Associations between match running performance and environmental temperatures in four professional football leagues.

Abstract:

Purpose. This study investigated associations between environmental temperatures and match running performance in four professional football leagues. **Methods.** Running performance indicators (PI's), including total, high-speed and sprint distances, were collated from 1610 matches from the German Bundesliga 1 and 2, Japanese J-League, and Turkish SüperLig. Environmental data for each of these matches was obtained for dry-bulb temperature (T) and wet bulb globe temperature (WBGT) retrospectively from public sources. Linear regressions were used to determine relationships between running PI's and both T and WBGT respectively, for individual leagues. Further, linear mixed models were used to determine associations across all four leagues, accounting for differences between them as random effects. Bonferroni corrections were applied to account for multiple tests. **Results.** Overall, combined-league data showed total distance (95%CI: [-0.50--0.37]; β: -0.36), number of high-speed runs (95%CI: [-4.57--2.93]; β: -0.29), high-speed distances (95%CI: [-0.07--0.05]; β: -0.28), number of sprints (95%CI: [-2.72--2.07]; β: -0.39) and sprint distances (95%CI: [-0.05--0.03]; β: -0.22) were all lower when WBGT was higher ($p<0.001$) while the peak speed recorded per match (95%CI: [0.01-0.03]; β: 0.18) was higher when WBGT was higher ($p<0.001$). Models with T instead of WBGT derived similar results. **Conclusion.** Warmer environmental conditions were associated with lower total, high-speed and sprint distances covered. These responses may result from an increased thermoregulatory load or indirectly from an adapted individual or team-tactical pacing strategy in warmer conditions. Teams should consider strategies to counter such effects to avoid lower distances covered at high intensities that are related to success in football.

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Introduction

There is a growing concern from football federations, teams and players about matches being held in warm to hot conditions[1, 2]. An important aspect of football match play in such conditions is the running performance of players, as high-speed distances covered have been associated with match outcomes and creating goal scoring opportunities[3-5]. While it has been shown that playing in the heat can be detrimental to running performance, findings from observations of competitive football matches remain from small samples and with inconsistent findings, especially regarding high-speed activities, which are relevant to goal scoring outcomes[6, 7]. Further understanding of the relationship between and environmental temperatures and match running is important to football federations and teams to support player health and performance in hotter conditions.

During exercise, thermoregulatory processes are enabled to dissipate endogenously produced heat. In hot and humid conditions, the efficacy of these mechanisms becomes reduced (i.e., lower convective heat loss, decreased evaporation of sweat) and therefore need to be increased to reach sufficient levels of heat dissipation, attempting to prevent excessive increases in core temperatures[8]. The increased dilation of peripheral blood vessels and increased sweating lead to a reduced central blood volume, reduced stroke volume and in turn increased heart rate and higher cardiovascular strain when temperatures are high[8] .This is accompanied by the earlier onset of fatigue in warmer environmental conditions, which impairs endurance and intermittent sprint performance[9]. Collectively, these responses can result in reduced physical or technical football performance, hence are of importance to ensure optimal player outcomes in the heat.

Running demands are critical in football, and total match running distance (although not necessarily linked to match success) is an often-reported performance indicator (PI) in football. In hotter temperatures match running is reported to be reduced due to players managing rising core temperatures, earlier onset of fatigue and potential for heat illnesses. While most studies report a reduction in match total distances in hotter temperatures[10-17], one study [18] reported no change. However, high-speed running activities have been found to be more important for success in football[3,5] , though the influence of hotter temperatures on high-speed activities remains less clear[7]. High-speed running was found to be reduced in hotter conditions in some studies[11, 13,15,18], but not all[10] while the number of sprints was also found to be reduced in some investigations[16-18]. Elite players might reduce running distances to maintain tactical and technical elements of the game, but this needs further investigation.

Differing outcomes regarding the association between environmental conditions and running PI's in football are potentially due to different methodological approaches. Whereby different definitions of high-speed and sprint activities, as well as different arbitrary thresholds for "hot" conditions are reported. Further, while most studies use a dichotomous categorisation of heat stress (comparing "hot matches" vs. "temperate matches")[10-12, 14,16], others used three[13,18] or four[15] categories. The hottest category in these studies ranged from > 14 °C[12] to > 43 °C[11]. As temperature is a linear variable, it makes sense that a more recent publication attempted to treat temperature as such and found that the relationship between temperature and physical performance parameters in football seemed to be linear [17]. However, these publications vary in their approach (observational vs. experimental), number of matches observed (n = 2 - 1530), type of measurements (global positioning system vs. optical tracking system), competition setting (experimental matches vs. World Cup matches), level of players (amateur vs. elite), regional settings and the gender of participants.

To better understand the relationship between environmental conditions and match running, we investigated data from four professional football leagues, both per league and in combination. We aimed at including large data sets from multiple leagues and settings, investigating total running distances and high-speed activities. We further aimed to include two different environmental conditions, comparing the associations between temperature (T) and wet bulb globe temperature (WBGT) on running PI's, while treating them as linear variables as opposed to temperature categories. We hypothesized that match running PI's would be reduced in hotter environmental conditions.

Methods

This study observed 1610 matches from four professional male football leagues across Germany, Turkey and Japan. The German data consists of all 612 matches from one season (2021-22) of first (BL1) and second (BL2) Bundesliga and includes match locations, kick-off times and match running statistics from official match reports that were shared from the league organisation (Deutsche Fußball Liga GmbH, DFL). Data from the Turkish SüperLig (SL) was collated from the official SL performance data for 312 matches of the 2021-22 season, including basic match information (time, location, teams) and running performance data. 68 remaining matches of the SL were missing due to no performance data (50) or unavailable weather conditions (18). Finally, all match data for two seasons (2021-22) of Japanese J-League (JL) were collated from their website (jleague.co), including basic match information (time, location, teams) and running performance resulting in 686 matches. All leagues used optical tracking to generate physical performance data but used different parameters and cut-off values to characterize physical performance. In total, seven performance indicators (PI's) were available for BL1 & BL2, ten for SL and two for the JL, which are summarized with definitions in Table 1. The definitions and threshold values of PIs are based on those defined by the respective leagues. In total seven PI's overlapped in at least three leagues and were included in a combined analysis including all observed matches. Total distance and number of sprints were the only available PIs available across all four leagues, although the definition of a sprint and high-speed run differed. Prior to analysis all individual team information was removed from the data set and data was analysed as PI per match for both teams, including goalkeepers. For example, if the two teams involved in a match performed 200 and 205 sprints respectively, this was summed to a single metric (405 sprints) to describe the overall sprint volume for that match. Ethical approval was granted by the Ethics Committee of the Faculty for Human and Business Sciences of Saarland University (Ref No.: 23-14).

For all observed matches, dry-bulb temperature (T) and wet bulb globe temperature (WBGT) were linked retrospectively. T is the commonly known and easily accessible ambient air temperature, whereas WBGT is a more inclusive heat-index adding the influence of relative humidity, wind, and solar radiation, for a more detailed interpretation of the observed heat stress[19,20]. The use, advantages, and disadvantages of WBGT have been described extensively in previous research[21]. This study included both indexes, to understand potential differences in their use as predictors for running performance changes, to provide further insight for using these indexes in heat policies and guidelines. Environmental data was obtained from Meteostat.net, which is an open-source service, providing hourly meteorological data to most given geographical locations. The service estimates T, relative humidity, dew point, wind-speed, air-pressure, total precipitation, and the descriptive weather condition (i.e., rain, cloudy, sunny, etc.) based on a weighted interpolation of up to four weather stations considering their distance and elevation difference to the actual location. Further, solar radiation was estimated using the solar angle at the time and location of the match. With this data, WBGT can be estimated by a validated and reliable method[22] developed by Liljegren et al. in 2008 [19] and implemented into R-code by Casanueva in 2019[23]. Overall, environmental conditions ranged from -8.8 to 45.4 °C T (Mean ± SD: 15.7 ± 8.4) and -8.1 to 29.7 °C WBGT (Mean ± SD: 13.6 ± 8.0), including matches within a 54.2 °C T and 37.8 °C WBGT range. The environmental conditions observed in each league are presented in Table 2.

For each individual league, linear regressions were performed to investigate relationships between PI's and T or WBGT, respectively. To interpret the relationship, the estimate (Est) and 95% confidence interval (95%CI), standardized estimate (β) and 95% confidence interval (β-95%CI), explained variance (marginal R^2) and p-value (p) were determined. Depending on β, effects can be categorised into small (0.10 – 0.29), medium (0.30 – 0.49) and large (> 0.50), while R^2 can also be interpreted as small (0.02 - 0.12), medium (0.13 – 0.25) and large (> 0.26). Further, to detect effects present across all four leagues, all matches were also combined into one large multi-league data set, including the PI's and environmental conditions for all 1609 matches. To account for differences in data sources, PI definitions and environmental conditions throughout the leagues, we performed mixed linear models and included the leagues as a random effect, resulting in the following models:

- ***Model_0:*** *PI ~ 1 + (1|league)*
- ***Model_T:*** *PI ~ T + (1|league)*
- ***Model_WBGT:*** *PI ~ WBGT + (1|league)*

The structure of the analysis is visualized in Figure 1. For the presentation of the full results in Table 3, the results of the combined leagues will also be presented as 'per player per 10 °C T or WBGT increase', to allow for an easy interpretation of the outcomes for individual performances. This value is derived by dividing the estimate for a 1 °C change in all players by 22 and multiple it by 10. Analysis and visualization were performed with R Studio 2022.07.1 using R version 4.2.1 stats, lme4, ggplot2 & jtools libraries. Statistical significance was defined at a level of 5% or less for the α-error ($p<0.05$). As for each league a series of relationships were observed, Bonferroni corrections were performed, and p-values were adjusted depending on the number of tested PI's per data set (BL1 & BL2: $p<0.0029$; JL: $p<0.025$; SL: $p<0.00417$; Combined: $p<0.00714$).

Results

Bundesliga 1

The total distance covered by players decreased by 0.4 km (95%CI: -0.5 - -0.2; p<0.001) for each 1° C T and 0.4 km (95%CI: -0.6 - -0.3; p<0.001) for each 1° C WBGT, resulting in a moderate effect (β: 0.32 – 0.33). Further the number of sprints was lower by a moderate sized effect (β: 0.39 – 0.40) for 1° C T (-2.8 sprints; 95%CI: -3.6 - -2.1; p<0.001) and 1° C WBGT (-3.3 sprints; 95%CI: -4.2 - -2.5; p<0.001), while sprint distance was also lower per 1° C T (-0.06 km; 95%CI:-0.07 - -0.04; p<0.001) or WBGT (-0.07 km; 95%CI: -0.09 - -0.04; p<0.001) was higher. Large effect sizes (β: 0.54-0.55) were detected for the association between the number of high-speed runs, being lower by 6.2 runs (95%CI: -7.3 - -5.1; p<0.001) for each 1° C T and 7.0 runs (95%CI: -8.3 - -5.8; p<0.001) for each 1° C WBGT, which resulted in a lower high-speed distance covered per 1° C T (-0.09 km; 95%CI: -0.11 - -0.07; p<0.001) or WBGT (-0.10 km; 95%CI: -0.12 - -0.08; p<0.001) was higher. Further, the peak speed recorded per match was higher by 0.03 km/h (95%CI: 0.01 - 0.04; p<0.001) for each 1° C T and 0.03 km/h (95%CI: 0.01 - 0.05; p<0.001) for each 1° C WBGT was higher, resulting in small effect sizes (β: 0.21-0.23).

Bundesliga 2

The distance players covered during matches was lower by 0.3 km (95%CI: -0.4 - -0.2; p<0.001) for each 1° C T or 0.4 km (95%CI: -0.6 - -0.3; p<0.001) for each 1° C WBGT, resulting in a small effect of both T and WBGT (β: 0.29). Further, players performed less sprints per 1° C T (-1.8 sprints; 95% CI: -2.5 - -1.1; p<0.001) or WBGT (-1.9 sprints; 95% CI: -2.7 - -1.1; p<0.001) was higher, while sprint distance was also lower per 1° C T (-0.04 km; 95% CI: -0.06 - -0.02; p<0.001) or WBGT (-0.04 km; 95% CI: -0.06 - -0.02; p<0.001) were higher. Moderate effect sizes (β: 0.40 - 0.43) were also present for the relationship between a lower number of high-speed runs per 1° C T (-5.2 runs; 95% CI: -6.4 - -4.0; p<0.001) and WBGT (-5.7 runs; 95%CI: -7.0 - -4.3; p<0.001) and lower high-speed distances covered per 1° C higher T (-0.07 km; 95%CI: -0.09 - -0.06; p<0.001) and WBGT (-0.08 km; 95% CI: -0.10 - -0.06; p<0.001). Lastly, the peak speed recorded per match was higher per 1° C T (0.03 km/h; 95%CI: 0.02 - 0.04; p<0.001) and WBGT (0.03 km/h; 95%CI: 0.02 - 0.05; p<0.001), resulting in a small effect (β: 0.27-0.28).

J-League

The total distance players covered was lower per 1° C T (-0.6 km; 95%CI: -0.7 - -0.5; p<0.001) or WBGT (-0.6 km; 95%CI: -0.7 - -0.5; p<0.001), resulting in moderate effect sizes (β: 0.34-0.39). Additionally, the number of sprints was lower by 2.7 sprints (95%CI: -3.3 - -2.1; p<0.001) and 3.1 sprints (95%CI: -3.6 - -2.5; p<0.001) for each 1° C higher in T or WBGT, resulting in a moderate effect (β: 0.34-0.40).

SüperLig

The total distance players covered during matches was not associated with changes in either temperature measurement after Bonferroni corrections were applied (p>0.01). In contrast, the number of sprints performed per match, was lower with a small effect size (β: 0.16) for each 1° C higher in T (-0.7 sprints; 95%CI: -1.1 - -0.2; p=0.003) and WBGT (-0.8 sprints; 95%CI: -1.3 - -0.2; p=0.002) but was not after Bonferroni corrections were applied (p>0.02). When observing distances covered in different speed zones, only the distance in speed zone 3 (2.01 - 4 m/s) was lower (p<0.001) when either temperature measure was higher. All other speed zones showed small but after Bonferroni corrections, non-significant reductions (p>0.01), when T or WBGT was higher, except speed zone 1 (0 - 2 m/s), which was conversely but also not significantly affected (p>0.02).

Combined leagues

When combining all match data, a reduction of total distance covered was associated with each 1° C higher in T (-0.4 km; 95%CI: -0.4 - -0.3; p<0.001) and WBGT (-0.4 km; 95%CI: -0.5 - -0.4; p<0.001) per match, resulting in a moderate sized effect (β: 0.32-0.36). Figure 2 shows the association between total distance and T and WBGT for each individual league, as well as the number of sprints, which was also lower with moderate effect sizes (β: 0.34-0.39) per 1° C higher in T (-2.0 sprints; 95%CI: -2.3 - -1.7; p<0.001) and WBGT (-2.4 sprints; 95%CI: -2.7 - -2.1; p<0.001). This resulted in the sprint distance covered being lower by 0.03 km (95%CI: -0.04 - -0.02; p<0.001) for each 1° C higher in T and 0.04 km (95%CI: -0.05 - -0.03; p<0.001) for each 1° C higher in WBGT. Similarly, high-speed runs were lower by 3.4 runs (95%CI: -4.2 - -2.7; p<0.001) per 1° C T and 3.8 runs (95%CI: -4.6 - -2.9; p<0.001) per 1° C WBGT was higher and accordingly, the high-speed runs distance was reduced per 1° C higher T (-0.05 km; 95%CI: -0.06 - -0.04; p<0.001) and WBGT (-0.06 km; 95%CI: -0.07 - -0.05; p<0.001), resulting in small to moderate effects on high-speed running (β: 0.28-0.30). Further, there were small effects (β: 0.18-0.19) on peak speed which increased at 0.02 km/h (95%CI: 0.01 - 0.02; p<0.001) per 1° C higher in T and 0.02 km/h (95%CI: 0.01 - 0.02; p<0.001) per 1° C higher in WBGT. Finally, there were marginal to small effects on the minutes the ball was in play (β: 0.09-0.10) which was 0.05 minutes (95%CI: -0.09 - -0.02; p=0.003) lower for each 1° C higher in T and 0.06 minutes (95%CI: -0.10 - -0.02; p=0.006) lower for each 1° C higher in WBGT. Table 3 summarizes all results for each PI per league and in the combined data set.

Discussion

This study investigated the relationship between environmental temperatures (T and WBGT) and running PI's in four professional football leagues. When combining match data of all leagues, a lower total running distance was observed when environmental temperatures were higher. Further, a lower number of sprints and high-speed runs, as well as distances covered at these speeds were observed when T or WBGT were higher. However, a higher peak speed was observed in matches with higher T or WBGT.

The total distance covered during football matches is an often-reported PI, though its usefulness as a predictor for success is questionable [4,24, 25]. While some studies found teams with higher running distances to be more successful[4], more often the less successful teams are found to run more, while successful teams only run more when in ball possession[24, 25]. In our study, total distance was clearly lower when T or WBGT were higher in the BL1, BL2, JL and the combined match data of all four leagues, which is in line with previous research[11,15,16]. Although speculative, these findings could result from increased player thermoregulatory and cardiovascular strain, leading to earlier onset of fatigue as part of a preventive measure against an elevated core temperature [8,9]. Furthermore, a conscious pacing strategy, in which players try to avoid elevated levels of fatigue to maintain their overall quality of playing could be another underlying reason[26]. Such pacing and tactical strategies exist even in non-thermoregulatory challenging matches, but are especially important in the heat, aiming to manage fatigue throughout the match and enabling high physical efforts when most critical[5].

The distance covered at a high speed, especially when in ball possession, is associated with successful match outcomes in football[24,27,28]. For example, increased high intensity distances and straight-line sprinting were the most frequent actions leading to goal scoring opportunities[3,5]. The current study found that less sprints were attempted in all four leagues and that the number of high-speed runs, as well as the sprint and high-speed distance was lower when T or WBGT were higher in the BL1, BL2 and when combining all match data, in line with previous studies[11,13-18]. Nevertheless, research has not shown that goals or shots are reduced in hotter temperatures[17,18]. Whilst speculative, this might again result from players pacing strategies, persevering thermoregulatory state, preventing heat-related illnesses and managing fatigue, by performing high-speed actions only when most needed.

A players ability to perform high maximum speeds and outrunning an opponent might aid in creating or preventing scoring opportunities. This study found a small effect for a higher peak speed, in BL1, BL2 and the combined match-data when T or WBGT were higher. This is in line with thermoregulatory theory, arguing that higher muscle temperatures in hot conditions are related to increased maximum velocities[9]. Accordingly previous research has shown markers of muscle damage to be reduced after a match in hot compared to temperate conditions, which may result from a combination of less muscle damage in warmer muscles and a reduced running volume in warmer conditions[29].

In this investigation there was no difference between model outcomes for T or WBGT as a predictor for running PI's. Although it is suggested that WBGT is better in describing athletes heat stress by including the effects of humidity, solar radiation and wind, the measure is also less accessible, especially to lower league clubs, who would need to invest in equipment and trained personnel to monitor WBGT. Therefore, when considering the implementation of heat guidelines, the use of T should not be neglected.

Limitations

The approach of this study including a large number of observations from four different leagues, was able to identify robust findings of environmental conditions on running performance but is also subject to some limitations. Although we accounted for differences in data sources and PI thresholds by including the leagues as a random effect in the mixed models, a more standardized data collection would be preferable. Similarly, measuring environmental conditions directly at match venues would improve accuracy of the observed temperatures. Nevertheless, the ability to combine multiple leagues and geographical settings and increases the number of observations lead to an increased external validity of the findings. Finally, although our data represented a large range of environmental conditions, it can be argued that the ratio of observations in very hot conditions was low, especially in the German leagues. Only 24 matches were held in > 30 °C T, 17 of these in the JL, 7 in the SL ad none in BL1 & BL2. The same number of matches were held in > 28 °C WBGT, with one of these in the SL and the rest in the in the JL. It must be assumed that hotter conditions could further increase the effects observed in this study, though more matches in such environments would be needed to better understand this relationship.

Practical Applications

Football teams should be aware of the associations between environmental conditions and running performance, to adjust their playing styles and tactical approaches accordingly. Performing a reduced warm up or applying cooling might help to mitigate some effects of hotter conditions [1,2]. Football federations should further monitor environmental conditions and their effects on players, as the observations of the current study were made in only moderately challenging conditions but may become more pronounced in more severe heat. Heat mitigating policies might be implemented to protect players from being exposed to hotter conditions in the future[1,2].

Conclusion

Higher T or WBGT were associated with a lower physical performance in football matches. This was not only observed for total distances covered, but importantly also for high-speed and sprinting activities, though peak speed was higher in warmer climate. The reductions may be a conscious or subconscious reaction to the increased heat stress observed by players, aiming to manage fatigue, preserve thermoregulatory state and prevent heat-illnesses.

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List of Tables and Figures:

Table 1: Definitions of performance indicators per league.

Table 2: Environmental conditions in degree Celsius (°C), including mean and standard deviation (mean ± sd), minimum (min) and maximum (max) temperature and wet bulb globe temperature for Bundesliga 1 (BL1), Bundesliga 2 (BL2), J-League (JL) and SüperLig (SL), as well as the combined data set (Combined) including all observed matches.

Table 3: Association between running PIs and environmental conditions, showing the mean and standard deviation (Mean ± SD) of each PI, as well as the estimate and 95% confidence interval (Estimate (95%CI); standardized estimate and 95% confidence interval (β (95%CI)), the marginal R^2 (R^2 (marg.)) and p-value (=significant after Bonferroni correction) for linear regressions in the Bundesliga 1 (BL1), Bundesliga 2 (BL2), J-League (JL) and SüperLig (SL) and linear mixed models in the combined data, including all observed matches (Combi).*

Figure 1: Visualisation of data structure and analysis.

Figure 2: Relationship of total distance and number of sprints with temperature and wet bulb globe temperature across all four leagues.

Figure 3: Relationship of sprint distance and high-speed distance with temperature and wet bulb globe temperature across BL1, BL2 and SL.