Apparent temperature and heat-related illnesses during international athletic championships: A prospective cohort study

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Abstract
International outdoor athletics championships are typically hosted during the summer season, frequently in hot and humid climatic conditions. Therefore, we analyzed the association between apparent temperature and heat-related illnesses occurrence during international outdoor athletics championships and compared its incidence rates between athletics disciplines. Heat-related illnesses were selected from illness data prospectively collected at seven international outdoor athletics championships between 2009 and 2018 using a standardized methodology. The Universal Thermal Climate Index (UTCI) was calculated as a measure of the apparent temperature based on weather data for each day of the championships. Heat-related illness numbers and (daily) incidence rates were calculated and analyzed in relation to the daily maximum UTCI temperature and between disciplines. During 50 championships days with UTCI temperatures between 15°C and 37°C, 132 heat-related illnesses were recorded. Average incidence
INTRODUCTION

International outdoor athletics (track and field) championships regularly take place during summer Northern Hemisphere months (July-August-September). This period frequently exposes athletes to hot weather that might be a risk for athletes’ health.\(^1,2\) Specifically, heat-related illnesses in athletics are reported to be more frequent in areas and months with elevated temperatures.\(^3,4\) Heat-related illnesses can range from relatively benign symptoms to severe malignant illnesses such as exertional heat strokes.\(^1\) Such potential serious consequences imply a need for better understanding of heat-related illnesses in order to optimize prevention.

There is good evidence for an association between climatic / environmental conditions and heat-related illnesses in road running events.\(^5-7\) In a recent systematic review, running was highlighted to be the organized sport with the highest rate of heat illnesses.\(^8\) The incidence rate for exertional heat illnesses was 0.7 per 10 000 athletes in female collegiate outdoor running events, with similar rates for competition and training, without specific details on the temperature at which exertional heat illnesses occurred.\(^3\) In addition, retrospective data from elite athletes participating in international athletics championships suggested that approximately 50% of these athletes have already experienced symptoms associated with heat-related illnesses, and 1 in 12 have been diagnosed with exertional heat illness.\(^9\) Based on these results, considerations of climatic conditions have been recommended for illness prevention strategies toward elite outdoor championships.\(^2,10,11\) However, no data on the association between climatic conditions and the occurrence of heat-related illnesses during major athletics championships have been reported to support these potential strategies with scientific evidence. Such results would have practical implications, especially in the context of the expected hot and humid conditions for Tokyo Olympic Games 2020 now scheduled for July/August 2021 (Figure 1),\(^2,12-15\) and for future major athletics championships.

Therefore, we 1) analyzed associations between daily heat-related illness incidence rates and daily climatic conditions measured by the universal thermal climate index (UTCI) and 2) compared the heat-related illnesses incidence rates between athletics disciplines during elite international outdoor athletics championships. Our hypotheses were that 1) there is an association of heat-related illness risk with apparent temperature, and 2) longer endurance events (ie, marathon and race walking) show increased risk for heat-related illnesses than disciplines with shorter duration.

MATERIALS AND METHODS

In this total population study, illness data were prospectively collected during seven international outdoor athletics championships held between 2009 and 2018 (Table 1). The seven championships represented a total of 50 competition days, 27 during World and 23 during European Championships. Overall, there were 11 251 athlete registrations with a cumulative number of 82 518 athlete days.

The methods of illness data collection were identical during all championships and have previously been described in detail.\(^16-18\) During each championship, illness data were reported daily by the national medical teams and the local organizing committee medical team. Data included sex, date of birth, discipline, diagnosis, mode of onset, date of occurrence, affected system, main symptoms, cause of illness,
and estimated absence in days (estimated time loss). All illness reports in the database were anonymous. Before each championship, athletes were informed about the study and that they can refuse that their data is used; no athlete refused to allow his/her data to be used for scientific research. There was no patient and public involvement. The study protocol
was reviewed and approved by the Saint-Etienne University Hospital Ethics Committee (Institutional Review Board: IORG0007394; IRBN742020/CHUSTE).

Illness was defined as a physical or psychological complaint or manifestation by an athlete not related to injury, any new illness (or acute episode of a chronic condition) was included and classified as described in the consensus statement for epidemiological studies in athletics. For the present study, an illness was classified as “heat-related illnesses” if (a) the diagnosis was heat syncope, heat exhaustion, exertional heat stroke, hyperthermia of exercise, or exertional heat injury; or (b) the cause was reported to be environmental or exercise-induced and associated with the following main symptoms: dehydration, hypotension, nausea/vomiting, hyperthermia, dizziness, vertigo, syncope, collapse, and loss of consciousness. Heat cramps were not included in this analysis, since they have been defined as injuries and might be due to muscle overload and neuromuscular fatigue. The selection of “heat-related illnesses” was independently performed by two experienced sports medicine physicians (KH and PE), and consensus achieved if needed. Disciplines were grouped into short-duration disciplines (sprints, hurdles, throws, and jumps), combined events (heptathlon, decathlon), middle-distance (800 m, 1500 m), long-distance running (3000 m steeplechase, 5000 m and 10000 m), marathon (half and full), and race walking (20 km and 50 km).

The level of external heat stress was quantified from the UTCI, which provides a unitary estimate of the physiological experience of temperature. UTCI uses data from the meteorological variables air temperature, humidity, wind speed, and radiation. The calculation of UTCI via the mean radiant temperature from weather and climate model data was conducted according to Di Napoli et al. Mean radiant temperature is calculated for a given location from the solar and thermal radiation which is itself calculated in weather and climate models. The methodology from Di Napoli et al. is applied here in the ERA5-Land reanalysis, which is a best estimate for the global weather over the last decades combining both observational data and model calculations. The ERA5-Land dataset provides the required meteorological variables to calculate UTCI at about 10 km global resolution in hourly time intervals. The closest point to the respective stadium for every championship was chosen, and available data in a radius of about 25 km were used to estimate the uncertainty of the UTCI calculation. Limited information was available on the whereabouts of athletes, such that we had to interpret our UTCI calculation to be a representative average of large outdoor spaces in the hosting city.

The incidence rates were calculated by dividing the number of new heat-related illnesses by the number of registered athletes, for female and male athletes, and according to the discipline groups. We also compared the relative risk (RR) of sustaining a heat-related illness (with 95% confidence interval (95%CI)) between female and male athletes (with male as reference), and between disciplines groups (with short-duration disciplines as reference) by dividing the incidence rates for the corresponding athlete categories.

Associations between daily heat-related illness rates and daily maximum UTCI temperatures during the championships were thereafter analyzed by fitting linear models. The daily incidence rates were calculated by dividing the number of recorded heat-related illnesses for a day by the number of registered athletes. As no personal identification data were collected, the study data do not account for athlete-level variations in the combined heat stress resulting from internal heat production and external climatic conditions during training and competitions. For a given temperature, a mean daily incidence rate was first calculated by fitting a linear model to the daily incidence rates observed within temperature categories of 3–5°C width. To account for the increased risk for endurance athletes on competition days, both a typical and a 1-in-10 highest possible daily incidence rate were thereafter calculated, where the mean incidence rate per temperature category was replaced with the 50th and 90th-percentile, respectively. To be able to determine statistical significance, the 95% CIs were estimated for each model with 1000 Monte Carlo experiments (corresponding to a Bootstrap method) by (i) varying randomly chosen reasonable temperature categories; (ii) sampling from the uncertainty distribution of daily maximum UTCI; and (iii) by sampling from the uncertainty of daily incidence rates which are assumed to be normally distributed with \( \sigma = 0.5 \). This was performed for all disciplines and according to disciplines. For statistical analysis, python (version 3.7.7, © Copyright 2001–2019, Python Software Foundation), numpy 1.18.5, and scipy 1.5.2 were used. All scripts and the respective weather data can be found at M Klöwer, 2021. milankl/AthleticsChampionshipsHeat: Meteorological data and analysis scripts for publication. (Version v1.0). Zenodo. http://doi.org/10.5281/zenodo.4946916

3 RESULTS
3.1 Climatic conditions during championships

The seven championships took place in the Northern Hemisphere during summer months (Table 1) and exposed the athletes to a wide range of apparent temperatures
Most championship days had daily maximum UTCI temperatures between 20 and 30°C (58% of days), only 5 days (10%) recorded a daily maximum below 20°C, but 16 days (32%) above 30°C, with 6 days above 36°C (12%) (Figure 2).

### 3.2 Heat-related illness during championships

During the seven championships, 534 illnesses in 513 athletes were reported. About a quarter of all illnesses...
(n = 132; 24.7%) were classified as heat-related illnesses (Table 2). Heat-related ill athletes accounted for 78.5% of all ill marathon runners, 56.1% of ill race walkers, 13.9% of ill long-distance runners, 14.6% of ill middle-distance runners, 7.1% of ill combined events athletes, and 4.3% of ill short-duration disciplines athletes.

An estimate of the duration of absence from sport was reported for 100 heat-related illnesses. About half (n = 51) were not expected to lead to estimated time loss, 47 were classified as mild (1–7 days) and two as moderate: dehydration in a female marathon runner (10 days) and hyperthermia in a male 10 000 m runner (28 days). No heat-related illness was expected to result in more than 28 days of estimated time loss.

Over all championships, the incidence rate of heat-related illnesses was 11.7 (95% CI 9.7 to 13.7) per 1000 registered athletes, without sex difference (RR = 0.93, 95% CI 0.66 to 1.31) (Table 2). Race walkers (RR = 45.5, 95% CI 21.6 to 96.0) and marathon runners (RR = 47.7, 95% CI 23.0 to 98.8) had higher heat-related illness rates than athletes competing in short duration explosive disciplines (Table 2). Long-distance runners had no higher heat-related illness rates compared with short duration events (RR = 3.2 (95% CI 0.96 to 10.7)). Daily incidence of heat-related illnesses differed according to the disciplines with higher rates in marathon and race walking, and according to the daily maximum UTCI temperatures with higher rates when UTCI temperature increased (Figure 3).

### Table 2

| Number (% of all heat-related illnesses) | Athletes | | | |
| --- | --- | --- | --- |
| | Total | Female | Male |
| | n | % | n | % | n | % |
| All heat-related illnesses | 132 (100.0) | 63 (47.7) | 69 (52.3) |
| Short-duration disciplines | 11 (8.3) | 7 (5.3) | 4 (3.0) |
| Combined events | 1 (0.8) | 1 (0.8) | 0 (0.0) |
| Middle distances | 7 (5.3) | 4 (3.0) | 3 (2.3) |
| Long distances | 5 (3.8) | 2 (1.5) | 3 (2.3) |
| Marathon | 62 (47.0) | 37 (28.0) | 25 (18.9) |
| Race walking | 46 (34.8) | 12 (9.1) | 34 (25.8) |

| Incidence rate per 1000 registered athletes | Rate (95%CI) | Rate (95%CI) | Rate (95%CI) |
| --- | --- | --- | --- |
| All heat-related illnesses | 11.7 (9.7 to 13.7) | 12.2 (9.2 to 15.2) | 11.3 (8.7 to 14.0) |
| Short-duration disciplines | 1.5 (0.6 to 2.4)) | 2.0 (0.5 to 3.5) | 1.0 (0.0 to 2.0) |
| Combined events | 2.5 (−2.4 to 7.4) | 5.4 (−5.2 to 16.0) | 0.0 (0.0 to 0.0) |
| Middle distances | 7.1 (1.9 to 12.4) | 9.2 (0.2 to 18.1) | 5.5 (−0.7 to 11.7) |
| Long distances | 4.8 (0.6 to 9.0) | 4.2 (−1.6 to 10.1) | 5.3 (−0.7 to 11.3) |
| Marathon | 71.8 (54.6 to 89.1) | 93.0 (64.4 to 121.5) | 53.8 (33.3 to 74.3) |
| Race walking | 68.6 (49.4 to 87.7) | 49.6 (22.2 to 76.9) | 79.3 (53.7 to 104.8) |

| Relative risk (RR) (with 95% CI) (Short-duration disciplines as reference) | RR (95%CI) | Rate (95%CI) | Rate (95%CI) |
| --- | --- | --- | --- |
| Short-duration disciplines | - - | - - | - - |
| Combined events | 1.67 (0.16 to 17.3) | 2.65 (0.24 to 28.9) | NA NA |
| Middle distances | 4.74 (1.61 to 14.0) | 4.49 (1.11 to 18.2) | 5.33 (0.97 to 29.4) |
| Long distances | 3.20 (0.96 to 10.7) | 2.08 (0.35 to 12.5) | 5.13 (0.93 to 28.3) |
| Marathon | 47.7 (23.0 to 98.8) | 45.6 (18.3 to 114.0) | 52.0 (15.6 to 172.7) |
| Race walking | 45.5 (21.6 to 96.0) | 24.3 (8.5 to 69.9) | 76.6 (23.6 to 248.9) |

Abbreviations: n: number; %: percentage; 95%CI: 95% confidence interval; NA: not applicable.

Note: Short-duration disciplines (sprints, hurdles, throws, and jumps), combined events (heptathlon, decathlon), middle-distance (800 m, 1500 m), long-distance running (3000 m steeplechase, 5000 m and 10000 m), marathon (half and full), and race walking (20 km and 50 km).
3.3 Associations between daily apparent temperatures and heat-related illness

The expected daily incidence rate of heat-related illnesses increased significantly with UTCI temperature (0.12 more illnesses per 1000 registered athletes/°C; 95%CI 0.08–0.16) (Figure 4). The 1-in-10 highest possible incidence rate significantly increased with temperature (0.26 more illnesses per 1000 registered athletes/°C; 95%CI 0.04 to 0.48); this means that in 1 out of 10 championship days at 25°C, an incidence rate for heat-related illnesses of about 3 per 1000 registered athletes and day was predicted, which increased to about 6 per 1000 registered athletes and day at 35°C (Figure 4). The baseline linear model of association between daily apparent temperature and heat-related illnesses showed that the modeled mean incidence increased with temperature from about 1 recorded illness per 1000 registered athletes and day at 25°C to 2 illnesses per 1000 registered athletes and day at 35°C UTCI (significant at the 5% level) (Figure 4). As expected from the competition schedules, hot days without any recorded heat-related illnesses were common during the championships, as the median daily incidence rate did not increase significantly with temperature.

4 DISCUSSION

The main findings of the present study were that 1) heat-related illnesses accounted for a quarter of all illnesses during international outdoor championships, and 78.5% of ill marathon runners and 56.1% of ill race walkers, 2) the probability that a heat-related illness is reported on a specific day increased with the apparent temperature on that day, 3) the predicted 1-in-10 highest possible heat-related illnesses doubled from 25°C to 35°C UTCI, while the predicted median was independent of the apparent temperature, and 4) the risk for suffering a heat-related illness during a championship was more than ~45-fold increased for elite marathon runners and race walkers, but not for long-distance runners, compared to other elite athletes competing in short-duration disciplines, with no differences between sexes.

4.1 Heat-related illnesses and the Universal Thermal Climate Index

Heat-related illnesses can occur during all seasons and in all geographical areas, but occur more often during summer months and in areas with higher temperatures. Our analysis showed a strong association between apparent temperature and the occurrence of heat-related illnesses. This is in accordance with data from running events, for which specific guidelines for preventive measures such as “do not start” temperatures have been developed. Furthermore, we attempted to quantify the relation between thermal stress (expressed by the UTCI) and the rate of heat-related illnesses in elite athletes during international athletics championships. These results provide important information for medical teams when preparing for events held in hot and humid condition (eg, anticipate the therapeutic measures, especially cold water immersion), as these pathologies can be life-threatening. However, it needs to be kept in mind that heat-related illness can occur in all climatic conditions, and in all athletic disciplines, even short ones.

4.2 Higher risk of heat-related illnesses for race walkers and marathon runners

As this was the first study to describe the epidemiology of heat-related illnesses during elite athletic championships, there are no adequate data to compare our reported rates to with regard to level and methodology. Nonetheless, there
are reports from heat-related illness during endurance events for example during 10 km road races of 1.6 heat illnesses per 1000 finishers. For collegiate sports, 6 heat illnesses per 1000 athlete exposures for female outdoor running events and 5 heat illnesses per 1000 athlete exposures in male cross-country were reported. A recent systematic review summarized the rate of (exertional) heat illnesses to be between 0.001 and 5.5 heat illness per 1000 participants of endurance events. Given the differences in illness collection methodology and exposures, these data on road races are not directly comparable to the heat-related illnesses rates reported for endurance athletes in our current study (~70 per 1000 registered athletes). However, higher risk in endurance athletes is consistent with our results.

FIGURE 4 Observed daily incidence rates (per 1000 registered athletes) of heat-related illnesses as a function of the daily maximum apparent temperature (UTCI) for all athletes (A) as well as athletes in short-duration events (B), combined events (C), middle distances (D), long distances (E), marathon (F), and race walking (G). Expected incidences, typical incidences, and 1-in-10 highest possible incidence rates are modeled as linear least squares fit to the mean, median, and 90th percentile incidence rates per temperature, respectively, with the 95%CI gray shaded. Please note that the vertical axis of the marathon and race walking (F and G) plots is 10-fold higher than plots A–E.
reporting an almost 45 times higher risk for heat-related illnesses in marathon runners and race walkers compared to athletes competing in short-duration disciplines (Table 2).

4.3 | **No sex-related differences in heat-related illnesses during international championships**

Our study found no differences between male and female athletes for heat-related conditions or heat illnesses. For exertional heat strokes, data from road races have suggested a similar risk for male and female runners.27 No sex differences were also reported in elite road cycling or beach volleyball.30 Opposite to popular belief, there may not be evident difference in thermoregulation between elite males and females athletes.30 Considering the low number of exertional heat strokes in our study and the differences in reporting methodology, no reliable conclusion can be reached. For future studies, a consensus for the inclusion of different pathologies as heat-related illnesses is recommended.

4.4 | **The issue of thermal indices**

Currently, no consensus exists which thermal index optimally applies to the need of sports medicine research.31 The WBGT has frequently been used to measure the heat exposure during a competition and is used by athletic federations to give recommendations.10 In recent years, the limitations of the WBGT have been discussed, and the UTCI or the modified physical equivalent temperature (mPET) have been proposed to be more accurate in modeling sport-specific heat stress.31 The heat stress perceived by a human body depends on physiological parameters (such as evapotranspiration) and meteorological variables (such as air temperature, humidity, wind speed, and radiation).21 The UTCI is measured in °C and takes these meteorological variables into account and provides a measure for the thermo-physiological experience in a wide range of climatic conditions.21-23 Furthermore, the UTCI can be derived from weather forecasts about one week prior to an event as well as re-calculated globally for the past decades.23 In that sense, the UTCI presents itself more useful and comparable than the WBGT to assess the heat stress arising from weather conditions globally.

4.5 | **Methodological considerations**

While this study gains strength from a valid and reliable data collection method that covered a large proportion of the athletes at the championships included,18 there are a number of confounding factors requiring consideration.

While collecting data using the same methods and following a consensus statement should help to provide reliable data,18 the illness reports relied on local organizing committee and team physicians, who may interpret things differently in terms of illness diagnoses. Especially with several different definitions and groupings of heat-related illness, without information about the rectal/core temperature, there is a possibility that heat-related illnesses were incorrectly categorized.3,19 Regular measurements of core temperatures at site and a clearer consensus on what is incorporated as a heat illness and a heat-related condition might help future studies on this topic.2

A limitation could be due to the limited information regarding the circumstance, onset, and time of the occurrence of the heat-related illnesses. A recent analysis of road races from Sweden has shown that a large increase in heat stress from the day prior to the race day may increase the rate of collapses.32 Future data collection should include the climatic conditions at the time of athletic competition and more precise information regarding the circumstances of the illness occurrence (eg, time, prior weather conditions, training, or competition). Although the daily maximum UTCI was used in this study, the daily mean or 3-day rolling average yield qualitatively comparable results.

4.6 | **Practical implications**

While training demands can be adjusted during a preparation phase, athletes strive to perform at a maximum effort at major championships. Accordingly, higher heat illness rates have previously been reported for competition compared to training.3 In order to anticipate the heat risks during competition, some adaptation of the schedule can be made. For example, the 2019 World Athletic Championships were held in Doha, Qatar, in September and October 2019 (later in the summer season than previous championships), along with some adaptations to the schedule, such as scheduling the road racing events outside daylight hours due to the heat.10 The athletics competitions in the upcoming Olympic Games in Tokyo and Sapporo for road races/Japan (30th of July till 8th of August 2021) are anticipated to become the hottest in history (Figure 1).33 When preparing for international outdoor athletics championships, healthcare professionals, from local organization and national teams, should consider the climatic conditions far in advance,33 as well as being mindful of local weather forecasts in the days leading up to and during the championships. Apparent temperatures can be derived from meteorological data, and forecast should be
used for the implementation of heat-related illness prevention and medical service provision strategies. Ideal would be a semi-automatic and interdisciplinary weather forecast providing the estimated UTCI on the competition day to give guidance on possible countermeasures for medical teams and local organizing committees. The most important countermeasure is acclimation or acclimatization to the expected climate. Additional countermeasures could include contingency plans for marathon and race walking (currently recommended above 28°C WBGT), protective clothing, and cooling, which might also have a positive effect on performance. The data from this study and the prediction of UTCI temperatures based on weather forecasts might be helpful in preventing heat-related illnesses. Reliable and relevant forecasting is needed which is possible for UTCI temperatures derived from weather forecasts. Medical teams supporting marathon and race walking in hot and humid conditions should receive education on diagnosis and management and should have the equipment and human resources available to treat these heat-related illnesses.

5 | PERSPECTIVES

Higher apparent temperatures were associated with more daily heat-related illnesses. Elite athletes competing in marathon and race walking had a higher risk of heat-related illnesses than athletes competing in shorter-duration disciplines. Heat-related illness prevention should be prioritized for marathon and race walking at outdoor athletics championships, particularly those taking place in warm and humid climates. UTCI temperatures can be derived from meteorological data and can be forecast.

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CONFLICT OF INTEREST

No author reported a conflict of interest.

ETHICAL APPROVAL INFORMATION

The study protocol was reviewed and approved by the Saint-Etienne University Hospital Ethics Committee (Institutional Review Board: IORG0007394; IRBN742020/CHUSTE).

DATA AVAILABILITY STATEMENT

The weather data and analysis scripts are available in M Klöwer, 2021. milankl/AthleticsChampionshipsHeat: Meteorological data and analysis scripts for publication. (Version v1.0). Zenodo. http://doi.org/10.5281/zenodo.4946916

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