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Epidemiology and risk factors for heat illness: 11 years of Heat Stress Monitoring Programme data from the FIVB Beach Volleyball World Tour

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What are the new findings?

- The risk of heat-related medical time-out was related to temperature but not to relative humidity during the FIVB Beach Volleyball World Tour.
- The absolute risk of heat-related medical time-out during the Beach Volleyball World Tour remained low, even at high WBGT.
- A recent illness may represent a risk factor for a heat-related medical time-out to lead to player forfeit.

How might it impact clinical practice in the near future?

- The ACSM cancelation policy shouldn't be enforced for elite beach volleyball players.
- Players with a recent episode of diarrhoea or gastroenteritis should seek replacement if playing under hot ambient conditions.

ABSTRACT

Purpose. To analyse 11 years of FIVB heat stress monitoring data to determine the relative influence of the different environmental parameters in increasing the likelihood of a heat-related medical time-out (MTOheat).

Methods. A total of 8,530 matches were recorded. The referee measured air temperature, black-globe temperature, relative humidity and wet-bulb globe temperature (WBGT) before the matches, and registered the MTOheat. The absolute humidity was computed at posteriori.

Results. There were 20 MTOheat, but only 3 resulted in forfeiting the match. MTOheat incidence was not statistically impacted by sex ($p=0.59$). MTOheat were more prevalent during the games played in Asia during the 4th quarter of the year ($p<0.001$). Two cases of MTOheat experienced diarrhoea or gastroenteritis during the five preceding days; both of them forfeited the match. A principal component analysis showed a specific environmental profile for the matches with MTOheat. They occurred at higher WBGT, temperatures and absolute humidity ($p<0.001$), but with a lower relative humidity ($p=0.027$).

Conclusions. The current data showed that an increase in ambient or black globe temperature, but not relative humidity, increased the risk of a MTOheat; but that the absolute risk remained low in elite beach volleyball players. However, suffering or recovering from a recent illness may represent a risk factor for a MTOheat to lead to player forfeit.

INTRODUCTION

Heat strokes have become more common during recent decades and are responsible for more deaths than all natural disasters combined.[1] While the classic heat stroke mainly affects vulnerable populations, exercising athletes are at risk of exertional heat stroke (EHS). EHS correspond to an increase in core temperature >40.5^{o}C along with central nervous system dysfunction.[2,3] Given that the primary trigger for the increase in core temperature is the exercise intensity,[4] it is not surprising that numerous elite athletes reach values of 40.5^{o}C and above during competitions in hot ambient conditions, yet not exhibiting symptoms of EHS.[4-6]

EHS is generally considered as the second cause of death in athletes, after cardiac conditions.[7] This alarming ranking may even underestimate the situation, as a recent study reported 10 times more EHS than cardiac events in endurance athletes.[8] As such, most international federations as well as the International Olympic Committee have formed expert groups and developed specific heat recommendations and/or policies.[9,10] The international volleyball federation (FIVB) went one step further and initiated a surveillance program in 2009, prospectively monitoring heat stress and recording any cases of heat-related medical forfeits on the FIVB Beach Volleyball World Tour. After 3 years, a preliminary analysis of the average and peak environmental conditions during 48 tournaments over 3 seasons revealed that wet-bulb globe temperature (WBGT) surpassing 32.3^{o}C in one in five tournaments.[11] Despite exceeding this threshold, considered as the limit triggering event cancelation by the American College of Sports Medicine (ACSM),[12] no EHS were recorded and only one medical forfeit was related to heat (in an athlete playing his 5th match in 3 days despite an altered fluid balanced following 3 days of acute gastroenteritis).[11] This preliminary analysis suggested that the ACSM cancelation policy may be too conservative for elite beach volleyball players, and the authors called for new guidelines to manage heat stress at the elite level.[11]

Such epidemiological data are required for evidence-based policies, but are unfortunately sparse in elite athletes. The aim of the current project was to comprehensively analyse 11 years of FIVB heat stress monitoring data to determine the relative influence of the different environmental parameters in increasing the likelihood of a heat-related medical time-out (MTOheat).

METHODS

As part of the FIVB heat stress monitoring program, the FIVB referee delegate was responsible for monitoring environmental data and any MTOheat for each match of every tournament of the FIVB Beach Volleyball World Tour and World Championships. A match lasts ~50 min for men and ~44 min for women, with a range of 28 to 93 min.[13] A tournament lasts 4-5 days and a total of 189 tournaments representing 8,530 matches have been recorded from 2009 to 2019.

Environmental conditions

The environmental conditions were recorded by the reserve referee before each match using a heat stress monitor (HT30, Extech Technology, USA). As per the FIVB heat stress monitoring protocol, temperature measurements were taken on centre court 5 min before the start of each game in front of the scorer table, ≈1.5 m above the sand level. If the scorer table was shaded, the measurement was made closer to the court or even on court in the sunny area. The device was used according to the manufacturer's instructions and set in outside mode. It monitored air temperature (Ta, °C), black-globe temperature (Tg, °C), relative humidity (RH, %) and wet-bulb globe temperature (WBGT, °C). The WBGT values were categorised at posteriori as black (≥32.3°C), red (30.1-32.2°C), yellow (27.9-30.0°C) and green (≤27.8°C) flags.[12]

Heat-related medical time-out

If a team called for a medical time-out (MTO), the referee queried if the intervention was related to heat illness and/or dehydration. If yes, the event was defined as MTOheat, irrespectively of the MTO leading to forfeit or not. The player was also asked if he/she experienced diarrhoea or gastroenteritis during the five preceding days. This information was noted on the score sheet and reported to the referee delegate for inclusion into the Heat Stress Monitoring Form.

Statistical analyses

The analyses were performed in R version 3.5.3 (R Foundation for Statistical Computing, Vienna, Austria). The absolute humidity (AH, $g.m^{-3}$) was calculated using the package *humidity*.[14] A principal component analysis (PCA) was performed using the *Factominer* and *missMDA* packages[15,16] to explore the association between environmental conditions and MTOheat. A Chi^2 test was used to determine the association of MTOheat with sex, location and period of the year of the match. A two-sample t-test with equal variances was used to compare the environmental conditions between the matches with and without MTOheat. Data are presented as mean±SD in the text and individual values in figures. Relative risk is presented with [95% Confidence Interval]. A p-value <0.05 was used for statistical significance.

RESULTS

Match and medical event characteristics

The matches were played by females (n=4384, 51%) and males (n=4143, 49%), in Europe (n=5057, 59%), Asia (n=1952, 23%), South America (n=718, 8%), North America (n=660, 8%), Africa (n=104, 1%) and Australia (n=39, <1%). Most matches were played in the 2nd (n=3161, 37%) and 3rd (n=3793, 44%) quarters of the year; in Europe (n=4827), Asia (n=1291), North America (n=420) and South America (n=416). Some matches were also played during the 1st (n=583, 7%) and 4th (n=993, 12%) quarters; in Asia (n=661), South America (n=302), North America (n=240), Europa (n=230), Africa (n=104) and Australia (n=39).

A total of 20 MTOheat were reported, including 3 forfeits (**Table 1**). MTOheat prevalence was not statistically impacted by sex (60% female, 40% male, Chi^2=0.30, p=0.590), but depended on tournament location with 13 cases (65%) in Asia (Chi^2=21.1, p<0.001), and on quarter with only 4 during the 2nd quarter but 8 during each of the 3rd and 4th quarter (Chi^2=16.9 p<0.001). Two of the 17 MTOheat cases who provided the information (i.e. 12%) experienced diarrhoea or gastroenteritis during the five preceding days; both of them forfeited the match (Chi^2=5.13, p=0.024). Among the MTOheat, the prevalence of forfeits did not depend on sex (2 females, 1 male, Chi^2=0.07, p=0.798), but the 3 forfeits all occurred in Asia, during the 4th quarter, under black (n=1), red (n=1) and green (n=1) flags.

Environmental conditions

Average WBGT, Ta, Tg and RH were 22.4±5.0°C, 26.6±6.2°C, 33.3±10.2°C and 50.6±20.5%, respectively (**Figure 1**). 183 matches (2%) were played under black flag, 455 (5%) under red flag, 731 (9%) under yellow flag, and 7141 (84%) with a green flag.

The four environmental variables were well projected (i.e. sum of cos^2 of both axes ranges from 0.88 to 0.99) on the PCA plan represented by the first and second dimensions which explained 57.1% and 37.4% respectively of the inertia (e.g. variance generalized to several dimensions, **Figure 2**). As 94.4% of the data inertia (or information contained in the dataset) was summarized by the first two dimensions, the dimensions 3 and 4 of the cloud were not analysed. Ta and Tg contributed at 34.5% and 37.5% to the first dimension, respectively, and were strongly correlated to it (both $r \geq 0.89$,, **Figure 2**). RH and AH contributed at 21.9% and 65.1% to the second dimension, respectively, and were positively correlated to it (r=0.57 for RH, r=0.99 for AH). In addition, RH contributed at 27.9% to the first dimension and was negatively correlated to it (r=-0.80); whereas AH did not contribute (0.1%) and was not correlated (r=-0.04) to the first dimension.

Relationship between environmental conditions and medical events

The PCA graph of individual matches shows that the matches without MTOheat were not specific to the environmental conditions (i.e. narrow ellipse centred on zero on both dimensions), whereas the ellipse and barycentre of the MTOheat was shifted toward the right and up (**Figure 2**).

Matches with MTOheat occurred at a higher WBGT (t=6.4, p<0.001), Ta (t=6.4, p<0.001), Tg (t=6.4, p<0.001) and AH (t=3.6, p<0.001) than the other matches, but with a lower RH (t=2.2, p=0.027, **Figure 1**). A red flag increased the relative risk of MTOheat by 8.1 [95%CI 5.6-11.7], and a black flag by 9.5 [3.9-23.1] (both p<0.001). The absolute risk for a match to have a MTOheat was 0.2% overall, and increased to 1.8% and 2.2% in red and black flag conditions, respectively. The absolute risk for a match to be stopped for forfeit was 0.4‰ of the overall matches, and increased to 2.2‰ and 5.5‰ in red and black flag conditions, respectively.

DISCUSSION

The FIVB should be complimented for monitoring heat stress and associated MTOheat during 11 years. The 8,530 matches recorded showed that i) numerous games were played at an elevated WBGT; ii) that the games with MTOheat were played with a higher WBGT, temperature and absolute humidity, but a lower relative humidity than the others; iii) that recent diarrhoea or gastroenteritis may increase the risk of forfeit in case of MTOheat; but iv) that the absolute risk of MTOheat and forfeit remained low in professional beach volleyball.

Environmental conditions

The current dataset represents the largest description of environmental conditions in elite sport. A total of 1369 matches or 16% of all international matches were played with a WBGT of 27.9°C or above, conditions where the ACSM recommended to cancel continuous activity and competition.[12] This proportion increased to 35% in North America (with 6% of the matches reaching 32.3°C). Racinais et al. also reported that 35% of the WBGT measures were above 27.9°C during the 2016 UCI cycling world championships, whilst 1% of them reached 32.3°C.[6] As in the current study, all the competitions were held and the UCI expert panel did not advise cancelling or shortening any of the races. The UCI expert panel based their decision on the cooling effect of the relative wind velocity while cycling at high speeds, whereas in the case of beach volleyball the intermittent nature of the game is an alleviating factor. The ACSM recommended to cancel or stop practice and competition for non-continuous activity at a WBGT of 30.1°C for non-acclimatized individuals, and 32.3°C for all athletes including fit and acclimatized.[12] These conditions were reached in 638 and 183 matches respectively. Given the difficulty of rescheduling so many matches or competitions within a congested calendar, this reinforces the message that the primary countermeasure that players should adopt is to heat acclimatize.[17] Indeed, heat acclimatization has no detrimental effect if a match is played under cooler conditions but can partly protect the health and performance of the players in the heat.

Medical events

There were a total of 20 MTOheat across the 11 years of monitoring. 60% of the MTOheat (n=12) and 2 of the 3 forfeits occurred in females. However, these proportions were not statistically different as, contrary to popular belief, there is no clear thermoregulatory difference due to sex if anthropometry and fitness are accounted for.[18] Likewise, oral contraceptive and menstrual cycle phase have a minimal impact on thermoregulation as compared to the environmental conditions.[19] This result is in line with a recent report showing no sex differences in history of a previous heat illness.[6]

Although the 4th quarter of the year represent only 12% of the matches, it included 40% of the MTOheat, all of them in Asia. Albeit the 4th quarter was predominantly played in Asia and included a higher relative proportion of red and black flags, the absolute number of matches in hot ambient conditions was lower than during the first semester (i.e. 42 black and 89 red flags during the 4th quarter vs 59 black and 171 red flags during the first semester) whilst the absolute number of MTOheat was doubled (i.e. 8 vs 4). This suggests that other factors than environmental conditions may have affected MTOheat. A potential explanation for the higher rate of MTOheat in the 4th quarter could be that players leaving in the north hemisphere would not benefit anymore of seasonal acclimation. Indeed, all MTOheat from the 4th quarter occurred in Asia (mainly Thailand) with players from Europe (specifically north or eastern Europe) (**Table 1**). This suggests that seasonal acclimation is important in protecting athlete health when playing in the heat and confirms a previous report showing that triathletes were at higher risk of MTOheat at the beginning than the middle of the summer.[20]

Medical events *vs.* environmental conditions

Environmental parameters are interdependent. In the current study, we used a PCA approach for linear data dimension reduction in order to provide a subspace that best represents the data,[16] retaining 95% of the matches variance (**Figure 2**). Most international federations use the WBGT to summarise the environmental conditions and guide their heat policy.[17] The WBGT is a compound index developed for military personnel based on ambient temperature, black-globe temperature (accounting for solar radiation) and wet-bulb temperature (accounting for the air capacity to evaporate water depending on its RH and velocity). Its use in sports was popularized by the ACSM,[12] but has been criticised for being a climatic index only, not accounting for metabolic heat production or for heat dissipation capacity in exercising athletes.[17] It has also been suggested that the WBGT may underestimate the rise in thermal stress due to high humidity and/or low air movement limiting sweat evaporation.[21] Therefore, it has been proposed to strengthen the original ACSM risk categories when RH increases by, for example, defining an excessive risk at a WBGT of 33°C if RH is ~50%, 29°C if RH is ~75% and 28°C if RH is ~100%.[17,22]

Yet, the current data showed that RH was actually lower during the matches with MTOheat (**Figure 1**). Given that the primary avenue for heat dissipation in athlete is sweat evaporation, this results may appear surprising;[17] especially as exercise capacity has been repeatedly shown to decrease at a given Ta when RH increases.[19,23,24] However, as mentioned above, environmental parameters are not independent of each other as a given AH represents a lower RH at a higher temperature.[25] Thus, the matches played at the highest Tg and Ta, and hence with MTOheat, were not associated with a high RH (**Figure 2**). Conversely, AH was higher in the matches with MTOheat. Taken together, the current results showed that an increase in Ta and Tg was more potent than an increase in RH to trigger a MTOheat. This could partially be explained by the fact that an increase in temperature may impair perceptual response for a given AH (i.e. despite a lower RH).[25] Importantly, this observation may be specific to beach volleyball, and the risk due to RH should not be underestimated during continuous activities such as running.

The absolute risk of MTOheat was 0.2% of the overall matches, and increased to 1.8% and 2.2% in case of red and black flag respectively. These numbers represent the global risk of a MTOheat occurring during a match. Given that four players were on the court each match, the absolute risk of MTOheat for a player was only 0.6‰ overall, and increased to 4.4‰ and 5.5‰ in case of red and black flag respectively. Although difficult to compare an 11-years database to a single championship, it is worth noting that seven cases of heat-related illness were reported among the 1,225 participants to the 2015 Para Athletics World Championships, representing a 5.7‰ incidence in a championship held with a WBGT of 25-36°C.[26] Similarly, three cases of heat-related illness were reported among the 982 participants to the 2016 Road Cycling World Championships, representing a 3.1‰ incidence in a championship held at a WBGT of 27°C.[6] Although these number may appear similar, the

FIVB databased included all MTOheat, even minor ones that were treated by event medical personnel during the MTO simply with fluids and 5 min maximum of shaded rest. Only three of the MTOheat in the current study resulted in a match forfeit (**Table 1**), none of them serious (not requiring hospital treatment), showing a very low absolute incidence of heat-related forfeit per player (0.1‰ overall, 0.6‰ under red flag and 1.4‰ under black flag). This suggests that, even when environmental conditions are taxing, beach volleyball at the professional level can be played safely. The consequences for recreational players or on match characteristics remain to be investigated.

Previous conditions

From the 20 MTOheat, only two reported a recent illness, but both of them led the player to forfeit the match. Thus, two of the only three forfeits were linked to an episode of diarrhoea or gastroenteritis within the five preceding days. This confirms the preliminary report after 3 years of the FIVB monitoring program,[11] and suggests that a recent illness may be a serious risk factor for heat-related forfeit.[17] It is unfortunately common for athletes to compete while suffering or recovering from recent symptoms. Indeed, 13% of elite athletes completing a questionnaire before the world athletic championships declared an illness within the past 4 weeks,[27] 19% of amateur athletes declared an illness in the 8-12 days preceding a distance running event,[28] and 22% of elite cyclists completing a questionnaire before the world cycling championships declared an illness in the 10 days preceding the championship, with 32% of those representing gastrointestinal symptoms.[6] The literature reports that recent symptoms of an acute illness increased the risk of forfeiting an endurance race by 1.9 times.[28] Although the current data do not allow us to calculate how a recent illness increased the risk of MTOheat, as only the MTOheat athletes were questioned, it showed that both of the players with a MTOheat while recovering from a recent illness forfeited, compared to only 1 amongst the 17 other MTOheat.

CONCLUSION

The current data showed that an increase in ambient or black globe temperature, but not relative humidity, increased the risk of a heat-related medical event; but that the absolute risk remained low in elite beach volleyball players. However, suffering or recovering from a recent illness may represent a risk factor for a MTOheat to lead to player forfeit.

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CONTRIBUTORS

All authors critically reviewed the manuscript, provided significant input and approved the final version. SR drafted the manuscript and interpreted the data. MA analysed the data. NN prepared the data. RB designed the FIVB Heat Stress Monitoring Program and monitored data collection.

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COMPETING INTERESTS

None declared.

ETHICS APPROVAL

The study is a retrospective analysis of a deidentified international federation database.

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Table 1. Individual details of all heat-related medical time-out

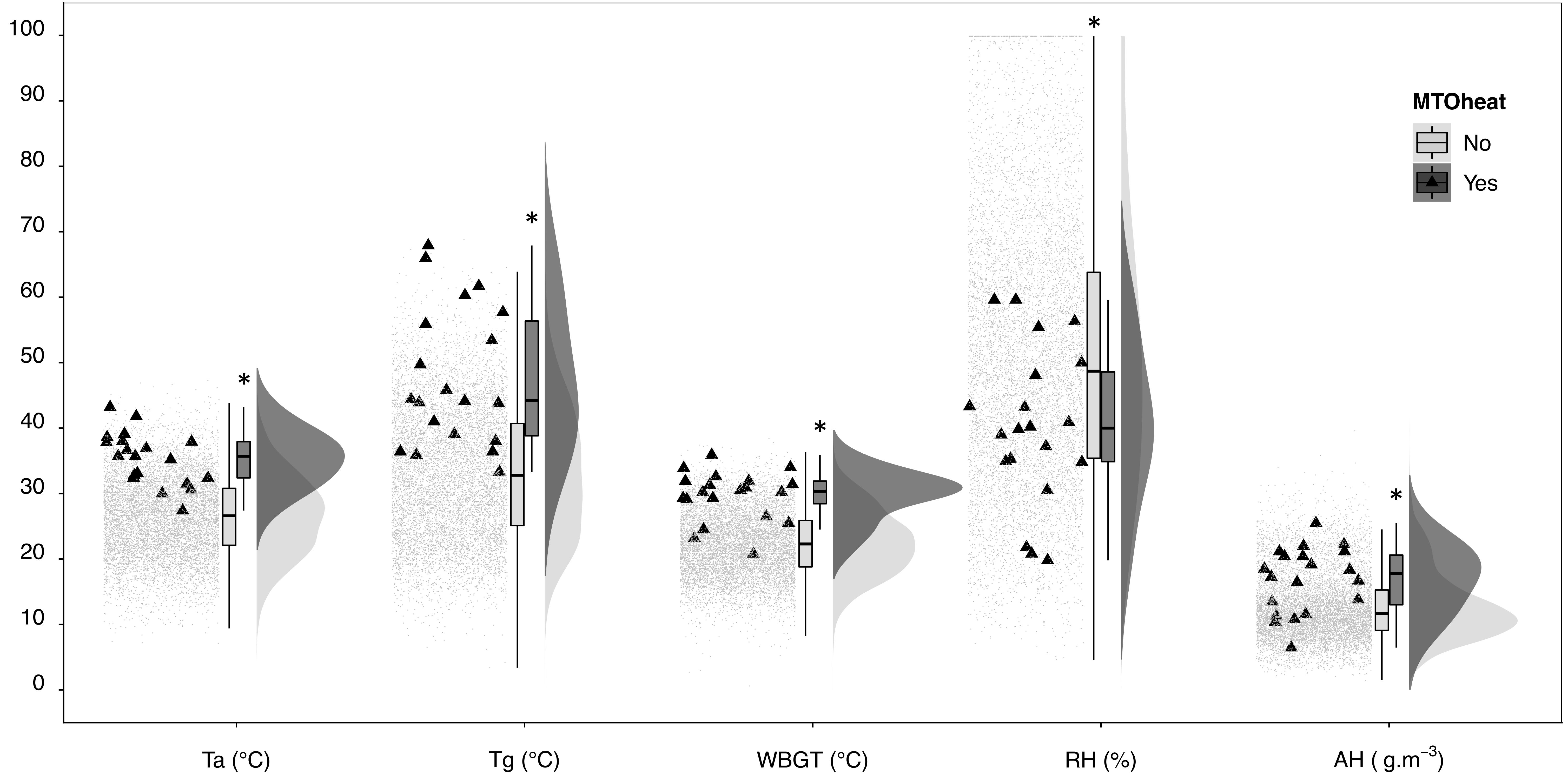
Saison	Year	Continent	Sex (F/M)	WBGT (°C)	Temperature (°C) Air	Temperature (°C) Black-globe	Humidity Relative (%)	Humidity Absolute (g.m^{-3})	Patient country	Previous illness	Forfeit
Q2	2012	Europa	M	20.8	30.0	35.9	20.8	6.5	SUI	No	No
Q2	2014	Europa	M	30.2	37.9	60.3	21.8	10.4	NED	No	No
Q2	2015	Europa	F	30.2	38.6	49.7	34.9	17.3	ITA	No	No
Q2	2018	Europa	F	24.5	27.4	44.1	40.2	10.8	CHN	No	No
Q3	2009	Europa	F	23.2	30.6	33.3	35.3	11.3	AUS	N/A	No
Q3	2014	Europa	M	33.9	41.8	66.0	19.8	11.6	BRA	N/A	No
Q3	2014	Europa	F	25.5	31.5	38.0	40.9	13.8	SUI	N/A	No
Q3	2017	Asia	M	31.4	35.7	43.8	48.1	20.4	TUR	No	No
Q3	2019	Asia	M	29.3	32.4	36.4	59.6	21.1	BRA	No	No
Q3	2019	Asia	M	29.3	32.4	36.4	59.6	21.1	BRA	No	No
Q3	2019	Asia	M	29.1	33.1	41.0	55.4	20.4	BRA	No	No
Q3	2019	Asia	F	31.9	35.2	55.9	39.8	16.4	JPN	No	No
Q4	2009	Asia	M	26.5	32.8	43.9	37.2	13.5	NOR	Yes	Yes
Q4	2011	Asia	F	30.9	36.6	44.4	50.0	22.3	RUS	N/A	No
Q4	2012	Asia	F	31.9	38.0	53.4	34.8	16.7	GER	Yes	Yes
Q4	2012	Asia	F	34.0	37.8	61.7	39.0	18.5	RUS	No	Yes
Q4	2013	Asia	F	32.6	35.7	57.7	43.2	18.3	RUS	No	No
Q4	2013	Asia	F	35.9	43.2	67.9	30.5	19.1	UKR	No	No
Q4	2013	Asia	F	30.5	36.9	45.8	56.3	25.5	RUS	No	No
Q4	2013	Asia	F	31.3	39.1	39.1	43.3	22.0	RUS	No	No

WBGT wet-bulb globe temperature, N/A data not available

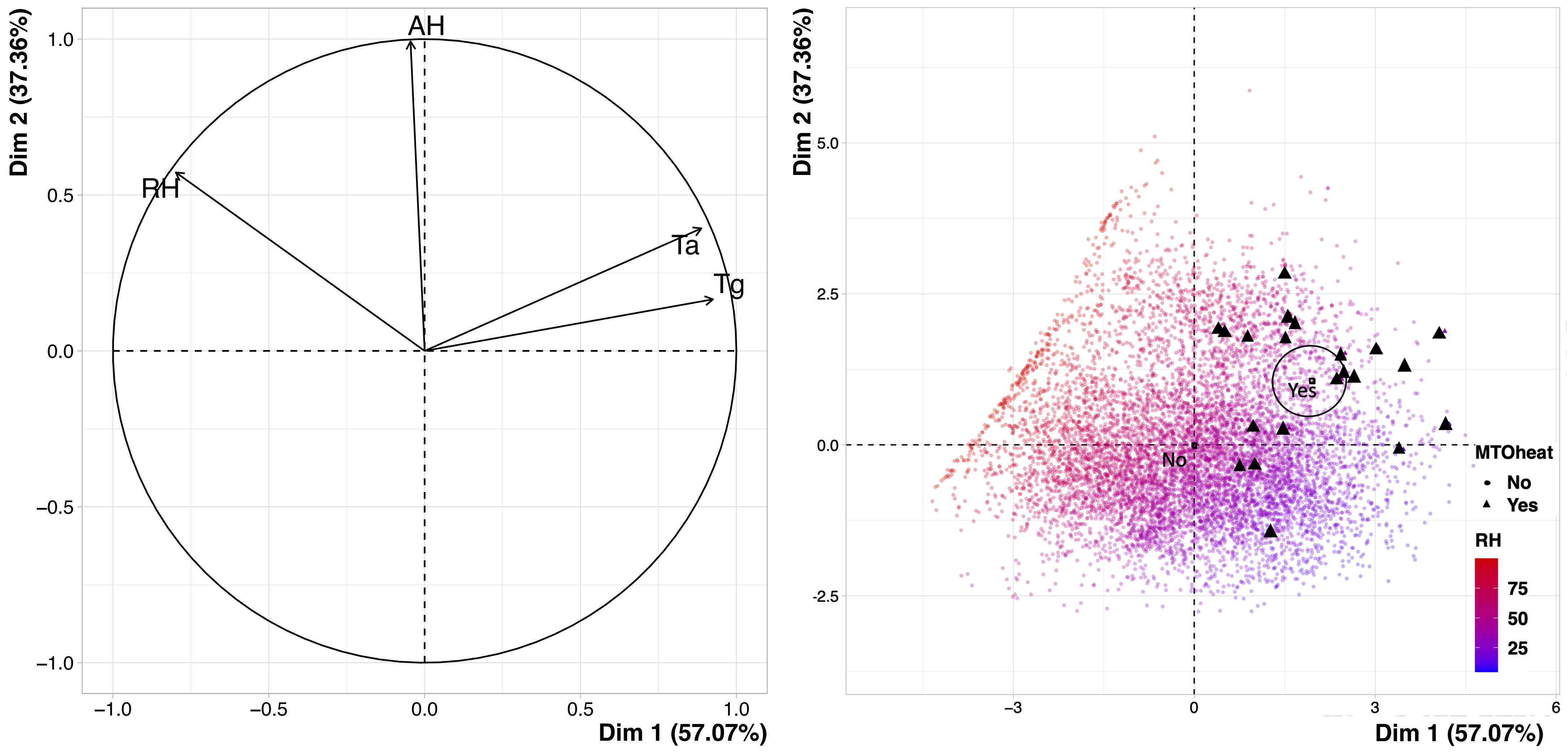
FIGURES LEGENDS

Figure 1. Environmental conditions during the games without (light grey) and with (dark grey) heat-related medical time-out events (MTOheat). The rainclouds[29] include individual points (with MTOheat indicated by black triangles). Ta: air temperature, Tg: black-globe temperature, WBGT: wet-bulb globe temperature, RH: relative humidity, AH: absolute humidity. * $p<0.05$.

Figure 2. Left panel: Circle of correlation between variables representing the covariance matrix of the Principal Component Analysis. Ta: air temperature, Tg: black globe temperature, RH: relative humidity, AH: absolute humidity. The vector arrow of a variable indicates the location of the matches with a high value for this variable on the right panel. Right panel: Cloud of the 8,530 individual matches. Heat-related medical time-out events (MTOheat) are marked with a black triangle. The ellipses and barycentres of the two categories (MTOheat: no/yes) are also represented.



MTOheat
No
Yes
100
90
80
70
60
50
40
30
20
10
0
*
Ta (°C)
Tg (°C)
WBGT (°C)
RH (%)
AH (g.m−3)


AH
RH
Ta
Tg
Dim 2 (37.36%)
Dim 1 (57.07%)
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
Yes
No
Dim 2 (37.36%)
Dim 1 (57.07%)
5.0
2.5
0.0
-2.5
-3
0
3
6
MTOheat
No
Yes
RH
75
50
25