Review

Heat-related risk at Paris 2024: a proposal for classification and review of International Federations policies

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ABSTRACT
Several International Federations (IFs) employ specific policies to protect athletes' health from the danger of heat. Most policies rely on the measurement of thermal indices such as the Wet Bulb Globe Temperature (WBGT) to estimate the risk of heat-related illness. This review summarises the policies implemented by the 32 IFs of the 45 sports included in the Paris 2024 Olympic Games. It provides details into the venue type, measured parameters, used thermal indices, measurement procedures, mitigation strategies and specifies whether the policy is a recommendation or a requirement. Additionally, a categorisation of sports' heat stress risk is proposed. Among the 15 sports identified as high, very high or extreme risk, one did not have a heat policy, three did not specify any parameter measurement, one relied on water temperature, two on air temperature and relative humidity, seven on WBGT (six measured on-site and one estimated) and one on the Heat Stress Index. However, indices currently used in sports have been developed for soldiers or workers and may not adequately reflect the thermal strain endured by athletes. Notably, they do not account for the athletes' high metabolic heat production and their level of acclimation. It is, therefore, worthwhile listing the relevance of the thermal indices used by IFs to quantify the risk of heat stress, and in the near future, develop an index adapted to the specific needs of athletes.

WHAT IS ALREADY KNOWN?

⇒ Exertional heat illness (EHI) is a major concern due to climate change and the globalisation of sports. The most serious form of EHI, exertional heat stroke, is a life-threatening event.
⇒ To anticipate the risk of EHI and implement mitigation strategies, international federations employ thermal indices; quantitative indicators for assessing the environmental impact on individuals.

WHAT ARE THE NEW FINDINGS?

⇒ 15 sports were identified as high, very high or extreme risk of heat stress. Among them, 1 does not have a dedicated policy, 3 do not specify the measurement of parameters in their policies and 11 mention the use of thermal indices. However, current thermal indices inadequately reflect thermal strain endured by athletes.
⇒ It is essential to develop thermal indices reflective of the athletes' thermal strain. More recent indices with an integration of heat budget models could be of interest, but their reliability needs to be tested against the incidence of EHI.
⇒ To anticipate the danger of heat before an event, the following three steps are recommended:
Adequately monitor the prevalence of athletes with EHI during competitions.
If the sport is at risk of heat stroke, choose and validate a thermal index that objectively represents the thermal strain athletes endure in this sport.
Define mitigation strategies to reduce the risk of EHI.

INTRODUCTION

Environmental conditions such as high air temperature, high humidity, low air movement or high radiant heat can be strenuous for athletes.[1] This stress emerges from the reduced capacity of the organism to evacuate heat generated by metabolic production to the surrounding environment.[2 3] Heat can hinder performance from 3% to 20%[4] and be lethal as it is one of the two main causes of death in athletes[5] and kills more than any other natural causes.[6] Exertional heat illnesses (EHI) encompass a spectrum of conditions ranging from muscle cramps and heat exhaustion to life-threatening events referred to as exertional heat stroke (EHS).[7] EHS is a medical emergency diagnosed by a core temperature exceeding 40.5°C in conjunction with central nervous system dysfunctions (eg, confusion, ataxia, loss of balance, apathy and irritability).[8]

With the climate change and sport globalisation, the risks of EHI will continue to rise during the next decades for major sporting events.[1 9 10] At the Tokyo 2020 Olympics, 50 cases of EHI (14%) occurred at the marathon and race-walking competition venue, and in total 100/567 athletes (18%) and 125/541 non-athletes (23%) were treated at the clinics for heat-related illnesses.[11] During the 2019 World Athletics championship at Doha (Qatar), in hot and humid condition, 20 cases of exercise-associated collapse, 16 cases of exercise-associated muscle cramps and 18 cases of heat exhaustion were reported among marathon and race-walk athletes.[12]

In this context, one of the missions of International Federations (IFs) is to anticipate and mitigate the danger of heat in order to protect athletes' health during competitions.[1 13] To achieve this, IFs have developed specific heat policies to anticipate the risks of environmental conditions and suggested mitigation strategies to reduce the risks of EHI on the competition venues.[14] To objectively measure the risks of EHI, IFs employ quantitative indicators that aim to represent the impact of the thermal environment on the individuals, known as thermal indices.[3 15 16] Some environmental thermal indices rely on measuring solely one or more of the four primary environmental parameters (ie, air temperature, humidity, radiant heat and wind velocity) while others incorporate physiological parameters such as people's activity and the resulting metabolic heat production and clothing.[2 3]

The aim of this review was, therefore, to determine the methods used by IFs participating in the Paris 2024 Olympic Games to assess the risk of heat-related illnesses among athletes, to define the associated procedures and mitigation strategies and to provide future recommendations on evaluating the heat-related illness risk in sports.

METHODS

The Games of the XXXIII Olympiad (Paris 2024) included 45 sports as per International Olympic Committee classification.[17]

Categorisation of heat stress risk

To our knowledge, no categorisation of heat stress risk per sport for all summer Olympic sports was previously provided in the literature. Therefore, to discuss the necessity of IFs to have a heat policy, the authors of this review underwent a blinded categorisation of Paris 2024 sports' heat stress risk from 1 to 5: 1-low risk of heat stress, 2-moderate risk of heat stress, 3-high risk of heat stress, 4-very high risk of heat stress and 5-extreme risk of heat stress. The first author suggested a primary categorisation based on five factors: the venue, the duration, the intensity, the exercise type and the clothing. Then, all authors edited this categorisation individually based on their expertise in heat stress. The final categorisation was determined by averaging the notation of each author. This method was conducted for every event in each sport of the 2024 Paris Olympic Games programme (eg, 26 events in athletics). The sport's final categorisation was determined by the event within the sport that had the highest risk level. In this review, the policy of the sports having high, very high or extreme risk of heat stress was considered 'at risk' and was further discussed.

Policy collection and analysis

The policies implemented by the 32 IFs representing the 45 sports engaged in Paris 2024 Olympics were systematically screened for regulations related to the heat. The English documentation on the official website of the IFs was searched to find the books where environmental surveillance was mentioned. The search focused on materials available as of 18 January 2024. When more than one policy was cited, only the major one was reported. In each document, the relevant chapter was identified with a search of the following keywords: 'temperature', 'weather', 'heat', 'hot', 'environment' or 'venue'. If no results emerged, the entire policies were checked, and a search engine search was performed for unofficial documents. If still no conclusive results emerged, the IFs were considered to have no policy for environmental condition surveillance. Finally, the commitment of the policy was categorised as a requirement or a recommendation, based on the obligation (eg, 'must', 'requires', 'will') or not (eg, 'recommend', 'should', 'may') to apply it. Importantly, the IFs were directly contacted for clarification whenever needed in case of any doubt, uncertainty or missing information. The sources related to the heat policy of IFs can be accessed in online supplemental materials.

Thermal index

The thermal indices used by the IFs to assess environmental conditions were also searched. A thermal index was defined as a quantitative indicator that aims to represent the impact of the thermal environment on the individuals.[15] The type of policy was listed as relying on a 'single' parameter (eg, air temperature), 'multiple' parameters (eg, air temperature and air humidity) or a 'calculation' like the Wet Bulb Globe Temperature (WBGT) which is based on multiple parameters (dry bulb, wet bulb, globe temperatures). When no parameter was mentioned in the heat policy, the policy depended on the judgement of the board organising the competition. The parameter measurement was indicated as 'no or unspecified' (ie, without mentioning any quantitative measurement). Ultimately, the procedure related to the measurement of thermal indices and the mitigation strategies proposed by IFs governing outdoor sports were collected.

Equity, diversity and inclusion statement

The author team comprised seven men, including one junior researcher and six experienced investigators with diverse backgrounds as exercise physiologist, medical doctor and senior lecturer. While three different nationalities are represented within the research team, we acknowledge that all team members are of European nationality. Participant recruitment was not conducted for this research; hence, no specific statement is formulated in this regard.

CATEGORISATION OF HEAT STRESS RISK AND PARAMETER MEASUREMENT

30 sports (67%) were estimated at low or moderate risk of heat stress out of the 45 engaged in the Paris 2024 Olympics (table 1). Among the 21 sports at low risk, 19 sports are indoor and 2 are outdoor with low physical intensity (eg, archery). Thermal strain in indoor activities requires a different approach compared with outdoor activities. The impact of radiant heat is less important indoors as it should be close to none, but the cooling effect of the wind is lacking, possibly hindering heat evacuation.[2] When an air conditioning system is missing, temperature and humidity can rise throughout the day due to the human activity and the weather outside, contributing to strenuous situations for the athletes.[18 19] Therefore, current proposed classification of heat stress may differ for amateur events playing in lower quality infrastructures. Only one indoor sport, track cycling, was considered at moderate risk of heat stress as it includes prolonged events (eg, Madison) in traditionally heated velodromes. The eight other sports with moderate risk are outdoors, with either a combination of low intensity and long duration activity (eg, golf) or a short duration (eg, canoe slalom).

15 sports (33%) were estimated at risk of heat stress (ie, high, very high or extreme risk, table 1). Extreme risk of heat stress was highlighted for three sports due to their events combining high intensity and long duration: athletics, cycling road and triathlon. Additionally, six sports were categorised at very high risk: cycling mountain bike, hockey, marathon swimming, rugby sevens, sailing and tennis. Finally, six sports were classified as high risk: basketball 3×3, beach volleyball, cycling

Table 1 Policy employed by the International Federations (IFs) of the 45 sports engaged in Paris 2024 Olympic Games to protect athletes from heat stress in the competitive environment

Sport	International Federation	Venue	Heat stress risk	Heat policy	Parameter measurement	Thermal index	Commitment
Athletics	World Athletics	Outdoor	Extreme	Yes	Calculation	WBGT	Requirement
Cycling Road	International Cycling Union	Outdoor	Extreme	Yes	Calculation*	WBGT	Recommendation
Triathlon	World Triathlon	Outdoor	Extreme	Yes	Calculation	WBGT †	Requirement
Cycling Mountain Bike	International Cycling Union	Outdoor	Very high	Yes	No or unspecified	–	Recommendation
Hockey	International Hockey Federation	Outdoor	Very high	Yes	Multiple	Air T° and rh%	Requirement
Marathon Swimming	World Aquatics	Outdoor	Very high	Yes	Single	Water T°	Requirement
Rugby Sevens	World Rugby	Outdoor	Very high	Yes	Calculation	Heat Stress Index	Recommendation
Sailing	World Sailing	Outdoor	Very high	Yes	No or unspecified	–	Recommendation
Tennis	International Tennis Federation	Outdoor	Very high	Yes	Calculation	WBGT	Requirement
Basketball 3×3	International Basketball Federation	Outdoor	High	No	–	–	–
Beach Volleyball	International Volleyball Federation	Outdoor	High	Yes	Calculation	WBGT	Requirement
Cycling BMX Racing	International Cycling Union	Outdoor	High	Yes	No or unspecified	–	Recommendation
Football	International Federation of Football Association	Outdoor	High	Yes	Calculation	WBGT	Requirement
Modern Pentathlon	World Pentathlon	Outdoor	High	Yes	Multiple	Air T° and rh%	Recommendation
Rowing	World Rowing	Outdoor	High	Yes	Calculation	WBGT	Recommendation
Canoe Flatwater	International Canoe Federation	Outdoor	Moderate	Yes	No or unspecified	–	Requirement
Canoe Slalom	International Canoe Federation	Outdoor	Moderate	Yes	Multiple	Air T° and air movement	Requirement
Cycling BMX Freestyle	International Cycling Union	Outdoor	Moderate	Yes	No or unspecified	–	Recommendation
Cycling Track	International Cycling Union	Indoor	Moderate	No	–	–	–
Equestrian	Fédération Equestre Internationale	Outdoor	Moderate	Yes	Calculation	WBGT	Recommendation
Golf	International Golf Federation	Outdoor	Moderate	Yes	Calculation	WBGT	Recommendation
Skateboarding	World Skate	Outdoor	Moderate	Yes	No or unspecified	–	Recommendation
Sport Climbing	International Federation of Sport Climbing	Outdoor	Moderate	No	–	–	–
Surfing	International Surfing Association	Outdoor	Moderate	Yes	No or unspecified	–	Recommendation
Archery	World Archery Federation	Outdoor	Low	Yes	No or unspecified	–	Recommendation
Artistic Gymnastics	International Gymnastics Association	Indoor	Low	Yes	Calculation	Humidex	Recommendation
Artistic Swimming	World Aquatics	Indoor	Low	Yes	Single	Water T°	Recommendation
Badminton	Badminton World Federation	Indoor	Low	Yes	Multiple	Air T° and air movement	Requirement
Basketball	International Basketball Federation	Indoor	Low	Yes	Single	Air T°	Requirement
Boxing	Athlete 365 Boxing	Indoor	Low	Yes	No or unspecified	–	Requirement
Breaking	World DanceSport Federation	Outdoor	Low	Yes	No or unspecified	–	Recommendation
Diving	World Aquatics	Indoor	Low	Yes	Single	Water T°	Recommendation
Fencing	International Fencing Federation	Indoor	Low	Yes	Single	Air T°	Requirement
Handball	International Handball Federation	Indoor	Low	Yes	Single	Air T°	Requirement
Judo	International Judo Federation	Indoor	Low	Yes	Single	Air T°	Requirement
Rhythmic Gymnastics	International Gymnastics Association	Indoor	Low	Yes	Calculation	Humidex	Recommendation
Shooting	International Shooting Sport Federation	Indoor	Low	No	–	–	–
Swimming	World Aquatics	Indoor	Low	Yes	Single	Water T°	Recommendation
Table Tennis	International Table Tennis Federation	Indoor	Low	No	–	–	–
Taekwondo	World Taekwondo	Indoor	Low	No	–	–	–
Trampoline	International Gymnastics Association	Indoor	Low	Yes	Calculation	Humidex	Recommendation
Volleyball	International Volleyball Federation	Indoor	Low	Yes	Single	Air T°	Recommendation
Water Polo	World Aquatics	Indoor	Low	Yes	Single	Water T°	Recommendation
Weightlifting	International Weightlifting Federation	Indoor	Low	No	–	–	–
Wrestling	United World Wrestling	Indoor	Low	Yes	Single	Air T°	Requirement

The policies collected were indicated in the official documentation of the IFs. A level of heat stress risk was also determined for each sport: low, moderate, high, very high or extreme.
Sources of policy can be found in online supplemental materials.
*Estimated WBGT based on: air temperature, relative humidity, estimated radiant temperature, estimated wind speed based on the expected peloton speed.
†The WBGT is employed for the cycling and running parts of the triathlon while the water temperature is measured for the swimming part.
rh%, relative humidity; T°, temperature; WBGT, Wet Bulb Globe Temperature.

BMX racing, football, modern pentathlon and rowing. Among sports at risk, one did not have a heat policy (7%), three did not specify any parameter measurement (20%), one relied on a single parameter (7%), two on multiple parameters (13%) and eight on a calculation from multiple parameters (53%) (figure 1).

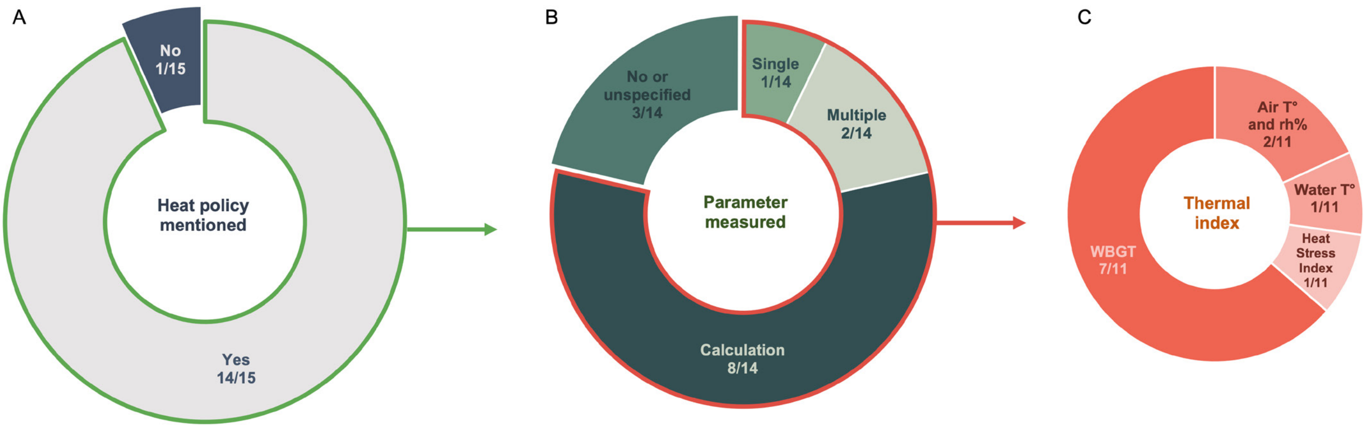

Figure 1 Heat policies for sports with high, very high and extreme risk of heat stress. The presence of a heat policy (A), the measured parameter(s) mentioned in the policy (B) and the thermal indices employed when there is a parameter measured (C). T°: temperature, rh%: relative humidity.

HEAT POLICY BASED ON SINGLE OR MULTIPLE PARAMETERS

Water temperature

A single parameter is employed in marathon swimming and for the swimming part of the triathlon (both in open water): the water temperature (table 1). Despite the conductive and convective cooling effects of water being approximately 2–5 times more effective than air at the same temperature, heat-related illnesses remain a significant risk for swimmers.[20] This is particularly crucial, as any loss of consciousness can lead to drowning. A complete review on heat injury in open-water swimming can be found elsewhere.[21]

Air temperature and relative humidity

The IFs of hockey and modern pentathlon are using multiple parameters, the air temperature and the relative humidity, to assess the risk of EHI (table 1). In hockey, the policy applies when the team bench area reaches 35°C, either 10 min before the match or during the third period (table 2). In areas with humidity over 65%, this threshold may be lowered on review. Longer breaks are introduced during the game under these conditions. In modern pentathlon, if the temperature exceeds 21°C and humidity surpasses 50%, a risk assessment matrix is used (table 2). While these are important initial steps, the limitation of this approach is the lack of consideration of other important factors such as wind velocity, radiant heat (eg, cloud covering, shaded area), metabolic heat production and clothing parameters.[22 23] These parameters are paramount in the heat generation and dissipation mechanisms and influence the occurrence of EHI.[2 24 25] Whenever feasible, it is also crucial to directly measure environmental parameters at the competition site.[26] Indeed, meteorological factors such as wind speed and radiant heat, vary significantly depending on surface type (eg, asphalt, grass) and environmental shading (eg, buildings, trees).[26 27]

Developing policies to prevent EHI requires collecting various data in a standardised manner, including environmental condition details but also practice session information (eg, duration, intensity, type).[24–26] Sports injury epidemiologists and clinicians should then analyse the associations between these variables and heat-related injury rates, enabling the establishment of more refined, evidence-driven policies.

HEAT POLICY BASED ON CALCULATION FROM MULTIPLE PARAMETERS

Wet Bulb Globe Temperature

The WBGT is employed in 7/15 (47%) sports at risk (table 1). Six sports directly measure the WBGT on the field of play (ie, athletics, triathlon, tennis, beach volleyball, football, rowing) while it is estimated from meteorological station data in road cycling(table 2). The WBGT[28] is a measure of the heat stress in direct sunlight, calculated by merging the wet bulb (T_{wb}), the black globe (T_{bg}) and the dry bulb (T_{db}) temperatures in outdoors as follow: $WBGT\ (^{\circ}C) = 0.7 * T_{wb} + 0.2 * T_{bg} + 0.1 * T_{db}$. It was developed in the 1950s by the US Army and Marine Corps after several heat-related casualties in training camps.[29] Over the years, it has been used in multiple fields going from military, industrial, biometeorology to sports.[3 30]

The American College of Sport Medicine (ACSM) recommended the use of the WBGT in its special communications of training and competing under the heat in 2007[31] and has recently renewed this advice in the 2023 edition.[32] In this updated consensus, the ACSM aims to account for the individual differences by publishing WBGT guidelines for different locations (ie, northern, middle and southern regions of USA) and different public (ie, acclimatised, fit, low-risk individuals or non-acclimatised, unfit, high-risk individuals). However, despite these individualisations recently proposed, the WBGT remains an environmental index with its limitations.[29] Indeed, the WBGT accuracy is impaired in high humidity and/or low air movement,[33] and it does not account for metabolic heat production and clothing, both being different within sports and different between athletes and soldiers.[29] Because the athletes' thermal strain relies heavily on the intensity of the activity realised and the evaporation capacity of sweating (ie, clothing, air humidity, air movement), WBGT inadequately reflects the thermal strain endured by athletes.[2 29 34–36]

Acknowledging those limitations, a strength of the WBGT is that the ACSM recommends thresholds for its implementation in sports, including increasing rest/work ratio, monitoring of fluid intake, decreasing the length of the activity or cancel the exercise.[32] To further facilitate WBGT interpretation, the ACSM, World Athletics, World Triathlon and the International Cycling Union are using a coloured flag system (figure 2). For example, the ACSM recommends cancelling any exercise when the WBGT is above 32.3°C, corresponding to a black flag while World Athletics black flag is set at 30.0°C and World Triathlon

Table 2 Procedures and mitigation strategies for outdoor sports using thermal indices

Sport	Heat stress risk	Thermal index	Procedures	Mitigation strategies
Athletics	Extreme	WBGT	For the period of the competition, and on race days, the local organising committee shall arrange to take frequent readings of temperature, humidity, Wet Bulb Globe Temperature (WBGT) and Physiological Equivalent Temperature (PET) at different competition sites. Readings will be performed at various times and the measurements displayed in banners of sufficient size to facilitate information available to athletes, officials and health staff. Warm-up area—one banner indicating the healthcare staff measured every 60 min on-site; road races—one banner at the start line, one at the finish line and another one showing the WBGT/PET measured every 20 min on-site; Race walking—one banner in front of the Team-Refreshments Station showing the WBGT/PET assessed every 20 min on-site. Other thermal stress indices can be used to provide more information as the modified PET (mPET) and Universal Thermal Climate Index (UTCI).	Timetable adjustment, continuous availability of ice supply and sealed cold-drinks, fans, ice packs. Shading areas and air-conditioned team tent. Cold-water immersion treatment available throughout the course and at the finish line. Additional hydration stations can be provided during the race.
Cycling Road	Extreme	WBGT	WBGT values are estimated with the model published by Liljegren *et al*.[40] Temperature and humidity are taken from nearest weather stations observation accessible through reference websites. Three standard values of wind speed are suggested based on the expected peloton velocity. Then, a UCI file is provided to calculate the WBGT based on temperature, humidity and wind value. The radiant temperature is calculated directly in the model.	WBGT <15°C, white zone: no specific countermeasures. WBGT 15°C–17.9°C, green zone: warm-up in the shade with fans, skin protection with non-greasy sun creams, choice of light-coloured clothing, normal hydration plan. WBGT 18°C–22.9°C, yellow zone: warm-up with ice vests, use of fresh towels, application of strict, individualised hydration plans, distribution of 'ice-socks', supply of ice to the teams during the race. WBGT 23°C–27.9°C, orange zone: adaptation of the start area to keep riders in the shade before the start, protect officials, organising staff and volunteers from the sun, increase the number of neutral motorbikes providing riders with drinks and ice packs, adapt the rules limiting hydration and cooling in competition. WBGT >28°C, red zone: modification of start and finish times, possible neutralisation of a section of the race or stage, cancellation of the stage/race.
Triathlon	Extreme	WBGT	The measurement tool should be taken at the finish area every 30 min starting 3 hours before the start of the competition. The device must be placed in direct sunlight 1.5 m above the ground. Provide announcements of its readings at the Sport Information Centre and the Athlete Lounge.	Timetable adjustment, tent with fans and air conditioned, water, sports drink cooled, towels immersed in ice water, ice, inflatable bath with water and ice, Improve the aid/drink stations numbers during the run course. WBGT 30.1–32.2, red flag: if the medical assistance follows all the rules of World Triathlon Event Organiser Manual Medical Services and Exertional Heat Illness Prevention document, standard distance events—change to sprint distance; sprint distance events and below—stay as originally planned. If the medical assistance does not follow all the rules, the competition must be rescheduled for sprint and standard distance events. Meeting conducted between delegates, director and doctor for agreeing the heat countermeasures to be implemented for middle-distance and long-distance events. WBGT >32.2°C, black flag: the competition must be rescheduled or cancelled for sprint and standard distance events. Meeting conducted between delegates, director and doctor for agreeing the heat countermeasures to be implemented for middle-distance and long-distance events.
Hockey	Very high	Air T° and rh%	A measurement device should be stationed at the technical table as this has same conditions with team benches and does not interfere with the teams. The FIH Sport Operations Managers and if available, the FIH Medical Officer will evaluate the measurements at half time/ between quarters.	Rehydration in team changing room or shading area, two fans for each team bench and one for the Technical Table. Temperature in the team bench area ≥35°C, ten minutes before the start of a match or the third period of a match (threshold figure may be reviewed and lowered in locations were relative humidity >65%): breaks at the end of the first and third period will be extended to 4 min. Humidity ≥75% and/or temperatures >42°C as measured on the field of play: break of 1 min to be provided at an appropriate break in play around 7 min and 30 s of the 1st and 2nd quarters. Any decision to apply these break times for 3rd and 4th quarters will be decided based on the weather condition assessed by the FIH Medical Officer, breaks at the end of the first and third period will be extended to 4 min.
Marathon Swimming	Very high	Water T°	Measurement should be checked the day of the race 2 hours before the start and at 1 hour intervals during the race at three points around the course at a depth of 40 cm. The agreed temperature will be the average of the three taken. This control should be done in the presence of a Commission made up of the following persons present: a Referee, a member of the organising committee and one coach from the teams present designated during the Technical Meeting.	Water temperature <16°C or >31°C: the water temperature shall be measured again in 30 min and if that measurement is also <16°C or >31°C, the race must be stopped until such time as the water temperature complies with this rule. Water temperature ≥18°C: swimsuits (men and women) shall not cover the neck, nor extend past the shoulder, nor extend below the ankle.
Rugby Sevens	Very high	Heat Stress Index	Measurement by a Whirling Hygrometer at the site of the game. The hygrometer needs to be whirled for 20 s to obtain readings. Three measurements should be undertaken and averaged. A chart provided by World Rugby allow to convert the measurement in a Heat Stress Index value.[64]	Heat Stress Index >150: timetable adjustment, provision of dressing room fans if air conditioning not available, provision of sideline shade if game played during the day when radiant heat (direct sunlight) is a contributing factor, strategic positioning of towels immersed in ice water around the ground—behind goal posts and at junction of each quarter line and sideline. 2 min break at the 20 min mark of each half: the focus of this break should be threefold, a medical assessment of each athlete for signs of heat stress, cooling of athletes and rehydration. It is suggested that cooling would be best achieved by immediately removing jersey and shoulder pads, application of ice water to head±body. Using sideline fans and shade (if game during day) would also be ideal. It should be noted that a 2 min break has been recommended (as opposed to a 1 min break) because the focus during this break is primarily medical assessment and cooling.

Continued

Table 2 Continued

Sport	Heat stress risk	Thermal index	Procedures	Mitigation strategies
Tennis	Very high	WBGT	The WBGT recording device should be in direct sunlight, mounted approximately 1 m above the ground and allowed to acclimatise for 2–3 min. Alternatively, Heat Index can be determined from temperature and humidity measured by nearest meteorological station with a chart provided by ITF.[65] The WBGT or Heat Index should be measured at least 3 times daily by the ITF Supervisor or his/her designee. Ideally, measurements should be taken every 2 hours, but a minimum 3 readings should be taken at the following times: 30 min before match play begins; middle of the scheduled day's play and just prior to beginning the last match of the day, or just prior to the start of the first evening session match. The WBGT or Heat Index should also be measured following any suspension of play and at the discretion of the ITF Supervisor, in consultation with the tournament doctor and/or sports physiotherapist.	Timetable adjustment, ice supply, cold-wet-towel, ice packs, shaded areas, safe drinking water. WBGT value ≥30.1°C or Heat Index ≥34°C: Modification of Play criterion—10 min break is allowed between the second and third sets (in a best of 3 tie-break sets match only), only if one or more of the players requests such a break. However, if a match has already resumed following the suspension of play and one set was completed before the suspension of play (in a best of 3 sets match), the 10 min break will no longer be available, unless otherwise decided by the ITF Supervisor. Possible to delay the starting time for matches until such a time as the Modification of Play criterion is no longer met. WBGT value ≥32.2°C or Heat Index ≥40.1°C: Suspension of Play criterion—the match cannot start or restart. If a game is in progress when the Suspension of Play criterion is met, play should be suspended at the end of that game.
Beach Volleyball	High	WBGT	Measurements are taken on centre court 5 min before the start of each game in front of the scorer's table, approximately 1.5 m above the sand level. If the scorer's table is shaded, the measurement must be made closer to the court or even on court in the sunny area. No measurements are necessary from the outside courts. The measurements are to be taken by a reserve referee (or the referee of the match before). The measurement is conducted using a Heat Stress WBGT Meter (Model HT30, Extech Technology) set for outside mode (OUT) with the protective sliding cover open.	–
Football	High	WBGT	In any location or environmental condition known to be hot and/or humid, a measurement is conducted 90 min before the start of the match and repeated 60 min before the start of the match.	WBGT value ≥32°C: mandatory cooling breaks of 2 min at 30 min and 75 min of play. The match may be either postponed or cancelled, depending on the level of the WBGT and the decision of the match management team. Additional ice supply, cooler boxes on wheels (x2), ice-water-soaked towels and cold bottled water (2 sets of 26 for the 2 cooling breaks, for each player and referees), other individual cooling item allowed, human resources to distribute the ice and the water (3 persons).
Modern Pentathlon	High	Air T° and rh%	–	Timetable adjustment, sport medical risk assessment carried out.
Rowing	High	WBGT	Measurement 1 m above water level from a pontoon.	Timetable adjustment, shaded rest area, crushed ice, extra-water, fans, possible cancellation of the event. Adaptation of the clothing or umpires, officials and volunteers. Temperatures >32°C or WBGT>28°C: teams advised to train in the morning and evening hours, cool and/or air-conditioned rooms, free-water should be at least 3 L/day, regular official and umpire rotation. Temperatures >38°C or WBGT>32°C: racing course should be closed for training
Canoe Slalom	Moderate	Air T° and air movement	The chief official must use available technology (weather reports, wind metres, etc) to be aware of changes to the competition conditions (eg, weather—wind, lightening, water level) and respond accordingly.	–
Equestrian	Moderate	WBGT	Measurement on course in direct sunlight.	Timetable adjustment, lighter clothing permitted, reduction of the cross-country distance, shaded or air-conditioned area, water/ice supply, fans, misting.
Golf	Moderate	WBGT	Daily measurement on the course and main spectators stands or assembly areas. It is important to coordinate the WBGT measurement with the watering of the pitch by the ground staff as this may artificially decrease the measured WBGT, with possible adverse effects. All WBGT measurements should be recorded on paper and, if possible, photographically.	Timetable and location adjustment, regular breaks, shade and cooling stations around the course, fans/mist and ice slushie drinks. Water, beverages and other fluids, preferably cooled to drink available for players, caddies, staff, media, and spectators. Clothing adaptations and permission of a mid-round change of clothes. Video surveillance to survey the courses and identify athletes in difficulty.

rh%, relative humidity; T°, temperature; WBGT, Wet Bulb Globe Temperature.

32.2°C. The International Tennis Federation, the International Federation of Football Association and World Rowing are also using thresholds to clarify the interpretation of the WBGT, without coloured flag (figure 2). The International Volleyball Federation uses the WBGT without specific thresholds and mitigation strategies (table 2). This decision is informed by the observation that, despite high WBGT levels recorded in Beach Volleyball, the incidence of EHI remains low over 11 years of heat stress monitoring.[37 38]

In addition to its simplified interpretation, the WBGT is easily measurable in the field using appropriate tools.[3 29] In cases where on-site measurement is impractical, WBGT can be estimated using meteorological station data as in road cycling event.[39–41] WBGT can also be computed on dedicated digital platform such as *Climate Chip*[42], *Fame Lab*[43] or *Zunis Foundation*.[44] The recommendations of the ACSM to use the WBGT, along with the time span of this index and its simplified measurement and interpretation, have likely influenced 7/11 (64%) of the IFs that employ a thermal index in their heat policies to rely on it (figure 1).

Heat Stress Index

World Rugby has chosen the Heat Stress Index (HSI) to estimate the risks of EHI in rugby sevens (ie, 1/11 sports using thermal indices, figure 1). They studied the risks of EHI associated with the practice of the activity and found that the WBGT would not represent the risks of thermal strain in rugby players, based on its intermittent nature, the length of the halves (40 min), and the facilitated access to water (World Rugby document in online supplemental materials). They observed that the HSI would better represent the thermal strain and recommend measuring it at the site of the game with a whirling hygrometer.[45] The HSI is a ratio between the evaporative requirement of the player and the maximum evaporative capacity of the environment. The higher the ratio, the more strenuous the conditions because the evaporative capacity of the sweat is reduced.[3] Therefore, HSI is

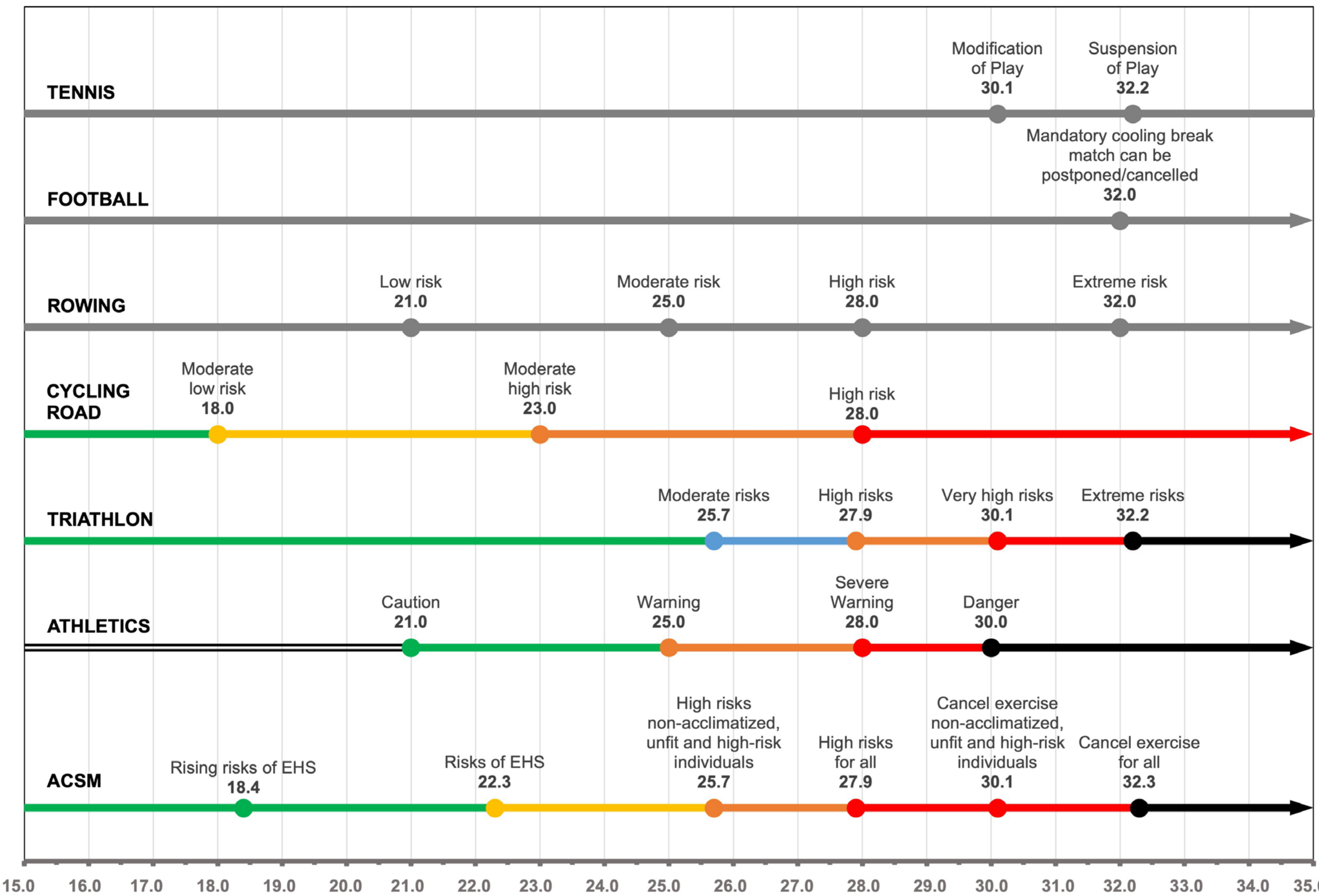

Figure 2 Wet Bulb Globe Temperature (WBGT) thresholds suggested by International Federations and the American College of Sports Medicine (ACSM). World Athletics, World Triathlon, the International Cycling Union and the ACSM are converting the WBGT in a coloured flag system to facilitate the interpretation of the index.

estimating the thermoregulatory response of the human body while the WBGT is characterising the environmental conditions,[46] probably leading to a better estimation of heat stress for rugby players. However, the limits of this index developed in 1956 have also been demonstrated, as the utilisation of a fixed skin temperature, the simplified heat balance calculation and the lack of consideration of evaporative efficiency of sweat.[3] Of note, temperature and humidity can also be used to calculate other thermal indices as the Humidex (table 1). However, this index is only used by the International Gymnastic Association governing sports with low risk of heat stress (ie, rhythmic gymnastics, artistic gymnastics and trampoline).

More than the half of sports at risk of heat stress (8/15 sports, 53%) are currently using thermal indices that are based on the calculation of multiple parameters to assess the environmental condition. In light of the rising concerns about these indices due to their lack of specificity to the world of sport, more recent indices including human thermoregulatory mechanisms and clothing should be tested and developed, to better represent the heat stress endured by athletes.

OTHER HEAT POLICY ASPECTS

No or unspecified parameter measurement

In documentation regarding cycling mountain bike, sailing (ie, both very high risk of heat stress) or cycling BMX racing (ie, high risk of heat stress), no measurements for evaluating the environmental conditions are cited. According to IFs policies, it is mentioned that in case of extreme weather (ie, freezing rain, snow, strong wind, extreme temperature, poor visibility and air pollution), the organising committee of the competition could meet and decide on modification or cancellation of the event. In this case, the risks' evaluation for EHI lacks quantitative and objective representation, presenting the potential for misinterpretation in strenuous situations.

Absence of heat policy

In basketball 3×3, despite a high level of heat stress (table 1), no official documentation on environmental conditions surveillance was found. It was, therefore, concluded that there is currently no heat policy for this sport (figure 1).

For sports at risk of heat stress, it is crucial to objectively assess environmental conditions to anticipate potentially fatal outcomes. This can be achieved through the use or the development of thermal indices that should be tailored to the world of sport.

HEAT POLICY PROCEDURES AND MITIGATION STRATEGIES

Among the 25 outdoor sports scheduled for Paris 2024, 14 (56%) incorporate the measurement of a thermal index into their heat policy. Table 2 summarises the measurement procedures and mitigation strategies adopted in these sports. For the majority of sports (n=11, 79%), on-site measurement of the thermal index is conducted as recommended to accurately describe the local thermal stress.[24–26] For cycling road, the WBGT is estimated using the Liljegren *et al* method[40] while limited information regarding procedures and mitigation strategies is available for modern pentathlon (high risk of heat stress) and canoe slalom (moderate risk). Mitigation strategies commonly include timetable adjustments to avoid the hottest part of the day and favour cooler morning or evening sessions (eg, athletics, triathlon and rowing). For intermittent activities, sports federations propose modifying work-rest ratios by adding or extending breaks (eg, hockey, football and tennis). In continuous activities, additional hydration stations (eg, athletics, triathlon and cycling road) or significant reduction of the course distance (eg, triathlon and equestrian) are implemented. On-site, the provision of cool areas is recommended by most sports, including air-conditioned rooms or tents for shade, along with the supply of ice, cold drinks, water-soaked towels and fans. In cases where environmental conditions pose critical danger, sports federations reserve the right to cancel competitions and reschedule them under safer conditions (eg, triathlon, marathon swimming and tennis).

PERSPECTIVES

The evolution of thermal indices

From solely meteorological data, thermal indices have integrated physiological parameters in the seventies, considering human thermoregulatory mechanisms and clothing.[47 48] These 'energy balance' called indices are numerical models able to estimate heat exchanges between the organism and the environment based on human tissue layers (eg, bones, muscles and skin).[3] More recently, these indices have become increasingly complex as the Universal Thermal Climate Index (UTCI)[49 50] or the modified Physiological Equivalent Temperature (mPET).[51 52]

UTCI has been developed by a working group of 45 scientists from 23 countries,[50] aiming to create a standard index able to represent the thermal strain of individuals in every region of the globe (computable on *Climate Chip*).[42]A clothing model is integrated to the index to adapt the seasonal habits of population depending on the climatic conditions.[53] However, this model has been developed for light activity (4 km/hour) and has been trained with general population data, therefore, extrapolation for athletes' heat strain warrant further investigations.[54]

To better evaluate existing indices, de Freitas and Grigorieva investigated the validity, usability, transparency, sophistication, completeness and scope of 165 indices.[15] With five points allocated to each category, the indices based on a single parameter or the ones relying only on environmental factors scored the lowest while energy balance thermal indices scored the highest. In details, air temperature scored 14/30, WBGT 20/30, HSI 26/30 and UTCI 27/30.

The mPET is the updated version of the PET suggested by Höppe.[55] The PET scored 26/30 on the de Freitas and Grigorieva classification.[15] The mPET was developed to estimate the thermal sensation of the population in every climate zone and incorporates a more precise division of the human tissue layers than the PET, along with a clothing model.[51 52] Like the other energy balance thermal indices, the mPET was designed for the general population and not for athletes, therefore, its reliability in estimating the thermal strain during competition is unknown.

The appearance in the last decades of sophisticated energy balance thermal indices is promising in the representation of athletes' thermal strain and risks of EHI. Studies conducted on the general population have observed a more precise estimation of energy balance than environmental thermal indices. Further investigations are now warranted to test the responses of these energy balance thermal indices in athletes.

Another challenge for IFs is to effectively communicate the heat stress levels to athletes and staff, once measured.[35] The IOC consensus statement by Racinais *et al* recommends using a five-level chart with corresponding colours to represent different levels of stress, along with mitigation strategies for each level.[1] For example, during the Australian Open Grand Slam Tennis tournament, heat stress levels are communicated to spectators and athletes via TV screens with clear and simple recommendations.[56] Similarly, World Athletics has developed an online platform that allows athletes, staff and visitors to remotely access on-site WBGT readings, displayed with a coloured flag system.[57]

Technological innovation for athletes' health

Recent technological advancements have enabled the live monitoring of physiological, biomechanical, bioenergetic and environmental data during competition.[58 59] These advancements offer the potential for comprehensive surveillance of athletes and could aid in the early recognition of EHS.[60 61] This technological advancement is associated with the emergence of new wearables, which must undergo validation to ensure the transmission of reliable data.[62] Moreover, the introduction of this technology brings ethical dilemmas related to the transmission of live data and the authority of the medical race director to withdraw an athlete from competition due to health considerations.[63]

CONCLUSION

Considering the life-threatening danger that EHS represents for athletes, the impact of heat on the athletes' performance, the human resources and financial burden associated with a modification of the competition, it is strongly recommended to implement an objective measurement (ie, a thermal index) of heat danger in sports at risk. This index should effectively represent the risk of EHI in the specific activity, be easy to use on the field during competition, and understandable by all (ie, athletes, coach, staff). Among the 15 sports in the Paris 2024 Olympics programme with high, very high or extreme risks of EHI, 14 have a heat policy. For three sports, there is no specification of the measurement of parameters in their heat policy, one is relying on a single parameter, two on multiple parameters and eight on the calculation of several parameters. To anticipate the danger of heat before an event, the three following steps are, therefore, recommended: (1) adequately monitor and diagnose the number of athletes suffering from EHI and/or EHS during competitions, (2) chose and validate thermal indices that objectively represent the thermal strain of athletes in the specific activity and (3) define mitigation strategies to reduce the risks of EHI.

Correction notice This article has been corrected since it published Online First. The ORCID has been added for author Antonio Tessitore.

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