

The influence of contextual variables on physical and physiological match demands in soccer referees

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doi: 10.18176/archmeddeporte.00111

Recibido: 11/02/2022

Aceptado: 13/09/2022

Summary

The aim of this paper was to examine how contextual factors affect match demands in amateur referees. Twenty-three field referees participated in this study. Match physical and physiological demands were monitored. Results showed that referees recorded greater total distance ($p < 0.01$), Power_{mean} ($p < 0.01$), Speed_{mean} ($p < 0.05$) and Cadence_{mean} ($p < 0.05$) on natural fields compared to artificial turf fields. Greater total distance ($p < 0.01$), Power_{mean} ($p < 0.01$), Speed_{mean} ($p < 0.01$), Cadence_{mean} ($p < 0.05$) and Stiffness_{mean} ($p < 0.05$) were recorded in above-standard fields in comparison to below-standard fields. Referees recorded greater total distance ($p < 0.05$), Power_{mean} ($p < 0.05$) and Speed_{mean} ($p < 0.05$) during matches played with an environmental temperature of over 20° compared to those matches played at temperatures below 10°. Referees covered more total distance in second-round matches compared to first round matches. Results suggest that the physical demands supported by soccer referees during official matches are influenced by the type of surface, pitch size, environmental temperature and period of the season, however, physiological demands do not seem to be conditioned by contextual factors

Key words:

Field referees. Season period. Field size. Turf. Temperature

La influencia de las variables contextuales en las cargas físicas y fisiológicas de los árbitros de fútbol

Resumen

El objetivo principal de este trabajo fue examinar cómo los factores contextuales afectan a la carga de partido de los árbitros amateur. Veintitrés árbitros de campo de la División de Honor española participaron en este estudio. Para ello se registraron la carga física y fisiológica de partido. Los resultados mostraron que los árbitros registraron una mayor distancia total ($p < 0,01$), potencia media ($p < 0,01$), velocidad media ($p < 0,05$) y cadencia media ($p < 0,05$) en los campos naturales en comparación con los campos de césped artificial. Se registró una mayor distancia total ($p < 0,01$), potencia media ($p < 0,01$), velocidad media ($p < 0,01$), cadencia media ($p < 0,05$) y media de stiffness medio ($p < 0,05$) en los campos más grandes que la media en comparación con los campos por debajo de la media. Los árbitros cubrieron más distancia total ($p < 0,05$), potencia media ($p < 0,05$) y velocidad media ($p < 0,05$) durante los partidos jugados con una temperatura ambiental superior a 20° en comparación con los partidos jugados con temperaturas inferiores a 10°. Los árbitros recorrieron más distancia total en los partidos de la vuelta en comparación con los partidos jugados en la ida ($p < 0,05$). Los resultados sugieren que la carga física de los árbitros de fútbol durante los partidos oficiales, están influenciadas por el tipo de superficie, el tamaño del campo, la temperatura ambiental y el período de la temporada, en cambio la carga fisiológica no parece estar condicionada por los factores contextuales.

Palabras clave:

Árbitros de campo. Período de temporada. Tamaño del campo. Césped. Temperatura.

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Introduction

Thousands of amateur soccer matches are played weekly around the world, officiated by field referees and their two assistants from the national level upwards, and with only field referees officiating the majority of matches at grassroots and lower senior competitive levels. From a physical and physiological perspective, refereeing is an intermittent activity that mainly requires the implication of the aerobic system, although it is interspersed with periods of high-intensity requiring the anaerobic system^{1,2}. In terms of total distance covered and distance covered at different speeds, amateur referees cover around 10-11 km per match, of which almost 3 km are covered at high intensity (over 13 km·h⁻¹) and approximately 800 m at high speed (over 18 km·h⁻¹)^{3,4}. In addition, the accelerations and decelerations of referees have also been investigated. In this respect soccer referees cover around 1.5 km accelerating and around 400 m decelerating^{3,5,6}. In addition, recent studies have validated the Stryd Power Meter as a suitable device to record the physical demands of referees during official matches^{4,7}. Moreover, these studies have reported that the mean power registered by soccer referees during a match is around 120.72 ± 11.75 W. It has also been reported that the mean vertical oscillation presented by referees is 8.00 ± 0.54 cm, the mean ground contact time is 541.21 ± 57.73 m·s⁻¹ and the mean stiffness is 9.28 ± 0.56 KN·m⁻¹⁽⁴⁾.

Moreover, referees present a mean heart rate (HR_{mean}) above 85% of their maximum HR (%HR_{peak})^{3,8} during matches, while according to the match load recorded using Edward's training impulse (TRIMP), this population recorded 390 ± 34 AU during match-play⁹. Therefore, possessing an adequate capacity to respond to these demands during match play can help them to face matches with sufficient ability to follow the pace of the match and be close to the actions in order to make correct decisions^{10,11}.

Contextual variables has been previously analyzed in soccer players showing that several of them could influence their physical and physiological demands during match-play, highlighting the level of the opposing teams¹², the match outcome¹³, the type of surface^{14,15}, the environmental temperature¹⁶⁻¹⁸ and/or the period of the season¹⁹, among other factors. Considering the strong association observed between the activity performed by outfield players and field referees²⁰⁻²², it could be assumed that such contextual variables could also influence referees' match demands. However, few studies have analyzed the influence of contextual variables such as age, experience and competitive level on the physical and physiological demands encountered by soccer referees during competition^{23,24}, and only one study has analyzed the influence of the level of the opposing teams on the referees' running activity²⁵. In this respect, a gap has been identified in the literature on how contextual factors such as field dimensions or type of field could influence the referees' match demands. This aspect could be important to analyze since official matches at the amateur level are played on fields of different characteristics in terms of type and dimensions. Likewise, there is a lack of studies considering the influence of environmental temperature and the period of the season on the referees' match demands, although Taylor *et al.*²⁶ observed that warm and cold environments do not influence decision-making ability.

Previous studies have analyzed the evolution of referees' demands as the match progresses showing a decrease in total distance or distance covered at high intensity (>13 km·h⁻¹) during the second half of matches compared to the first half^{7,27-29}. Similarly, it was found that amateur referees showed higher values regarding physiological indicators such as HR, lactate concentration and tympanic temperature at the end of the matches and immediately after completion³⁰. In addition, neuromuscular fatigue (i.e., distance decrease in horizontal jump performance) after finishing the matches has been previously reported¹. Other studies have gone further and have analyzed referees' match demands during shorter periods (i.e., 15 min) showing that professional referees' match demands are higher in the initial periods of the match^{5,31,32}. However, Ozaeta *et al.*⁷ showed that the match demands increased in the last 15 min of the match in amateur soccer referees, so it would be interesting to investigate whether contextual factors may be the reason for the increased match demands.

Attending to the aforementioned information, and to understand the physical and physiological demands in soccer referees as well as to optimize the training process, the aim of this study was twofold: 1) to assess the differences in the physical and physiological responses encountered by soccer referees regarding each contextual variable (i.e., type of turf, pitch size, period of season, and environmental temperature) during official matches, and 2) to analyze the physical and physiological variations during 15 min periods according to each contextual variable (i.e. type of turf, pitch size, period of season, and environmental temperature). We hypothesized that contextual variables could influence the referees' physical and physiological responses during match play.

Material and method

Design

An observational (i.e., descriptive-comparative) design was used to analyze the physical and physiological demands encountered by field soccer referees according to contextual variables (i.e., type of turf, pitch size, period of season, and environmental temperature). A total of 23 official matches were analyzed during the in-season period (i.e., from November to March) of the 2019-2020 season. The data included measures of physical [total distance covered, power, speed, cadence, vertical oscillation, ground contact time (GCT) and stiffness] and physiological [HR_{mean}, %HR_{peak}, HR zones (from zone 1 to zone 5) and TRIMP] match demands.

Subjects

Twenty-three male field referees (age: 25.65 ± 3.30 years; height: 173.4 ± 3.8 cm; body mass: 64.86 ± 5.82 kg; body mass index, BMI: 21.56 ± 1.67 kg·m⁻²) who officiated soccer matches in the División de Honor de Vizcaya (Spain), participated in the present study. The referees had an experience in the category at least 3 years. All the participants trained at least twice a week and officiated matches in the category twice a month. Participants were informed of the procedures, methods, benefits, and possible risks involved in the study before signing their written consent. This investigation was performed in accordance with

the Declaration of Helsinki and was approved by the Ethics Committee of The University of the Basque Country (Code: M10/2018/289).

Procedures

Before the beginning of the match all the officials performed a 10 min warm-up consisting of running, stretching, short sprints and progressive sprints. The 15 min half-time data were excluded from the external and internal match load analysis. All the matches were played between 11 am and 5 pm.

Type of turf. The soccer matches were played on natural grass and artificial surfaces as proposed by Stone *et al.* (2016)¹⁴.

Pitch size. According to the rules of the game approved by the International Football Association Board (IFAB) for international matches, the touch line must have a minimum length of 100 m and the goal line a minimum length of 64 m³³. In this regard, we opted to differentiate fields with a size of over 100 x 64 m (above-standard) versus fields with a size below 100 x 64 m (below-standard).

Period of the season. Two rounds (first and second) were determined as previously used by Mohr *et al.* (2003) with soccer referees.

Environmental temperature. Matches played at below 10° and above 20° were selected because previous studies have mainly focused on matches played at high temperatures (>20° Celsius)^{16,17} and this study tried to see if there were differences between matches played at high and low temperatures.

Physical demands. Referees' physical demands were monitored using a Stryd Power Meter (Stryd, Inc., Boulder, Colorado, USA), which was placed over the right soccer boot with a plastic clip regardless of lower limb dominance³⁴. The Stryd Power Meter has been shown to be a valid device for measuring external demands in soccer referees⁴. The Stryd was activated following the manufacturer's recommendations for offline use. It records total match data for the following variables: total distance covered (km), mean power (W), mean speed (km·h⁻¹), mean cadence (steps·min⁻¹), mean vertical oscillation (cm), mean GCT (m·s⁻¹) and mean stiffness (KN·m⁻¹).

Physiological demands. Referees' HR was monitored during matches with a Polar Team 2 device (Polar Team System™, Kempele, Finland) at 1 s intervals. HR_{mean} and %HR_{peak} were considered for this study, and TRIMP was also calculated. According to the study by Edwards (1993)³⁵, intensity was represented by the time spent in 5 arbitrary HR zones (Zone 1, 50–60% of HR_{peak}; Zone 2, 60–70% of HR_{peak}; Zone 3, 70–80% of HR_{peak}; Zone 4, 80–90% of HR_{peak}; and Zone 5, 90–100% of HR_{peak}) multiplied by the number of each zone (1, 2, 3, 4, and 5). The sum of values obtained for each zone represented TRIMP, measured by arbitrary units (AU).

Statistical analyses

Data are presented as mean ± standard deviations (SD). Normality of data distribution and homogeneity of variances were tested using the Shapiro–Wilk and Levene tests, respectively. A two-way analysis of variance (ANOVA) was applied in order to test for differences in variables recorded during 15 min in-game periods, with contextual variables (i.e., type of turf, pitch size, period of season and environmental temperature) introduced as between-subject factors, and 15 min periods as a

within-subject factor. Data sphericity was evaluated using Mauchly's test, and Greenhouse–Geiser or Huynh–Feldt corrections were applied for non-spherical distributions. The Bonferroni corrections were applied for post-hoc comparisons. Practical significance for pair wise comparisons was assessed by calculating Cohen's d effect size³⁶. Effect sizes (d) of above 0.8, between 0.8 and 0.5, between 0.5 and 0.2 and lower than 0.2 were considered as large, moderate, small, and trivial, respectively³⁷. Further, ANOVA effect sizes were calculated using partial eta squared (η_p^2), and <0.25, 0.26–0.63 and >0.63 were considered small, medium and large effect sizes respectively^{38,39}. All statistical tests were performed using the IBM SPSS Statistics for Mac (IBM Corp., version 20.0, Armonk, NY, USA). Statistical significance was set at $p \leq 0.05$.

Results

Referees' physical demands according to the type of turf during official matches are shown in Table 1. Referees recorded greater total distance ($p < 0.01$), Power_{mean} ($p < 0.01$), Speed_{mean} ($p < 0.05$) and Cadence_{mean} ($p < 0.05$) on natural fields compared to artificial turf fields. However, no significant differences were found in Vertical oscillation_{mean}, GCT_{mean} and Stiffness_{mean}. Neither were differences found in any physiological variable according to the type of turf (Table 2).

Referees' physical demands according to the pitch size during official matches are shown in Table 3. Referees recorded greater total distance ($p < 0.01$), Power_{mean} ($p < 0.01$), Speed_{mean} ($p < 0.01$), Cadence_{mean} ($p < 0.05$) and Stiffness_{mean} ($p < 0.05$) in above-standard in comparison to below-standard fields. However, no significant differences ($p > 0.05$) were found in Vertical oscillation_{mean} and GCT_{mean}. Regarding physiological demands, referees spent more time in Zone 5 in above-standard fields, but no differences were found in any other HR zones, HR_{mean}, %HR_{peak} or TRIMP (Table 4).

According to the period of the season, during the second round, referees covered more total distance in the matches compared to the matches played in the first round ($p < 0.05$) (Table 5). However, no differences were found in most of the physical (Power_{mean}, Speed_{mean}, Cadence_{mean}, Vertical oscillation_{mean}, GCT_{mean} and Stiffness_{mean}) or physiological demands (Table 6).

Referees' physical demands according to the environmental temperature during official matches are shown in Table 7. Referees recorded greater total distance ($p < 0.05$), Power_{mean} ($p < 0.05$) and Speed_{mean} ($p < 0.05$) during matches played with a higher environmental temperature (more than 20°) compared to those matches played in temperatures below 10°. However, no significant differences were found in other physical (Cadence_{mean}, Vertical oscillation_{mean}, GCT_{mean} or Stiffness_{mean}) or physiological demands (Table 8).

No significant interaction ($p > 0.05$) was observed in physical and physiological demands within 15 min periods according to type of turf, field, size, period of season or environmental temperature.

Discussion

The main aim of this study was to analyze how contextual variables (i.e., type of turf, pitch size, period of season, and environmental

Table 1. Physical demands registered by soccer referees according to type of turf (i.e., natural and artificial) during official matches.

Physical variables	Contextual variable	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	Entire match	Type of turf	Type of turf x period
Total distance (km)	Natural	1.57±0.17	1.48±0.10	1.54±0.13	1.46±0.19	1.37±0.17	1.77±0.27	9.18±0.62#	$F_{1,21} = 10.076$ $p = 0.005$ $\eta_p^2 = 0.324$	$F_{5,00,105,00} = 0.922$ $p = 0.470$ $\eta_p^2 = 0.042$
	Artificial	1.37±0.21	1.40±0.14	1.31±0.31	1.31±0.16	1.29±0.14	1.57±0.19	8.25±0.75		
Power _{mean} (W)	Natural	136.21±11.51	129.18±14.23	125.88±10.19	127.35±14.08	125.08±18.53	126.75±14.55	128.36±11.48#	$F_{1,21} = 11.373$ $p = 0.003$ $\eta_p^2 = 0.351$	$F_{5,00,105,00} = 0.637$ $p = 0.672$ $\eta_p^2 = 0.029$
	Artificial	120.04±15.55	120.02±16.34	109.67±7.63	117.14±8.89	110.87±9.54	110.80±11.24	114.84±7.68		
Speed _{mean} (km·h ⁻¹)	Natural	7.87±0.58	7.57±0.56	7.27±0.54	7.52±0.82	7.27±0.78	7.37±0.71	7.48±0.55#	$F_{1,21} = 7.256$ $p = 0.014$ $\eta_p^2 = 0.257$	$F_{5,00,105,00} = 0.417$ $p = 0.836$ $\eta_p^2 = 0.019$
	Artificial	7.08±0.79	7.04±0.78	6.66±0.56	6.96±0.57	6.66±0.59	6.60±0.75	6.83±0.56		
Cadence _{mean} (steps per min)	Natural	65.80±2.92	63.81±1.77	63.99±2.01	63.88±3.26	62.77±3.27	62.61±2.64	63.80±1.69#	$F_{1,21} = 6.855$ $p = 0.016$ $\eta_p^2 = 0.246$	$F_{5,00,105,00} = 1.274$ $p = 0.281$ $\eta_p^2 = 0.057$
	Artificial	63.42±2.24	62.79±2.93	60.45±3.49	63.33±1.62	61.36±2.47	60.94±1.90	62.07±1.43		
Vertical oscillation _{mean} (cm)	Natural	8.20±0.95	8.04±0.43	8.06±0.66	8.06±0.58	8.08±0.82	7.82±0.66	8.04±0.61	$F_{1,21} = 0.161$ $p = 0.692$ $\eta_p^2 = 0.008$	$F_{5,00,105,00} = 0.412$ $p = 0.839$ $\eta_p^2 = 0.019$
	Artificial	8.07±0.58	8.00±0.58	7.86±0.63	7.84±0.44	8.08±0.73	7.88±0.65	7.96±0.47		
GCT _{mean} (m·s ⁻¹)	Natural	504.44±69.91	538.74±68.03	546.58±81.73	527.77±78.40	524.30±76.12	525.33±56.44	527.75±59.67	$F_{1,21} = 0.881$ $p = 0.359$ $\eta_p^2 = 0.040$	$F_{3,820,80,221} = 0.835$ $p = 0.502$ $\eta_p^2 = 0.038$
	Artificial	528.40±80.86	563.78±66.95	542.36±118.13	532.24±80.60	572.37±50.22	568.23±66.00	551.56±58.73		
Stiffness _{mean} (KN·m ⁻¹)	Natural	9.24±0.56	9.24±0.53	9.30±0.52	8.82±0.43	9.07±0.59	9.02±0.52	9.12±0.36	$F_{1,21} = 1.480$ $p = 0.237$ $\eta_p^2 = 0.066$	$F_{5,00,105,00} = 1.116$ $p = 0.356$ $\eta_p^2 = 0.050$
	Artificial	9.59±1.05	9.52±0.92	9.31±0.67	9.46±0.76	9.33±0.70	9.12±0.68	9.41±0.66		

GCT: ground contact time; #Significantly different ($p < 0.05$) from artificial turf.

Table 2. Physiological demands registered by soccer referees according to type of turf (i.e., natural and artificial) during official matches.

Physical variables	Contextual variable	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	Entire match	Type of turf	Type of turf x period
HR _{mean} (bpm)	Natural	156.60±10.80	159.86±11.89	158.59±12.58	154.69±14.84	155.12±12.51	157.84±13.27	157.17±12.16	$F_{1,21} = 0.311$ $p = 0.583$ $\eta_p^2 = 0.015$	$F_{2,659,55,836} = 0.934$ $p = 0.421$ $\eta_p^2 = 0.043$
	Artificial	163.00±16.46	163.90±12.79	159.56±16.18	157.53±11.35	158.44±10.98	157.37±13.42	159.83±12.23		
%HR _{peak}	Natural	87.83±2.98	88.09±3.13	88.08±2.15	88.04±2.07	86.80±2.33	88.20±2.14	85.56±2.50	$F_{1,21} = 0.406$ $p = 0.531$ $\eta_p^2 = 0.019$	$F_{2,853,59,919} = 1.774$ $p = 0.164$ $\eta_p^2 = 0.078$
	Artificial	85.13±6.43	87.67±5.15	87.91±5.24	87.98±2.10	88.83±2.32	85.60±4.10	82.28±6.04		
Zone 1 (min)	Natural	0.194±0.32	0.00±0.00	0.00±0.00	0.02±0.05	0.03±0.10	0.00±0.01	0.25±0.34	$F_{1,21} = 2.167$ $p = 0.156$ $\eta_p^2 = 0.094$	$F_{1,946,40,869} = 0.246$ $p = 0.777$ $\eta_p^2 = 0.012$
	Artificial	0.80±2.30	0.18±0.63	0.55±1.89	0.32±1.07	0.15±0.55	0.22±0.74	2.22±4.21		
Zone 2 (min)	Natural	0.29±0.40	0.25±0.47	0.16±0.22	0.47±0.77	0.61±0.92	0.33±0.62	2.12±2.47	$F_{1,21} = 1.012$ $p = 0.326$ $\eta_p^2 = 0.046$	$F_{1,709,35,895} = 1.550$ $p = 0.227$ $\eta_p^2 = 0.069$
	Artificial	0.51±0.62	0.45±1.15	1.14±2.90	1.16±2.35	1.14±2.91	1.95±3.53	6.34±13.04		
Zone 3 (min)	Natural	2.65±1.70	2.18±1.62	3.20±2.22	3.53±2.05	3.01±1.73	3.30±1.90	17.88±8.02	$F_{1,21} = 1.044$ $p = 0.318$ $\eta_p^2 = 0.047$	$F_{5,00,105,00} = 1.260$ $p = 0.287$ $\eta_p^2 = 0.057$
	Artificial	3.38±2.87	2.96±3.35	3.81±3.51	4.39±3.57	4.27±3.81	5.89±4.50	24.70±19.82		
Zone 4 (min)	Natural	6.90±1.65	6.50±1.28	6.35±1.27	7.10±1.62	7.40±1.85	9.00±1.45	43.25±5.04	$F_{1,21} = 0.302$ $p = 0.589$ $\eta_p^2 = 0.014$	$F_{5,00,105,00} = 1.060$ $p = 0.387$ $\eta_p^2 = 0.048$
	Artificial	5.49±1.96	7.02±2.42	6.79±2.98	6.53±3.04	6.90±3.47	7.74±4.73	40.48±15.23		
Zone 5 (min)	Natural	4.55±2.11	5.63±2.38	5.84±2.69	3.50±3.00	3.55±1.80	5.96±3.44	29.04±11.94	$F_{1,21} = 2.132$ $p = 0.159$ $\eta_p^2 = 0.092$	$F_{5,00,105,00} = 1.203$ $p = 0.313$ $\eta_p^2 = 0.054$
	Artificial	4.49±3.23	4.25±3.69	3.81±3.47	2.50±2.04	2.47±2.18	3.24±3.37	20.76±14.54		
TRIMP (AU)	Natural	59.07±3.82	61.25±4.99	64.52±7.06	57.45±6.00	57.63±5.20	76.40±8.92	376.32±28.53	$F_{1,21} = 1.343$ $p = 0.260$ $\eta_p^2 = 0.060$	$F_{2,603,54,666} = 0.644$ $p = 0.569$ $\eta_p^2 = 0.030$
	Artificial	56.37±11.44	59.29±8.12	60.48±12.80	54.42±9.88	55.19±9.66	68.96±12.51	354.72±53.16		

HR_{mean}: mean heart rate; %HR_{peak}: percentage of their maximum heart rate achieved during the match; TRIMP: training impulse.

Table 3. Physical demands registered by soccer referees according to pitch size (i.e., over standard and below standard) during official matches.

Physical variables	Contextual variable	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	Entire match	Pitch size	Pitch size x period
Total distance (km)	Over standard	1.57±0.17	1.48±0.11	1.51±0.12#	1.41±0.19	1.37±0.15	1.74±0.25	9.08±0.59##	$F_{1,21} = 22.682$ $p = 0.000$ $\eta_p^2 = 0.519$	$F_{5,00,105,00} = 1.449$ $p = 0.213$ $\eta_p^2 = 0.065$
	Below standard	1.25±0.12	1.34±0.10	1.23±0.37	1.30±0.14	1.23±0.13	1.50±0.12	7.85±0.58		
Power _{mean} (W)	Over standard	135.67±11.00	129.93±13.95	121.28±11.22	125.50±12.54	122.57±15.74	123.10±14.00	126.21±10.03##	$F_{1,21} = 17.836$ $p = 0.000$ $\eta_p^2 = 0.459$	$F_{5,00,105,00} = 1.290$ $p = 0.274$ $\eta_p^2 = 0.058$
	Below standard	110.95±9.92	112.88±13.42	108.15±8.06	114.22±8.04	106.70±8.78	107.67±11.16	110.41±5.56		
Speed _{mean} (km·h ⁻¹)	Over standard	7.83±0.6	7.61±0.61#	7.18±0.50	7.48±0.76	7.20±0.69	7.24±0.74	7.42±0.53##	$F_{1,21} = 17.432$ $p = 0.000$ $\eta_p^2 = 0.454$	$F_{5,00,105,00} = 0.817$ $p = 0.540$ $\eta_p^2 = 0.037$
	Below standard	6.67±0.52	6.64±0.48	6.44±0.55	6.68±0.23	6.42±0.52	6.35±0.64	6.54±0.37		
Cadence _{mean} (steps per min)	Over standard	65.50±2.42	63.76±2.25	63.16±2.54	63.75±2.82	62.36±2.90	62.03±2.49	63.39±1.74#	$F_{1,21} = 6.128$ $p = 0.022$ $\eta_p^2 = 0.226$	$F_{5,00,105,00} = 1.362$ $p = 0.245$ $\eta_p^2 = 0.061$
	Below standard	62.51±2.40	62.26±2.79	59.80±3.85	63.22±1.52	61.24±2.84	60.97±2.03	61.77±1.26		
Vertical oscillation _{mean} (cm)	Over standard	8.23±0.88	8.12±0.48	8.08±0.69	8.05±0.57	8.20±0.78	7.88±0.71	8.10±0.61	$F_{1,21} = 1.764$ $p = 0.198$ $\eta_p^2 = 0.077$	$F_{5,00,105,00} = 0.320$ $p = 0.900$ $\eta_p^2 = 0.015$
	Below standard	7.94±0.35	7.81±0.54	7.69±0.47	7.72±0.25	7.85±0.71	7.79±0.52	7.81±0.24		
GCT _{mean} (m·s ⁻¹)	Over standard	511.08±66.17	537.64±60.62	550.3±66.70	518.50±83.16	541.41±68.67	541.33±52.93	533.68±51.47	$F_{1,21} = 0.721$ $p = 0.406$ $\eta_p^2 = 0.033$	$F_{3,852,80,882} = 0.821$ $p = 0.511$ $\eta_p^2 = 0.038$
	Below standard	530.92±94.38	581.49±73.19	532.64±152.95	552.41±66.07	570.34±59.86	565.04±83.83	555.33±72.81		
Stiffness _{mean} (KN·m ⁻¹)	Over standard	9.20±0.58	9.16±0.60	9.22±0.58	8.96±0.57	8.97±0.56	8.90±0.56	9.07±0.43#	$F_{1,21} = 7.862$ $p = 0.011$ $\eta_p^2 = 0.272$	$F_{5,00,105,00} = 0.626$ $p = 0.680$ $\eta_p^2 = 0.029$
	Below standard	9.88±1.17	9.84±0.91	9.47±0.64	9.60±0.78	9.67±0.60	9.41±0.57	9.68±0.57		

GCT: ground contact time; #Significantly different (#p < 0.05, ##p < 0.01) from below standard fields.

Table 4. Physiological demands registered by soccer referees according to pitch size (i.e., over standard and below standard) during official matches.

Physiological variables	Contextual variable	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	Entire match	Pitch size	Pitch size x period
HR _{mean} (bpm)	Over standard	159.50±12.83	162.64±12.84	159.05±16.30	156.38±13.39	157.45±11.58	158.22±14.44	158.84±12.89	$F_{1,21} = 0.006$ $p = 0.939$ $\eta_p^2 = 2.847$	$F_{2,633,55,288} = 0.308$ $p = 0.794$ $\eta_p^2 = 0.014$
	Below standard	161.58±17.75	161.21±12.00	159.30±11.02	156.13±12.34	156.15±12.15	156.38±10.77	158.36±10.96		
%HR _{peak}	Over standard	88.06±2.63	88.40±2.80	87.45±4.93	87.65±2.06	87.10±2.05	86.90±3.79	85.41±2.66	$F_{1,21} = 0.110$ $p = 0.744$ $\eta_p^2 = 0.005$	$F_{3,985,83,682} = 4.200$ $p = 0.004$ $\eta_p^2 = 0.167$
	Below standard	83.04±7.45	86.82±6.37	88.99±1.62	88.67±1.94	89.53±2.60	86.40±3.36	80.51±6.86		
Zone 1 (min)	Over standard	0.13±0.27	0.00±0.00	0.46±1.76	0.03±0.07	0.02±0.08	0.01±0.04	0.65±1.77	$F_{1,21} = 2.157$ $p = 0.157$ $\eta_p^2 = 0.093$	$F_{1,989,41,770} = 1.467$ $p = 0.242$ $\eta_p^2 = 0.065$
	Below standard	1.30±2.90	0.29±0.80	0.05±0.13	0.48±1.37	0.25±0.70	0.33±0.94	2.70±4.92		
Zone 2 (min)	Over standard	0.30±0.35	0.17±0.40	0.23±0.43	0.49±0.70	0.47±0.77	0.64±1.58	2.30±2.82	$F_{1,21} = 2.223$ $p = 0.151$ $\eta_p^2 = 0.096$	$F_{1,709,35,895} = 1.353$ $p = 0.269$ $\eta_p^2 = 0.061$
	Below standard	0.64±0.75	0.74±1.43	1.62±3.66	1.54±2.97	1.73±3.67	2.38±4.09	8.65±16.37		
Zone 3 (min)	Over standard	2.69±1.83	1.83±1.52	2.97±2.32	3.52±1.89	2.99±1.52	3.74±2.07	17.75±7.57	$F_{1,21} = 2.946$ $p = 0.101$ $\eta_p^2 = 0.123$	$F_{5,00,105,00} = 0.931$ $p = 0.464$ $\eta_p^2 = 0.042$
	Below standard	3.76±3.28	4.11±3.82	4.61±3.88	4.93±4.39	5.10±4.69	6.68±5.46	29.19±24.11		
Zone 4 (min)	Over standard	6.55±1.50	6.80±1.80	6.33±1.56	7.19±1.60	7.53±1.64	8.72±2.31	43.12±5.22	$F_{1,21} = 0.629$ $p = 0.437$ $\eta_p^2 = 0.029$	$F_{5,00,105,00} = 1.112$ $p = 0.359$ $\eta_p^2 = 0.050$
	Below standard	5.26±2.44	6.80±2.42	7.10±3.49	6.00±3.66	6.34±4.33	7.48±5.52	38.99±19.21		
Zone 5 (min)	Over standard	4.97±2.41	5.82±2.62	5.67±3.03	3.43±2.51	3.66±1.72	5.45±3.70	29.00±11.15#	$F_{1,21} = 5.958$ $p = 0.023$ $\eta_p^2 = 0.221$	$F_{5,00,105,00} = 0.701$ $p = 0.624$ $\eta_p^2 = 0.032$
	Below standard	3.66±3.27	3.04±3.56	2.86±2.99	2.02±2.34	1.58±2.04	2.49±2.62	15.65±14.81		
TRIMP (AU)	Over standard	59.87±4.93	62.10±4.82	63.52±9.05	57.47±5.30	58.37±4.49	74.68±9.62	376.01±29.10	$F_{1,21} = 3.400$ $p = 0.079$ $\eta_p^2 = 0.139$	$F_{2,606,54,732} = 0.244$ $p = 0.854$ $\eta_p^2 = 0.011$
	Below standard	53.19±12.94	56.47±8.83	59.82±13.59	52.49±12.10	52.28±11.46	67.53±13.85	341.78±60.83		

HR_{mean}: mean heart rate; %HR_{peak}: percentage of their maximum heart rate achieved during the match; TRIMP: training impulse. #Significantly different (p < 0.05) from below standard fields.

Table 5. Physical demands registered by soccer referees according to period of season (i.e., first and second round) during official matches.

Physical variables	Contextual variable	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	Entire match	Round	Round x period
Total distance (km)	First round Second round	1.39±0.19 1.54±0.24	1.44±0.13 1.42±0.12	1.34±0.33 1.51±0.11	1.30±0.15 1.47±0.18	1.30±0.16 1.35±0.16	1.57±0.19 1.78±0.26	8.33±0.75# 9.07±0.77	$F_{1,21} = 5.452$ $p = 0.030$ $\eta_p^2 = 0.206$	$F_{5.00, 105.00} = 1.538$ $p = 0.184$ $\eta_p^2 = 0.068$
Power _{mean} (W)	First round Second round	121.19±14.41 134.72±15.07	123.07±14.79 125.21±17.79	113.12±11.07 121.39±11.83	116.82±11.07 127.76±11.42	114.22±11.13 120.73±20.00	115.54±11.75 120.58±18.43	117.50±7.98 124.89±14.35	$F_{1,21} = 2.572$ $p = 0.117$ $\eta_p^2 = 0.113$	$F_{5.00, 105.00} = 1.084$ $p = 0.373$ $\eta_p^2 = 0.049$
Speed _{mean} (km·h ⁻¹)	First round Second round	7.18±0.75 7.75±0.79	7.20±0.75 7.37±0.73	6.78±0.67 7.11±0.52	6.97±0.67 7.50±0.73	6.81±0.69 7.07±0.80	6.76±0.66 7.16±0.97	6.95±0.55 7.32±0.71	$F_{1,21} = 2.023$ $p = 0.170$ $\eta_p^2 = 0.088$	$F_{5.00, 105.00} = 0.814$ $p = 0.542$ $\eta_p^2 = 0.037$
Cadence _{mean} (steps per min)	First round Second round	63.78±2.67 65.33±2.79	63.78±2.80 62.54±1.95	62.06±4.03 61.89±2.53	63.18±2.53 64.06±2.80	61.62±3.15 62.42±2.53	61.70±2.02 61.61±2.84	62.76±1.72 62.92±1.87	$F_{1,21} = 0.139$ $p = 0.713$ $\eta_p^2 = 0.007$	$F_{5.00, 105.00} = 1.086$ $p = 0.373$ $\eta_p^2 = 0.049$
Vertical oscillation _{mean} (cm)	First round Second round	7.98±0.75 8.32±0.74	7.95±0.49 8.09±0.55	7.70±0.54 8.27±0.63	7.77±0.45 8.15±0.52	8.13±0.79 8.01±0.75	7.74±0.66 7.99±0.61	7.88±0.49 8.15±0.55	$F_{1,21} = 1.452$ $p = 0.242$ $\eta_p^2 = 0.065$	$F_{5.00, 105.00} = 1.916$ $p = 0.098$ $\eta_p^2 = 0.084$
GCT _{mean} (m·s ⁻¹)	First round Second round	524.62±85.08 509.36±64.58	555.32±76.66 549.73±56.08	536.85±129.37 553.75±52.94	530.09±80.48 530.09±78.64	548.82±67.82 554.91±66.73	541.01±63.85 560.71±66.86	539.19±66.16 543.83±51.62	$F_{1,21} = 0.021$ $p = 0.885$ $\eta_p^2 = 0.001$	$F_{3.154, 66.232} = 0.345$ $p = 0.803$ $\eta_p^2 = 0.016$
Stiffness _{mean} (KN·m ⁻¹)	First round Second round	9.33±0.76 9.57±1.03	9.36±0.73 9.45±0.88	9.26±0.40 9.37±0.80	9.24±0.81 9.10±0.58	9.24±0.73 9.18±0.57	9.03±0.52 9.13±0.72	9.27±0.48 9.30±0.67	$F_{1,21} = 0.057$ $p = 0.814$ $\eta_p^2 = 0.003$	$F_{5.00, 105.00} = 0.420$ $p = 0.834$ $\eta_p^2 = 0.020$

GCT: ground contact time; #Significantly different ($p < 0.05$) from second round matches.

Table 6. Physiological demands registered by soccer referees according to period of season (i.e., first and second round) during official matches.

Physiological variables	Contextual variable	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	Entire match	Round	Round x period
HR _{mean} (bpm)	First round Second round	160.84±14.09 159.42±15.42	162.97±13.56 161.07±13.56	158.12±17.29 160.46±10.27	153.63±14.02 159.76±10.56	156.22±13.54 158.00±8.83	155.04±13.61 160.87±12.17	157.66±13.27 159.99±10.66	$F_{1,21} = 0.173$ $p = 0.682$ $\eta_p^2 = 0.008$	$F_{2.628, 55.184} = 1.993$ $p = 0.133$ $\eta_p^2 = 0.087$
%HR _{peak}	First round Second round	88.15±3.08 83.91±6.69	87.87±5.30 87.82±2.80	87.61±5.14 88.47±2.34	87.18±1.77 89.08±1.91	88.19±2.92 87.62±1.92	86.07±3.96 87.58±2.98	83.87±5.22 83.50±5.01	$F_{1,21} = 0.008$ $p = 0.927$ $\eta_p^2 = 4.038$	$F_{3.086, 64.796} = 2.931$ $p = 0.039$ $\eta_p^2 = 0.122$
Zone 1 (min)	First round Second round	0.18±0.41 1.01±2.60	0.18±0.63 0.00±0.02	0.55±1.89 0.00±0.00	0.31±1.07 0.03±0.08	0.18±0.55 0.00±0.00	0.22±0.74 0.00±0.00	1.61±3.79 1.04±2.61	$F_{1,21} = 0.165$ $p = 0.688$ $\eta_p^2 = 0.008$	$F_{2.003, 42.056} = 1.395$ $p = 0.259$ $\eta_p^2 = 0.062$
Zone 2 (min)	First round Second round	0.34±0.63 0.51±0.38	0.37±1.16 0.36±0.49	1.06±2.92 0.26±0.35	1.23±2.37 0.37±0.54	1.16±2.99 0.58±0.46	1.64±3.55 0.74±1.14	5.80±13.24 2.82±2.20	$F_{1,21} = 0.492$ $p = 0.491$ $\eta_p^2 = 0.023$	$F_{1.713, 35.977} = 1.139$ $p = 0.324$ $\eta_p^2 = 0.051$
Zone 3 (min)	First round Second round	3.12±2.03 2.98±2.96	1.82±2.08 3.66±3.17	2.31±2.01 5.14±3.34	3.81±1.90 4.27±4.09	2.81±1.92 4.91±3.95	4.28±2.19 5.40±5.26	18.16±9.786 26.38±21.16	$F_{1,21} = 1.548$ $p = 0.227$ $\eta_p^2 = 0.069$	$F_{5.00, 105.00} = 2.962$ $p = 0.015$ $\eta_p^2 = 0.124$
Zone 4 (min)	First round Second round	6.28±2.21 5.87±1.56	6.72±2.14 6.90±1.87	6.72±2.67 6.44±2.01	6.83±2.67 6.71±2.38	7.59±2.92 6.50±2.73	8.85±3.92 7.56±3.37	43.00±13.50 39.98±9.53	$F_{1,21} = 0.363$ $p = 0.553$ $\eta_p^2 = 0.017$	$F_{5.00, 105.00} = 0.509$ $p = 0.769$ $\eta_p^2 = 0.024$
Zone 5 (min)	First round Second round	4.80±2.53 4.14±3.08	5.62±3.39 3.84±2.78	4.86±3.31 4.47±3.35	2.55±2.31 3.45±2.75	3.02±2.11 2.83±2.09	3.60±2.36 5.50±4.69	24.46±11.85 24.22±16.74	$F_{1,21} = 0.002$ $p = 0.968$ $\eta_p^2 = 0.891$	$F_{5.00, 105.00} = 2.503$ $p = 0.035$ $\eta_p^2 = 0.106$
TRIMP (AU)	First round Second round	59.39±5.39 55.15±11.99	61.39±7.58 58.52±5.78	60.83±12.75 64.06±7.44	54.26±9.42 57.66±6.80	56.43±9.43 56.02±6.02	69.73±11.29 75.41±11.52	362.02±49.94 366.82±39.18	$F_{1,21} = 0.062$ $p = 0.805$ $\eta_p^2 = 0.003$	$F_{2.807, 58.945} = 2.689$ $p = 0.058$ $\eta_p^2 = 0.114$

HR_{mean}: mean heart rate; %HR_{peak}: percentage of their maximum heart rate achieved during the match; TRIMP: training impulse.

Table 7. Physical demands registered by soccer referees according to environmental temperature (i.e., below 10° and over 20°) during official matches.

Physical variables	Contextual variable	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	Entire match	Temperature	Temperature x period
Total distance (km)	Below 10° Over 20°	1.40±0.23 1.56±0.22	1.42±0.12 1.48±0.11	1.31±0.35 1.53±0.13	1.31±0.16 1.43±0.17	1.26±0.16 1.41±0.08	1.53±0.19 1.82±0.24	8.23±0.74# 9.23±0.65	$F_{1,21} = 5.024$ $p = 0.017$ $\eta_p^2 = 0.334$	$F_{5,00,105,00} = 0.757$ $p = 0.669$ $\eta_p^2 = 0.070$
Power _{mean} (W)	Below 10° Over 20°	120.72±15.64 137.35±13.37	123.69±16.13 128.89±15.63	112.42±11.15 122.00±11.66	113.91±7.64 131.08±9.83	110.44±7.76 127.69±16.44	112.21±9.30 125.72±16.90	115.79±6.51# 128.50±11.98	$F_{1,21} = 4.775$ $p = 0.020$ $\eta_p^2 = 0.323$	$F_{5,00,105,00} = 0.981$ $p = 0.465$ $\eta_p^2 = 0.089$
Speed _{mean} (km·h ⁻¹)	Below 10° Over 20°	7.14±0.76 7.92±0.71	7.15±0.78 7.59±0.62	6.72±0.66 7.21±0.44	6.80±0.42 7.71±0.68	6.64±0.60 7.41±0.56	6.63±0.57 7.45±0.84	6.85±0.46# 7.54±0.57	$F_{1,21} = 4.421$ $p = 0.026$ $\eta_p^2 = 0.307$	$F_{7,128,71,276} = 0.793$ $p = 0.598$ $\eta_p^2 = 0.073$
Cadence _{mean} (steps per min)	Below 10° Over 20°	63.83±2.90 65.12±2.64	63.62±3.19 63.30±1.82	62.46±4.39 62.15±2.41	63.03±2.28 63.48±2.47	61.60±3.48 62.71±2.27	61.26±1.98 62.19±2.41	62.73±1.76 63.10±1.69	$F_{1,21} = 0.256$ $p = 0.776$ $\eta_p^2 = 0.025$	$F_{5,00,105,00} = 0.779$ $p = 0.649$ $\eta_p^2 = 0.072$
Vertical oscillation _{mean} (cm)	Below 10° Over 20°	7.95±0.57 8.46±0.97	7.94±0.54 8.13±0.54	7.67±0.56 8.17±0.70	7.74±0.51 8.24±0.47	7.95±0.60 8.43±0.91	7.77±0.63 8.03±0.76	7.85±0.41 8.24±0.67	$F_{1,21} = 1.924$ $p = 0.172$ $\eta_p^2 = 0.161$	$F_{5,00,105,00} = 0.919$ $p = 0.519$ $\eta_p^2 = 0.084$
GCT _{mean} (m·s ⁻¹)	Below 10° Over 20°	533.76±81.10 552.78±76.70	556.15±83.81 549.32±47.29	543.81±147.05 555.39±31.28	547.28±62.07 502.89±91.31	553.54±64.80 537.76±71.44	543.04±67.74 543.09±55.96	545.75±68.52 531.64±40.38	$F_{1,21} = 0.202$ $p = 0.819$ $\eta_p^2 = 0.020$	$F_{7,892,78,920} = 0.714$ $p = 0.676$ $\eta_p^2 = 0.067$
Stiffness _{mean} (KN·m ⁻¹)	Below 10° Over 20°	9.42±0.83 9.37±1.11	9.41±0.65 9.23±0.88	9.36±0.48 9.08±0.76	9.33±0.90 8.99±0.57	9.38±0.76 9.10±0.60	9.05±0.52 8.87±0.58	9.35±0.49 9.12±0.69	$F_{1,21} = 0.734$ $p = 0.492$ $\eta_p^2 = 0.068$	$F_{5,00,105,00} = 0.643$ $p = 0.774$ $\eta_p^2 = 0.060$

GCT: ground contact time; #Significantly different (p < 0.05) from over 20° matches.

Table 8. Physiological demands registered by soccer referees according to environmental temperature (i.e., below 10° and over 20°) during official matches.

Physiological variables	Contextual variable	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	Entire match	Temperature	Temperature x period
HR _{mean} (bpm)	Below 10° Over 20°	165.50±15.10 158.13±11.34	165.98±15.63 160.52±9.01	163.45±16.50 155.70±14.91	156.00±18.18 156.77±8.47	157.38±16.34 158.32±6.32	158.73±15.85 157.99±13.13	161.09±15.41 157.86±10.08	$F_{1,21} = 0.460$ $p = 0.638$ $\eta_p^2 = 0.044$	$F_{5,271,52,706} = 1.757$ $p = 0.135$ $\eta_p^2 = 0.149$
%HR _{peak}	Below 10° Over 20°	88.48±3.48 86.46±3.60	87.73±6.20 88.57±1.52	89.30±2.07 86.37±6.00	87.48±2.04 87.75±1.98	87.84±3.19 88.19±1.91	86.52±3.03 87.48±4.63	83.70±5.81 84.52±3.95	$F_{1,21} = 0.522$ $p = 0.601$ $\eta_p^2 = 0.050$	$F_{6,134,61,336} = 2.456$ $p = 0.033$ $\eta_p^2 = 0.197$
Zone 1 (min)	Below 10° Over 20°	0.17±0.43 0.11±0.23	0.23±0.72 0.00±0.00	0.04±0.12 0.76±2.28	0.40±1.22 0.03±0.08	0.23±0.62 0.00±0.00	0.27±0.84 0.02±0.05	1.34±3.94 0.91±2.29	$F_{1,21} = 0.284$ $p = 0.756$ $\eta_p^2 = 0.208$	$F_{4,059,42,593} = 2.565$ $p = 0.052$ $\eta_p^2 = 0.204$
Zone 2 (min)	Below 10° Over 20°	0.39±0.71 0.31±0.25	0.48±1.31 0.18±0.47	1.18±3.33 0.32±0.54	1.51±2.67 0.44±0.56	1.57±3.34 0.30±0.44	1.54±3.74 1.12±2.10	6.68±14.96 2.66±3.20	$F_{1,21} = 0.398$ $p = 0.677$ $\eta_p^2 = 0.038$	$F_{3,218,32,177} = 0.769$ $p = 0.528$ $\eta_p^2 = 0.071$
Zone 3 (min)	Below 10° Over 20°	2.70±1.89 3.89±2.91	1.89±2.32 2.64±2.79	2.29±2.32 4.57±3.46	3.80±2.32 4.00±2.98	3.26±1.96 3.58±3.47	4.37±2.46 4.22±4.24	18.30±11.06 22.91±18.33	$F_{1,21} = 0.511$ $p = 0.607$ $\eta_p^2 = 0.049$	$F_{5,00,105,00} = 2.177$ $p = 0.025$ $\eta_p^2 = 0.179$
Zone 4 (min)	Below 10° Over 20°	6.44±2.30 5.93±1.66	6.66±2.38 7.30±1.67	6.71±2.73 5.77±1.79	6.85±2.93 6.72±1.94	7.41±3.25 6.89±2.60	9.05±4.40 7.27±3.27	43.11±15.23 39.89±9.04	$F_{1,21} = 0.167$ $p = 0.847$ $\eta_p^2 = 0.016$	$F_{5,00,105,00} = 0.896$ $p = 0.540$ $\eta_p^2 = 0.082$
Zone 5 (min)	Below 10° Over 20°	5.16±2.10 4.26±3.04	5.54±3.68 4.52±2.39	5.24±3.87 4.50±2.97	2.33±2.80 3.38±2.26	2.41±2.00 3.86±1.83	3.66±3.53 5.87±3.89	24.34±14.74 26.40±13.02	$F_{1,21} = 0.295$ $p = 0.748$ $\eta_p^2 = 0.029$	$F_{5,00,105,00} = 1.491$ $p = 0.154$ $\eta_p^2 = 0.130$
TRIMP (AU)	Below 10° Over 20°	60.61±4.81 57.44±6.00	61.18±8.46 60.07±4.83	62.29±13.19 60.72±9.13	53.84±11.23 56.71±4.88	54.85±10.28 58.23±5.29	70.98±13.82 73.36±11.86	363.74±57.43 366.54±35.62	$F_{1,21} = 0.031$ $p = 0.969$ $\eta_p^2 = 0.003$	$F_{5,480,54,901} = 1.661$ $p = 0.154$ $\eta_p^2 = 0.142$

HR_{mean}: mean heart rate; %HR_{peak}: percentage of their maximum heart rate achieved during the match; TRIMP: training impulse.

temperature) affect referees' physical and physiological demands during official matches. This is the first study to analyze this topic, opening up a new line of research that may allow referees' strength and conditioning specialists to be more precise in prescribing training sessions and planning post-match recovery. This study showed that playing on natural grass meant that referees had to cover more distance, using higher power, speed and cadence than on artificial grass. Also, in above-standard fields more distance, power, speed, cadence and stiffness and more time in zone 5 were recorded than in below-standard fields. Also, referees covered more total distance during matches played in the second round in comparison to the first. Finally, more distance, power and speed were recorded in matches with environmental temperatures over 20° than below 10°. No differences were found within 15 min periods according to type of turf, pitch size, season period or environmental temperature in physical and physiological variables.

Knowing whether contextual variables influence the demands of official matches in soccer referees may be of great interest to strength and conditioning specialists in order to plan training sessions and to establish more appropriate recovery strategies. Previous studies carried out with soccer players have observed that contextual factors affect match demands^{12-14,16,19,26,40}, so it is of interest to analyze whether these factors also affect referees. In this vein, in our study it has been shown that matches played on natural grass imply greater total distance, power, speed and cadence for amateur soccer referees compared to matches played on artificial grass. Although other research has not found significant differences in physical demands between matches played on artificial turf and natural grass^{14,15}, the artificial turf standards in the aforementioned studies were higher than in the present study. These differences may be due to the fact that first-generation artificial grass (old-aged) decreases ball and game velocity and thus the physical demands on the referee. Likewise, refereeing on above-standard pitches meant greater total distance, power, speed, cadence and stiffness, and time spent in zone 5 than on below-standard pitches. In small sided soccer games it has been demonstrated that bigger soccer fields are related to higher physical demands⁴¹, so this study would confirm the same pattern during official matches.

On the other hand, the fact of covering more total distance during matches played in the second round in comparison to the first could be associated with the pressure involved in playing the last matches of the season when the referees have to be prepared to keep up with the pace of play in matches with high physical and physiological demands. Also, playing with an environmental temperature above 20°C is associated with more total distance, power and speed than in matches played with an ambient temperature below 10°C. However, other studies have found that lower temperatures are associated with higher physical demands in professional soccer players^{17,18}, so the disparity of results found on this aspect may be due to the fact that in amateur leagues cold temperatures below 10°C can lead to a lower body temperature and therefore to a lower intensity, reducing the physical demands on the referees. These results suggest the need to consider contextual variables during training periodization for this population. However, in general, no differences were found in vertical oscillation, GCT and stiffness, nor in the majority of physiological responses in any of the variables studied. However, this is the first study to analyze the influence of contextual variables on

these parameters, so it would be interesting to perform further studies that address the analysis of these variables.

When isolated 15 min periods were analyzed, we did not observe significant differences between contextual variables and referees' match performance in physical and physiological variables, except a significant interaction ($p < 0.05$) between season periods and %HR_{peak}, time spent in zone 3 and time spent in zone 5, but post hoc analysis did not reveal significant differences ($p > 0.05$). These results show that contextual variables do not influence the demands of the match in 15 min periods, although as demonstrated above, these variables influence the demands encountered during the entire match. The scientific literature has shown disparate results according to how physical and physiological demands evolve in referees over the course of matches. While some studies observed that physical demands decrease and physiological demands are maintained as the match progresses³¹, other studies have shown that physiological demands also diminish as the match progresses⁵, and other studies have shown that physiological demands increase as the match progresses⁴². The responses of the referees in each 15 min period can be associated with the requirements of the game (e.g., score, pace of the match imposed by the players due to their physical and technical capabilities, tactical and strategic decisions, etc.). Hence, there is no clear trend in the evolution of physical and physiological responses during each 15 min period, and in our case, the contextual variables analyzed did not appear to influence this evolution. To conclude, referees may need to be prepared for highly variable demands during a match and be able to respond to them at any time of the match whatever the contextual factors.

Although this study shows that contextual variables have an impact on the knowledge about the physical and physiological demands in amateur referees, it is not without limitations, so we see the need to extend the sample to other categories of grassroots soccer and to professional referees. Considering that there are studies that have proved the validity of subjective quantification methods⁴³ and more specifically in soccer referees^{9,44}, including these quantification methods could have provided valuable information to complement the results obtained. Finally, the contextual factors analyzed in this study are limited, which opens up a line of research to take into account other contextual factors such as the style of play of the teams, effective playing time, the referee's physical fitness level, etc.

Conclusions

The results of this study show that the type of surface, pitch size, the environmental temperature and season period influence the physical demands of soccer referees during official matches. Therefore, it is suggested that strength and conditioning specialists should consider the influence of contextual variables on the match demands involved in refereeing activities, in order to prescribe more appropriate training and recovery strategies to face the matches with greater guarantees. Furthermore, the fact that no differences were found within 15 min periods throughout the match according to the contextual variables studied could indicate that it is not possible to determine a specific period in which the contextual variables play a determining role, but rather that the entire match should be taken into account.

Acknowledgements

The authors gratefully acknowledge the support of a Spanish government subproject mixed method approach on performance analysis (in training and competition) in elite and academy sport (PGC2018-098742-B-C33) (2019–2021) from the Ministry of Science, Innovation and Universities (MCIU), the State Research Agency (AEI) and the European Regional Development Fund (ERDF), that is part of the coordinated project New Approach of Research in Physical Activity and Sport from Mixed Methods Perspective (NARPAS_MM) [SPGC201800X098742CV0].

Conflict of interest

The authors do not declare a conflict of interest.

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