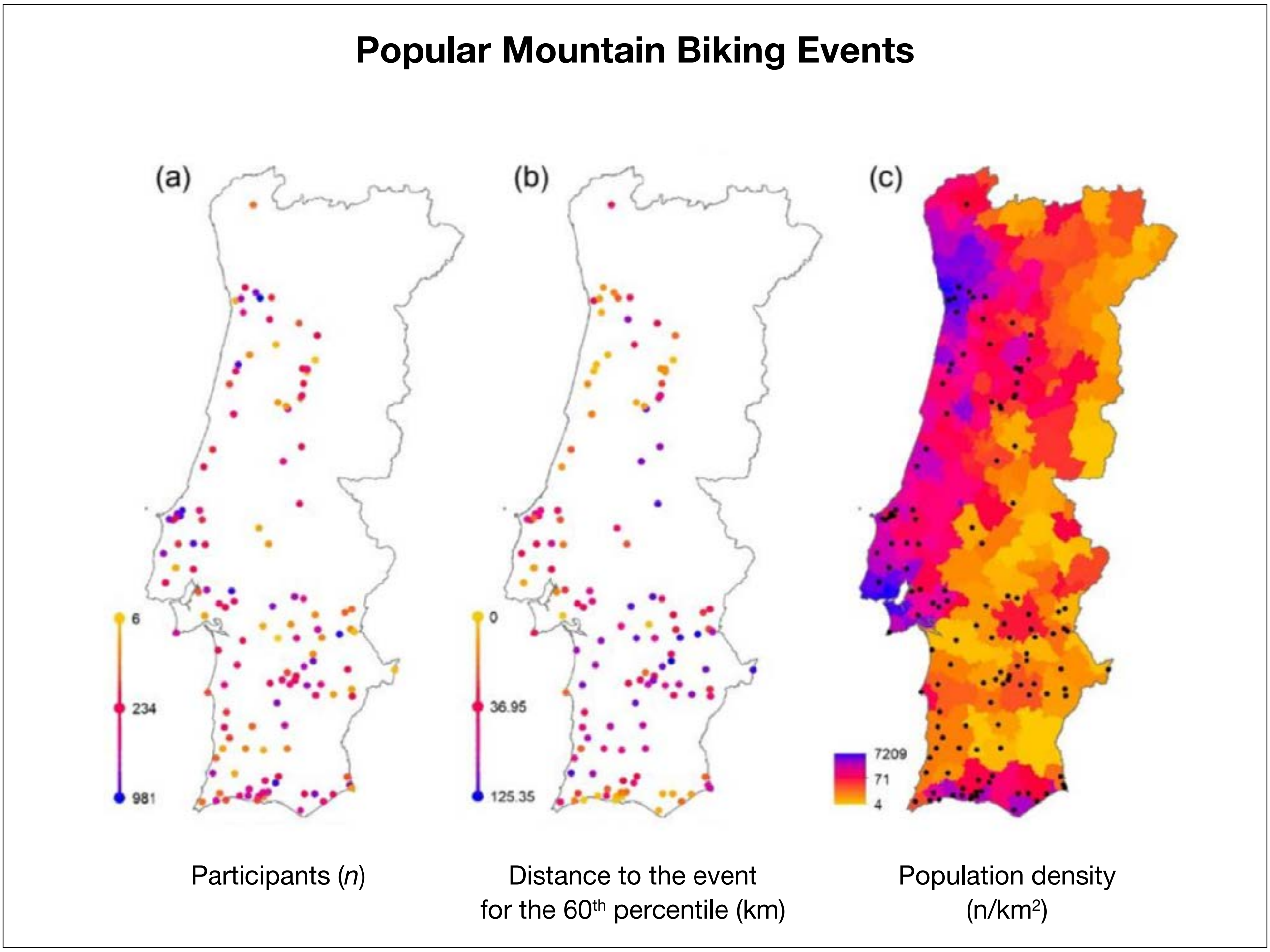


Table 2
Overall percentiles of distances from the place of residence to the mountain biking popular race events for the national level analysis, and the number of events where x % of the participants come from no more than 50 km away (data from Apedalar.pt).

	Avg	Percentiles									Max
		P25th	P50th	P60th	P70th	P75th	P80th	P85th	P90th	P95th	
Distance to the event (km)	44.44	15.75	36.91	36.95	46.36	52.64	60.09	71.22	88.60	123.43	590.16
Events where x % of the participants come from < 50 km (*n*)	106	145	116	116	97	80	64	44	19	7	2

Figure 5
National-level analysis: (a) Number of participants per event; (b) Distance from the place of residence to the event for the 60th percentile; (c) Population densities of Portugal's mainland plotted against locations of popular mountain biking events. (Sources: Apedalar.pt)



National-scale Analysis

Stage 3 – Proof of concept

In the national-scale analysis (see Table 2 and Figure 5), overall average distances are higher than those found within the local-scale analysis. Nevertheless, over 70 % of the participants live within a 50 km radius of the event's location. Moreover, even for the 75th percentile, for which overall distances to the event average 52.64 km, 80 out of the 148 events analysed (over 54 %) have three-quarters of participants from no more than 50 km away.

Discussion

Mountain biking is popular in natural and protected areas in peri-urban contexts. Compared to other popular outdoor activities such as walking, hiking, or even trail running that target off-road trails, paths, or single tracks, mountain biking raises different and more complex challenges for managers: (i) It can contribute to more significant soil erosion due to speed and tire width, especially on wet surfaces (Evju et al., 2021) or downhill trails, many of which are illegal (Campelo & Nogueira Mendes, 2016; Farías-Torbidoni & Morera, 2020); (ii) Compared to other regular users, bikers are more frequent visitors than hikers and walkers (Farías-Torbidoni & Morera, 2020); (iii) Compared to other users, bikers are often less aware of their impacts and conflicts (Cessford, 1995; Dorado et al., 2022); and (iv) Increased accessibility due to e-Bikes, allowing more people to go for longer rides, attracting new and less sportive bikers to the activity (Mitterwallner et al., 2021), thus contributing to massification.

Acknowledging and monitoring the habits, expectations, motivations, preferences, and behaviors of mountain bikers, as well as those of other users, can influence the management of recreational activities directly. A network of recognised trails and paths that match the parks' conservation goals and users' preferences, re-routing users if necessary (Evju et al., 2021), would positively impact nature conservation. As is already the case in some PA, race routes could be limited to the main network of tracks and paths with preservation and conservation in mind (Gómez-Limón García & Martínez Alandi, 2016).

The results of this study show that secondary data –in this case, the place of residence of events' participants– could contribute to understanding and monitoring recreational sports activities. Our results demonstrate that most participants of popular mountain biking events (up to 70–75 %) are from the surrounding regions and consider themselves regular users of the race territory. Even without the event, most would probably ride in the area. Regarding the rest of the participants, some also use the park as one of their regular riding areas –which is common within LMA (Nogueira Mendes et al., 2023). While popular sporting events such as the Maratona BTT Pinhal Novo/Arrábida concentrate users along the race route, they also avoid dispersion, which could easily lead to social conflicts and environmental impacts, such as trespassing and habitat fragmentation–to name just two of the severe impacts of recreational uses within PNArr and other parks in the region (Nogueira Mendes et al., 2023).

Although these results may be specific to the event analysed and its context, the observed spatial patterns repeat themselves at the national level within other popular race events of mountain biking. Nevertheless, recreational outdoor sports in different development stages may demonstrate different spatial patterns. In Portugal, for example, trail running is a relatively new activity compared to mountain biking and still attracts participants from far away (Julião et al., 2018; Nogueira Mendes et al., 2021b), but this is a pattern that might change with the sport's growing popularity and with the promotion of more events. Different patterns are also seen in more specialised sports, which usually involve fewer participants. For example, all triathlon events held in Portugal in 2015 combined involved only 15,673 participants, including affiliated and unaffiliated athletes (Federação de Triatlo Portugal, 2016), compared to the 35,147 participants for a quarter of all mountain biking events in Portugal studied here for the same year. Distances traveled to participate in popular sporting events may also depend on economic contexts, though this has yet to be studied in more detail. The larger average distances travelled by participants in events in southern Portugal are due not only to the lower population densities of the region, but also to the higher participation of bikers from Spain, for whom a drive of 80-100 km could represent the same cost (in terms of time and money) as for an AML resident participating locally.

An important reason to look at popular events such as the Maratona is that such races are the second largest manifestations of these popular outdoor activities themselves, regular practice being the first. Although only part of practitioners regularly participate in events, considering those who do have a high desire to participate again (Quirante-Mañas et al., 2023), surveying such events can help to monitor regular practice that also targets natural and protected areas (Julião et al., 2020) but is more challenging to study. For example, field surveys focusing solely on mountain bikers' places of residence would require substantially more resources to achieve the same amount of data.

Popular sports events could also be used to the direct advantage of the park's mission and conservation aims, for instance, to announce or advertise properly regulated trails and paths. Based on the number of participants and different race routes, events could also be used to test and verify the results of recreational ecology studies.

Trails and paths could be kept open, in good condition, and free from pioneer or exotic vegetation, and their sporadic use for events could simulate the now-abandoned practice of transhumance of sheep and goat herds (common in many mountain protected areas). This change has had significant environmental impacts, such as decreased native flora species.

Since few recreational ecology studies are conducted in real situations, demonstrations, and controlled field tests to study trampling or soil erosion (done before an event, immediately after it, and later) could be promoted, preferably outside the park's limits or in less sensitive areas. These events would also be an excellent opportunity to test new gear, such as drones or laser scans, to help improve monitoring techniques. Finally, popular race events can be an excellent opportunity to increase communication, raise awareness about regulations, environmental impacts, and conflicts, and promote best practices and behaviors.

Conclusions and recommendations

Popular sports events in peri-urban areas are mostly just another "Sunday ride" for their participants, who tend to take part in events held in areas that they already use regularly and are relatively close to their places of residence (up to 1 hour away). Distances from the place of residence to the event are consistent at peri-urban and national scales, although they tend to be greater for events with more participants or the ones in less-populated areas.

As suggested by previous research, e.g. Norman and Pickering (2017), this study demonstrates the value of using secondary data to monitor outdoor recreational uses of PA. Although some limitations could be pointed out to this type of research, namely the fact that not all practitioners of outdoor recreational activities are participants in this type of events, gathering secondary data from events is a relatively easy way to profile regular users, which could be important for park managers. Furthermore, popular mountain biking and trail running races, given the concentration in space and time of a significant number of participants, are also good opportunities to survey regular users of PA regarding other important issues related to the park's mission, such as preferences or expectations, which could be used to develop recreational offers under the PA's management plans and mandates. Future work could verify how these results are comparable for other sports or socioeconomic contexts or dig into the riding and sports attitude, which could lead to the mitigation of environmental impacts and promotion of better sustainable uses of PA.

To allow events or not in PA where strict conservation aims prevail, one should always consider the season and the projected race route, seeking alternatives if necessary. Creating new trails or paths for specific events should never be allowed, as well as night races. Races should start at least half an hour from the park limits to avoid large groups of riders arriving simultaneously on narrow roads or trails, and if this is not possible, small groups departing at short intervals should be arranged.

In the interest of limiting conflicts and impacts of popular outdoor recreational activities, it is preferable to sacrifice one day in the year, welcoming between 15 to 25 % of new visitors to participate in an organised event, than to have similar numbers of practitioners disorderly spread around every weekend during peak season. Finally, both environmental and social, direct and indirect knock-on effects of races should be evaluated in collaboration with practitioners and promoters (Campbell et al., 2021). This would allow participant numbers in future iterations of a race to be increased or decreased, with the agreement and understanding of all those involved, promoting compatibility between recreational uses, events, and nature conservation in these peri-urban contexts.

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SPORTS EDUCATION

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Effect of court dimensions on continuity in small-sided volleyball

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Laura Kluge fighting for the puck in the match between Germany and Hungary during the Eishockey Deutschland Cup, in Landshut, Germany, on November 9, 2024
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Abstract

Sport initiation through small-sided games in cooperative-oppositional sports has been shown to be an effective pedagogical strategy. Coaches or educators modify certain features of the internal logic, such as the playing space, in order to favour the adaptation of the sport to the players' potential and to develop specific playing principles. The aim of this study was to evaluate the effect of the dimensions of the playing space on the principle of continuity in gameplay during the initiation to small-sided volleyball. A total of 136 university students participated in an experimental study with a simple crossover design. The influence of wider courts (4.5 m x 6 m; 27 m^2) compared to narrower courts (6 m x 4.5 m; 27 m^2) on four variables in 3 x 3 situations was analysed: number of contacts, possessions, completed complexes and use of the overhead pass in the first action of each possession or complex of play. Mixed-effects multilevel linear regression models were constructed. The results revealed a significant increase in all variables analysed in favour of the wide court. The court size was found to significantly increase continuity in small-sided volleyball, respectively from highest to lowest were the variables of possessions, number of contacts, overhead passes in the first action and completed complexes. The importance of considering not only smaller playing spaces, but also the dimensions of the playing spaces in the initiation to volleyball was emphasised.

Keywords: comprehensive models, crossover design, internal logic, small-sided games, volleyball.

Introduction

In the field of sport education, the search for effective pedagogical methods and strategies to enhance learning in sport is a constant challenge (Abad-Robles et al., 2020; Fernández-Espínola et al., 2020; Hernández-Hernández et al., 2016). The most recent research on cooperative-oppositional sports indicates that game-based pedagogy is effective (Abad-Robles et al., 2020; Miller, 2015). To this end, research that evaluates sport teaching models offers essential evidence for the training and development of participants' competencies (Barba-Martín et al., 2020; Ortiz et al., 2023).

According to the principles of motor action theory, teachers and coaches must have an in-depth knowledge of the distinctive features of the internal logic of the sport, in order to introduce modifications in the relationships that the player will establish with other participants, space, time and equipment (Parlebas, 2001). These modifications will allow players to adapt their motor actions to new challenges that develop their thinking as a unit (in decisional, emotional, relational and structural dimensions) (Lavega-Burgués, 2007; Ureña-Espa et al., 2022). In this way, a logical correspondence will be established between the teaching-learning situations and the acquisition of the principles of play, which are the pillars of game-based teaching models (Martínez-Santos et al., 2020; Menezes-Fagundes et al., 2021; Palao-Andrés & Guzmán-Morales, 2008; Ureña-Espa et al., 2022).

These adaptations of the game situations applied from the comprehensive model (Teaching Games for Understanding), are usually expressed through two fundamental pedagogical principles: modification by representation and exaggeration (Thorpe et al., 1986). Modification by representation involves recreating conditions similar to those of the formal sport, usually incorporating changes such as a reduction in the playing space, the number of players, or the way equipment is handled. The aim is for participants to face challenges similar to those they would experience in a match and try to solve the problems posed by applying the basic principles of the game, while considering the adaptation of the game situation to their abilities (Thorpe et al., 1986). On the other hand, modification by exaggeration consists of highlighting or emphasising certain internal features of a game situation in order to emphasise a certain game principle or a specific action. This manipulation of the internal logic of the game enables the creation of specific learning situations in which players are able to understand and apply certain strategic principles or actions more effectively than in the context of formal sport (Thorpe et al., 1986).

There is scientific evidence of the effects of spatial modification on tactical and technical learning in cooperative-oppositional sports; a topic which is of scientific interest (Rico-González et al., 2020). Studies (mostly of invasion sports) show a significant improvement in tactical-technical behaviour in football, basketball, handball and hockey, among others (Rocha et al., 2020a). The manipulation of space in different game situations has distinct effects on the occupation, exploration and domination of the court, ball circulation, performance of technical actions, decision-making and specific tactical behaviours (Dello Iacono et al., 2018; Ric et al., 2017; Rico-González et al., 2020; Timmerman et al., 2017).

However, research examining the effects of modifying the internal logic in split-space sports is still scarce (Menezes-Fagundes et al., 2024; Palao-Andrés & Guzmán-Morales, 2008; Rocha et al., 2020a). In the specific case of sports such as volleyball, more scientific evidence is needed to demonstrate how the acquisition of fundamental principles of play in sport initiation, such as continuity, initiative and finishing, can be improved (Contreras-Jordán et al., 2007; Ureña-Espa et al., 2022).

Inexperienced players often find it difficult to sustain long sequences of play. Hence, learning to build continuity within the game is fundamental knowledge in the initial stages (Arias-Estero, 2008; Ureña-Espa et al., 2013, 2022). In volleyball, this continuity consists of maintaining an uninterrupted sequence of actions during the game (Ureña-Espa et al., 2013). It is therefore imperative that the proposed learning situations provide a minimum level of continuity to ensure the development of the players' skills and the understanding of the principles of play that are applied in each task (Arias-Estero, 2008).

Among the different principles of play, Hopper (1998) defines consistency as the ability to resend the ball to the opponent's field, favouring the continuity of the play. The existence and relevance of this principle of play underlines the need to provide learning situations that promote the ability to maintain a minimum level of continuity (Ureña-Espa et al., 2013).

However, we are not aware of research that has explicitly examined the effect of court size in relation to the game principle of continuity in sport initiation. In light of this theoretical framework, the present research aims to evaluate the effects of the dimensions of the playing space on the principle of continuity during the initiation to small-sided volleyball. The following hypothesis is put forward: in areas of the same dimension, those spaces with greater width will generate greater continuity than courts with greater depth.

Method

Participants

A total of 136 university students participated with a mean age of 20.85 (SD = 2.44 years), 46 females (33.82%) and 90 males (66.18%). The inclusion criterion was that participants had no sporting history associated with federated volleyball. All students agreed to participate in the study by signing the informed consent form. This research was approved by the Clinical Research Ethics Committee of the Catalan Sports Council in 2022 (Code 011/CEICGC/2022). In addition, the present research followed the ethical guidelines set out in the Declaration of Helsinki.

Regarding the observation units, 38 games were analysed, totalling 1,072 analysed points that made up the sample of this research.

Design and Procedures

To determine the effect of a binary categorical variable (court dimension) on a quantitative response variable (continuity), an experimental study was carried out with an AB-BA crossover design. Observation was used as a technique for data collection within the experimental methodology. The participants were divided into five teaching groups. Each teaching group was organised into teams of three to five players. In order to homogenise the levels of play of the teams, 1 x 1 situations were previously conducted to classify them by different levels (from 1 to 8). This action led to the identification of 38 teams of a similar level.

Each game was played on two different areas of play: a wide court and a narrow court. The wide court measured six metres wide by four and a half metres long (6 m x 4.5 m), while the narrow court measured four and a half metres wide by six metres long (4.5 m x 6 m). Therefore, the total area of play in each situation was 27 m^2, with the dimensions of these areas being modified. Thus, two groups (eight games) followed the wide-narrow sequence, while the remaining three groups (11 games) followed the reverse sequence. A set of eight minutes was played on each court, with a wash-out period of five minutes between the two matches. At the start of the second situation, the same initial rotation adopted in the first scenario was maintained. Teams with more than three players made constant changes of one player in each rotation.

The allocation of the sequence of courts for each group was done on a randomised basis. All the matches were recorded with Sony Handycam cameras (HDR-CX405 model) from a low angle and in a perpendicular position to the net, in order to facilitate the subsequent observational analysis.

The game situations consisted of 3 x 3 games, with the following rules of play: underarm serve or overhead pass behind the baseline; maximum three serves per player (when any player reaches this limit, the team rotates and holds serve); and change of sides every seven points. In both situations, the net was located at a height of 2.35 metres.

38 matches were observed, with 19 games between the teams on each of the courts. We used court design as an independent variable and four dependent variables linked to continuity of play (see Table 1).

Table 1
Description of the variables studied.

Role	Variable	Categories	Description
Independent	Court design	Wide (W)	Court of 6 metres wide by 4.5 metres deep.
		Narrow (N)	Court of 4.5 metres wide by 6 metres deep.
Dependent	Number of total contacts produced in each rally	C	Number of contacts made in each rally between the two teams.
Dependent	Possessions made per point	P	Total number of ball possessions per team executed in each rally.
Dependent	Game complexes completed per point	K	Frequency at which the maximum number of contacts (three) was used up in each possession per rally.
Dependent	Number of overhead passes in the first action per point	O	Number of defensive actions carried out with overhead pass on the first touch in each rally.
Covariate	Period	Per	Allocation of the period in which each set is played in relation to the intervention (match one or match two).
Covariate	Sequence	Seq	Order of allocation of the courts on which the sets were played (WN or NW).
Possible confounding variable	Score difference	SD	Difference in the score between the two teams at the end of each set played.

WN: wide-narrow; NW: narrow-wide.

Finally, 1,072 rallies were observed on the *ad hoc* observation instrument, with the observation criteria set out in Table 1. The analysis was recorded using Microsoft Excel. For the reliability process of the observational record, two observers conducted joint pilot tests to test the observation instrument, followed by a reliability test in which both observers independently observed 411 points in the sample (38.34%), therefore reaching an excellent level of agreement for all the variables analysed (contacts per rally: 0.980; possessions per point: 0.962; completed complexes per point: 0.974; overhead pass in the first action: 0.850) (Fleiss, 1986).

Statistical Analysis

For the data analysis, the 1,072 observed points were collated to generate a mean for each of the four observed variables per match (see Table 2).

Table 2
Data analysed in the mixed models.

G	Per	Seq	Ct	PP	C	P	K	O	SD	NP	PM	AA
1	1	WN	W	17	10.8	5.4	2.2	1	0	9	77.8	22.1
1	2	WN	N	22	7.4	3.8	1.4	0.6	10	9	77.8	22.1
2	1	NW	N	27	6.1	3.4	1.1	0.4	3	8	37.5	21
2	2	NW	W	35	5.8	3.2	0.9	0.7	9	8	37.5	21
3	1	WN	W	25	8.1	4.4	1.4	0.8	0	8	62.5	22.7
3	2	WN	N	35	5.3	3	0.8	0.8	7	8	62.5	22.7
4	1	NW	N	26	6.8	3.7	1.3	0.4	5	9	55.6	20.3
4	2	NW	W	32	8.8	4.3	1.9	1	6	9	55.6	20.3
5	1	NW	N	32	7.4	4.1	1.3	0.5	9	6	100	21.7
5	2	NW	W	28	8.3	4.5	1.3	0.9	1	6	100	21.7
6	1	WN	W	33	6.3	3.4	1.2	0.4	12	8	87.5	21.4
6	2	WN	N	22	6.2	3.3	1.1	0.5	1	8	87.5	21.4
7	1	NW	N	24	6.2	3.2	1.3	0.5	4	6	100	20
7	2	NW	W	20	8.1	4.3	1.1	0.9	5	6	100	20
8	1	WN	W	36	6.9	3.8	1.1	1	11	6	100	20.3
8	2	WN	N	30	6.5	3.6	1.0	0.9	1	6	100.0	20.3
9	1	WN	W	33	5.9	3.4	1.1	0.4	4	7	71.4	22.6
9	2	WN	N	25	7.5	3.9	1.3	0.5	8	7	71.4	22.6
10	1	WN	W	25	9.4	4.6	2.0	0.6	3	8	87.5	20.3
10	2	WN	N	29	5.7	3.2	1.0	0.4	3	8	87.5	20.3
11	1	NW	N	28	6.2	3.2	1.3	0.5	2	8	87.5	21.0
11	2	NW	W	27	7.2	3.6	1.5	0.1	5	8	87.5	21.0
12	1	NW	N	24	6.3	3.2	1.4	0.3	7	8	62.5	21.3
12	2	NW	W	27	7.7	4.0	1.5	0.7	3	8	62.5	21.3
13	1	NW	N	36	4.8	2.8	0.8	0.5	13	6	66.7	19.8
13	2	NW	W	37	4.8	3.2	0.5	0.7	8	6	66.7	19.8
14	1	WN	W	30	5.2	2.9	1	0.7	0	7	28.6	19.8
14	2	WN	N	24	3.8	2.4	0.4	0.7	11	7	28.6	19.8
15	1	NW	N	23	6.5	3.7	1	0.7	4	7	28.6	20.2
15	2	NW	W	8	5.3	3.3	0.9	0.8	3	7	28.6	20.2
16	1	WN	W	30	5.3	3.1	0.9	0.6	5	7	57.1	20.8
16	2	WN	N	26	5.5	3	1	0.6	6	7	57.1	20.8
17	1	NW	N	34	4.7	2.7	0.8	0.1	5	6	50	20.2
17	2	NW	W	32	6.8	3.8	1.2	0.5	4	6	50	20.2
18	1	NW	N	37	4.2	2.9	0.4	0.9	9	6	33.3	19.7
18	2	NW	W	30	3.6	2.8	0.1	0.7	5	6	33.3	19.7
19	1	NW	N	31	4.9	2.7	0.8	0.7	10	6	66.7	19.9
19	2	NW	W	32	5.8	3.4	0.8	1.4	2	6	66.7	19.9

G: game; Per: period; Seq: sequence; Ct: court; PP: points played; C: contacts per rally; P: possessions per rally; K: complexes completed per rally; O: overhead passes in the first action per point; SD: score difference; NP: number of players in the match; PM: percentage of men per match; AA: mean age of players.

Four multilevel mixed-effects linear regression models were then constructed. The independent variable (exposure) was the court dimension, wide (= 1) and narrow (= 0). The dependent variables (response) reflected the continuity of play: number of contacts, possessions, completed game complexes, number of overhead passes in the initial action. The narrow court was considered as a reference category on the basis of the hypothesis put forward. The covariates considered were period and sequence, and the potential confounding variable was the score difference at the end of the match.

The covariates of period and sequence originally constituted a crossover design study, with the aim of neutralising possible external effects on the dependent variables (Doménech, 2017). The covariate of period ensures that having played in a previous situation (Period 1) does not impact on the results found in the second situation (Period 2). This covariate reflects how these effects capture possible interactions between intervention, period and group in the observed variables. The covariate of sequence is intended to ensure that the order of match play (wide-narrow or narrow-wide) does not interfere with the observed variables (Doménech, 2017). Non-significant results of these covariates point to the non-existence of these effects on the dependent variables and provide a more robust test of the effect of the independent variable. Finally, in the regression process, when inserting the possible confounding variable "score difference", a difference of more than 5% in the averages of the dependent variables was identified and, for this reason, it was added to the model as an adjustment variable.

Results

According to the data presented in Table 3, in all the mixed models there was a significant increase in the continuity of play in the analysed variables when playing on a wide court compared to a narrow one (contacts per point: 0.874, standardised coefficient = .306, 95% CI [0.210, 1.539], possessions per point: 0.414, standardised coefficient = .352, 95% CI [0.128, 0.699]; completed complexes per point: 0.181, standardised coefficient = .232, 95% CI [0.014, 0.348]; overhead pass on first action: 0.129, standardised coefficient = .271, 95% CI [0.005, 0.252]). All results were statistically significant ($p < .05$) and the effect size was moderate for all variables studied (Fey et al., 2023).

The mixed models did not show significant differences on the covariate period, except for the variable of overhead passes in the first defensive action. In this case, the results of Period 2 were influenced by Period 1. In relation to the covariate of sequence, no significant difference was found for all variables, meaning that there was no interference with the results regardless of the order of the intervention. The results of the mixed models, and the standardisation of the coefficients obtained, can be found in Tables 3 and 4, respectively.

Table 3
Effect of court dimensions on continuity variables (mixed models).

Variables	Categories	Coefficient	Standard error	z	p	Confidence interval
Contacts per point	Court					
	Narrow	(base)				
	Wide	.874	.339	2.58	.010*	[.210, 1.539]
	Sequence					
	WN	(base)				
	NW	–.370	.566	–0.65	.514	[–1.480, .740]
	Period					
	1	(base)				
	2	–.129	.339	–0.38	.702	[–.794, .534]
		–.110	.051	–2.13	.033	[–.212, –.008]
	Constant	6.803	.573	11.86	.000	[5.679, 7.928]

* $p < .05$; W: wide; N: narrow; WN: wide-narrow sequence; NW: narrow-wide sequence.

Table 3 (continued)
Effect of court dimensions on continuity variables (mixed models).

Variables	Categories	Coefficient	Standard error	z	*p*	Confidence interval
Possessions per point	Court					
	Narrow	(base)				
	Wide	.414	.145	2.85	.004*	[.128, .699]
	Sequence					
	WN	(base)				
	NW	−.089	.223	−0.40	.688	[−.526, .347]
	Period					
	1	(base)				
	2	.013	.145	0.09	.925	[−.271, .298]
		−.055	.022	−2.50	.012	[−.098, −.012]
	Constant	3.635	.234	15.51	.000	[3.176, 4.094]
Complexes completed per point	Court					
	Narrow	(base)				
	Wide	.181	.085	2.12	0.034*	[.014, .348]
	Sequence					
	WN	(base)				
	NW	−.110	.163	−0.67	0.500	[−.431, .210]
	Period					
	1	(base)				
	2	−.116	.085	−1.37	.171	[−.284, .050]
		−.024	.013	−1.83	.068	[−.049, .001]
	Constant	1.269	.157	8.07	.000	[.961, 1.578]
Overhead pass on the first defensive action	Court					
	Narrow	(base)				
	Wide	.129	.063	2.04	0.041*	[.005, .252]
	Sequence					
	WN	(base)				
	NW	−.015	.092	−0.17	0.864	[−.196, .164]
	Period					
	1	(base)				
	2	.142	.063	2.26	.024*	[.018, .266]
		−.011	.009	−1.23	.217	[−.030, .006]
	Constant	.576	.099	5.82	.000	[.382, .770]

* *p* < .05; W: wide; N: narrow; WN: wide-narrow sequence; NW: narrow-wide sequence.

Table 4
Standardisation of coefficients for the effects of court size on continuity.

Variables	Contacts per point	Possessions per point	Complexes completed per point	Overhead pass on the first defensive action per point
Narrow court	(base)			
Wide court	.306	.352	.232	.271
WN sequence	(base)			
NW sequence	−.136	−.089	−.144	−.041
Period 1	(base)			
Period 2	−.026	.030	−.128	.298

WN: wide-narrow; NW: narrow-wide.

Discussion

This article has evaluated the effect of the dimensions of the playing space on the principle of continuity in initiation to small-sided volleyball. The results obtained revealed significant differences in favour of the wide court in all the variables related to the continuity of play (number of contacts, number of possessions, number of completed complexes and number of overhead passes in the first touch per point).

When these data were subjected to the coefficient homogenisation process, the most pronounced effect manifested itself in the possessions per point variable, followed by the number of contacts per point. Considering that a medium effect size was obtained for all variables, we can conclude that the wide court led to more continuity than the narrow court.

No scientific articles have been found that have specifically investigated the impact of the configuration of the playing space on the principle of continuity. However, research has identified significant correlations between the effects of the configuration and use of space, and the quality of play in volleyball, which refer to variables linked to continuity (Barsingerhorn et al., 2013; Gil-Arias et al., 2016; Jorge Rodrigues et al., 2022; Paulo et al., 2016; Rocha et al., 2020a, 2020b).

Findings similar to ours were identified by Rocha et al. (2020a) that compared the technical-tactical performance in side out (reception, set and attack) of male juniors in two situations of 2 x 2 in a reduced space (court 3 metres long by 3 metres wide and court 2 metres long by 4.5 metres wide). It is observed that using the wider court significantly improves technical execution, adjustment and decision making in side out. On the other hand, by playing on the square court, players improve the effectiveness of their reception. The authors suggest that a shorter court allows for better technical performance in reception (Rocha et al., 2020a). In line with our findings, it is plausible to assert that by creating situations on wider rather than longer courts that encourage execution, adjustment and decision making on the first touch, continuity of play is enhanced.

In contrast to our study, where both courts had the same total area (27 m^2), other studies have analysed the effect of different court sizes on game variables. Jorge Rodrigues et al. (2022) compared the tactical-technical performance of novice players on four volleyball courts of different sizes (3.0 x 3.0 m, 4.0 x 4.0 m, 4.6 x 4.6 m and 5.2 x 5.2 m). The results obtained indicate that on smaller courts the execution of defensive actions is improved by generating shorter movements and facilitating the adjustment of their interventions. However, a decrease in the effectiveness of attacks was identified; this is attributable to the greater demand for precision in the execution of these actions due to the use of limited space. On the other hand, larger courts provided better results in effectiveness and decision making, especially in offensive actions.

Similarly, Gil-Arias et al. (2016) implemented a didactic unit focused on volleyball, where different elements of its internal logic were manipulated (the playing space, the height of the net and the number of participants). The aim was to assess the effects of these modifications on the efficacy and decision making of the attack among schoolchildren. The results obtained indicated a significant improvement in the variables analysed. In relation to playing space, especially in the early stages of the process, it has been observed that larger courts promote decision-making and the execution of attacks. This is mainly due to the greater space that is created between the defenders, making it easier to identify empty spaces.

However, Barsingerhorn et al. (2013) observed that the trajectory of the ball influences the choice of the action used, indicating that there is greater difficulty in making receptions that require a displacement prior to contact. These results help to strengthen the idea that the dimensions and configuration of the playing space influences the motor behaviour of the players.

In relation to continuity in 6 x 6 volleyball, in the children and adult categories, other studies have identified that approximately a quarter of the points played are lost exclusively due to a lack of continuity, mainly due to lack of coordination of the team in the side out (complex I) or difficulty in executing the first action (Callejón-Lirola, 2006; Ureña-Espa et al., 2013).

Regarding the lack of coordination in the team, our findings suggest that the use of small-sided situations in spaces with more width than length seem to encourage the execution of the three contacts allowed per possession, as an increase in the number of completed complexes was observed. This result, combined with the increase in the number of possessions and contacts per rally, indicates that the wide court seems to stimulate more collective play than the narrow court.

With regard to the difficulty of carrying out the first action, different studies have examined this issue in depth (Afonso et al., 2009, 2012; Barsingerhorn et al., 2013; Paulo et al., 2016). Afonso et al. (2009) found that the use of overhead passes increases the likelihood of successful ball reception in real game situations with professional players.

About the types of pass used in the first action, Paulo et al. (2016) concluded that a more advanced initial receiving position favours the use of overhead passes in decontextualised situations among expert players. In our research, we have not considered the position of the players, but it is intuited that the wide court naturally generates a more forward position in relation to the narrow court, as the players tend to position themselves centrally in relation to the playing space.

In the study we conducted, we found that more overhead actions are performed on the wide court compared to the narrow court. Barsingerhorn et al. (2013) found that bumping is used more frequently in situations that require greater displacement, especially when balls are directed towards the forward area. However, their results showed no significant difference in effectiveness between the use of overhead passes and bump passes.

However, the application of the AB-BA crossover design showed that the variable overhead pass in the first action had a non-systematic effect. It has been observed that, on average, overhead passes are used more frequently in the second situation in a systematic way, regardless of the order used. This means that there was some kind of learning between the two situations that systematically encouraged the use of overhead passes in the second game. Therefore, from the data we obtained, we cannot affirm that it is the court width variable that favours the use of the overhead pass, as there may be other variables that enhance this effect. For further crossover design studies, we suggest a wash-out time to neutralise possible learning effects of situation one on situation two.

Conclusions

This study confirms that the configuration of the playing space significantly influences the continuity of volleyball game actions. This finding strengthens the hypothesis that modifying the internal logic of game situations generates different impacts on participants. It is therefore advisable to incorporate different criteria for selecting and proposing learning situations (Gil-Arias et al., 2016).

The internal logic of any sport requires participants to solve problems related to the relationship with others, space, equipment and time. Understanding the effects of modifying any of these relationships on motor behaviour is a key factor in favouring personalised sport initiation programmes (Gil-Arias et al., 2016; Martínez-Santos et al., 2020; Menezes-Fagundes et al., 2021; Parlebas, 2020).

According to the specific literature, analysing crossover designs based on several students' *t* tests is a suitable procedure for simple crossover design studies (Doménech, 2017). This statistical analysis allows for the inclusion in the model of the independent and dependent variables, the covariates of period and sequence, as well as other possible covariates such as score difference, gender and mean age.

This study has certain limitations, most notably the absence of a control group. It would have been feasible to propose in this study the inclusion of a group participating in a 5 m x 5 m court. Also, the short washout period of five minutes may also have interfered with the non-systematic effect observed for the variable overhead pass in the first action. However, it is important to note that this court would not have the same surface area in square metres as those used in the study. For future research, the use of the standard mini-volleyball court as a control group could be considered. In addition, it would be relevant to explore alternative wide and narrow court designs that maintain the same or similar 36 m^2 area as the standard court (6 m x 6 m), to enable comparisons between court designs (for example, 5.08 m x 7.1 m and 7.1 m x 5.08 m).

We suggest further research to broaden the understanding of the effects of playing space in a variety of split-space sports. In addition, it would be interesting to explore how the modification of other factors of internal logic influences the players' motor behaviours when trying to appropriate the game principles of sports.

Despite the fact that this was an experimental study and the groups were homogenised according to their level of play, there were matches in which the difference in the score between the two teams at the end of the match was considerable. Therefore, when introducing the score difference covariate in the mixed model, we observed differences of more than 5% in the mean of all the variables studied. This means that the difference in score must be taken into account as it adjusts the results obtained. We recommend that future studies that want to analyse continuity should consider score difference as a possible adjustment variable.

The consistency of the results on the variables studied supports the relevance of the dimensions of playing space in the teaching of volleyball. The results corroborate the hypothesis that wider and shorter courts may be more conducive to continuity than narrower and longer courts. This finding provides interesting information for the design of game situations aimed at optimising the initiation of players into sport using small-sided games in split-space sports.

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