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A modified Sports Medicine Australia extreme heat policy and web tool

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SUMMARY

The new extreme heat policy (EHP) issued by Sports Medicine Australia (SMA) in 2021 (SMA EHP v1 (2021)) was designed to protect healthy adults playing recreational sports from heat-related illness. Using a fundamental biophysical heat balance model to estimate heat stress risk, this extreme heat policy offered significant improvements on the policy previously used by SMA (2009). Yet, community feedback highlighted opportunities for further improvement. Specifically, heat stress risk was reportedly underestimated in very hot and dry extremes but overestimated in humid extremes. Due to SMA EHP v1 (2021) being a printed policy document, users were required to manually consult graphs for 40 sports – which were broadly classified into 5 separate groups – to determine the overall heat stress risk using temperature and humidity data extracted from local weather services – a process vulnerable to human error. Here, we propose a further updated SMA extreme heat policy (SMA EHP v2 (2024)). Adapting the validated International Standards Organisation Predicted Heat Strain model, updated heat stress risk curves were developed for the 40 most popular Australian sports with the aim of providing greater protection in very hot and dry extremes by accounting for high required sweat rates and additional cardiovascular strain. SMA EHP v2 (2024) reduces previously high rates of disruption to play in humid extremes by preferentially recommending active cooling and rest breaks. It also incorporates sport-specific metabolic rates, clothing and self-generated wind speeds to provide more precise estimations of heat stress risk. A freely accessible cross-platform web tool is described enabling convenient implementation with location specific, hour-by-hour risk classification, hierarchical recommendations of risk reduction strategies, and 7-day risk forecasting (https://sma-heat-policy.sydney.edu.au). Intended users are sporting administrators, coaches, and sport medical teams responsible for the safety and well-being of healthy adults engaging in recreational and community sports in hot weather, and people wishing to manage heat stress risk during planned training activities.

Practical implications

- We present a modified version of the Sports Medicine Australia Extreme Heat Policy, designed to protect community members engaging in recreational and community sports in hot weather across Australia.
- A free-to-use online web tool has been made publicly available to conveniently assess the heat-stress risk for more than 30 sports, based on environmental data automatically extracted from the nearest weather station.
- Users of the online web tool are provided with evidence-based heat stress risk reduction strategies tailored to the level of heat stress risk encountered.
- Intended users are sporting administrators, coaches, and sport medical teams responsible for the safety and well-being of healthy adults engaging in recreational and community sports and physical activity in hot weather.

1. Introduction

Sport and physical activity are cornerstones of the Australian way of life. In 2023, 78 % of all adults reported participating in some form of sport or physical activity, whilst 40 % reported participation every week.[1] The sporting preferences of the Australian public are diverse with running and cycling amongst the most popular sports for both males and females.[1] Sports such as cricket and tennis are traditionally

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played in summer, but other common recreational activities are enjoyed by Australians year-round.

Another defining feature of Australia is its climate. Summers are long and very hot, with ambient temperatures in the shade regularly exceeding 35 °C in all state capitals and surrounding areas.[2] Additionally, in many locations, temperatures above 30 °C are accompanied by high levels of relative humidity that further impede heat dissipation from the body by restricting sweat evaporation. As such, the risk of heat illness, which is characterised by nausea, dizziness, vomiting, and syncope – and can even result in death[3] – is progressively greater as the environment becomes hotter and more humid.[4,5] During exercise, the critical environmental limits at which heat illness can start to develop are lower compared to when people are at rest, as large quantities of metabolic heat generated by the active musculature must be dissipated to the environment to avoid the development of dangerous hyperthermia.[6]

Whilst fatal heat injury during sports is relatively rare, thousands of cases of heat-related illness (e.g., heat exhaustion) during sport competitions and training have been reported in recent decades in Australia.[7–9] Cases captured in these data are only those resulting in direct hospitalisation, and it is widely accepted that the incidence of heat-related illnesses in sports is vastly underreported.[10] Given this concern, Sports Medicine Australia (SMA) has historically provided a public extreme heat policy (EHP) as a protective measure. Twenty years ago, SMA published "Preventing Heat Illness in Sport" guidelines and in 2009 published the updated "Hot Weather Guidelines".[11] Whilst these guidelines were based on the best available scientific evidence at the time – and undoubtedly served to protect the public against the ill effects of exertional heat illness – there were several important limitations. A stepwise risk stratification used in the SMA policy (2009) left blind spots between risk categories. For example, very hot but relatively dry (air temperature > 38 °C and relative humidity (RH) < 30 %) conditions were left unclassified. These conditions, commonly observed across all the major cities in Australia, yield relatively low dew point temperatures yet induce high levels of sweating and physiological strain, particularly during exercise. Moreover, when the combined heat stress imposed by a given ambient temperature and humidity is simply expressed using a single value, e.g. a "heat index", under the 2009 SMA policy, nearly all conditions in the "high" zone and about one-third of those in the "moderate" zone exceeded the higher heat stress threshold for "extreme" (36 °C, 30 % RH).[12] To protect the health of Australians participating in summer sports, it was crucial that these policy gaps in the early SMA policy were bridged with evidenced-based knowledge and a physiological model that accounts for clothing, metabolic rate, and duration of the activity instead.

In 2021, we created an updated SMA Extreme Heat Policy SMA EHP v1 (2021).[13] It utilised a fundamental biophysical heat balance model[14] to determine the combination of dry-bulb air temperature (measured in the shade) and the corresponding relative humidity at which critical levels of heat stress risk to health are predicted to occur.[14,15] These models were adjusted to account for the effects of thermal radiation from the sun, clothing, and activity level. The SMA EHP v1 (2021) also adopted a continuous approach to defining heat stress risk, covering all possible ambient temperature and relative humidity combinations. Once a risk threshold is reached, a simple colour coding system indicates the optimal evidence-based cooling actions that should be taken to minimise heat stress risk. Since its launch, the SMA EHP v1 (2021) has been widely adopted by recreational athletes and community sporting organisations and codes across the country[16–18] and has been used to inform decision-making in recreational community sport settings.

However, despite the clear advantages of the updated SMA EHP v1 (2021), several opportunities for improvement were reported. Firstly, the policy, which is targeted foremost at recreational sportspeople, is too lenient in very hot but dry conditions, allowing activity to continue for too long. For example, it permits tennis and soccer activity when the ambient temperature is > 38 °C with a relative humidity of ~20 %. Yet, similar environmental conditions led to play suspension for highly conditioned and optimally heat-resilient professional athletes competing at the 2024 Australian Open tennis tournament, and A-League soccer fixtures in 2022. On the other hand, the SMA EHP v1 (2021) can be too conservative in warm but very humid conditions. This is particularly problematic for some regions of Australia where such conditions are regularly encountered (e.g., Darwin) and where if applied, would have resulted in at least 1 h of play suspension on at least 158 days (86 %) between October 1st and March 31st for soccer during a typical meteorological year. Overly conservative risk classification leads to excessive disruption to activities and increases the likelihood of non-compliance to policy recommendations.

Additionally, being a printed document, the SMA EHP v1 (2021) broadly differentiates between sport-specific activity levels and clothing/equipment requirements, dividing the 40 most popular sports into 5 heat risk categories. This approach limits the extent to which heat stress management guidance can be tailored to the specific demands of each sport. For example, wind velocity is assumed to be consistent – and minimal ($0.5\ m \cdot s^{-1}$) – for all sports. This assumption does not account for self-generated airflow due to the propulsion of the body through the air and the movement of limbs which modifies heat transfer between the human body and the environment through convective and evaporative pathways. In very hot conditions (e.g. > 35 °C), high airflow is particularly influential for sports like cycling, because of disproportionately large increases in dry heat gain from the environment relative to the minimal differences in evaporative cooling potential.[14] Similar environmental conditions (> 38 °C, ~10 % RH) led to a major disruption of the 2018 Tour Down Under cycling event contested by elite athletes, and will pose a greater safety risk to recreational athletes. Yet these conditions were not adequately captured by the SMA EHP v1. Finally, this policy has general accessibility and usability limitations. Users must consult a physical document to determine the heat stress risk for a given activity on any given day, using temperature and humidity data manually acquired from online weather services. This task is a labour-intensive and error-prone process that needs to be repeated on an hourly basis.

To overcome these limitations and to ensure the policy adequately manages heat stress risk across all included sports, we propose a modified policy (SMA EHP v2 (2024)), to calculate sport-specific heat-stress risk for recreational adults playing 33 separate sports. We also describe the development of a freely accessible cross-platform companion web tool that enables users to implement the policy at the sport-specific level conveniently and includes hour-by-hour risk classification and 7-day risk forecasting. Intended users are sporting administrators, coaches, and sport medical teams responsible for the safety and well-being of healthy adults playing recreational and community sports in hot weather, as well as people wishing to manage heat stress risk during planned training activities. The scientific underpinnings of SMA EHP v2 (2024) are also described.

2. Development of the modified extreme heat policy - SMA EHP v2 (2024)

2.1. Selection and characterisation of sports

We used data from the AusPlay[1] survey to identify the most popular sports in Australia. We excluded any sports in which participants are predominantly immersed in water (e.g., swimming) due to the profound impact that water has on human heat exchange with the environment. For each sport, we obtained data relating to clothing insulation, metabolic rate, and expected activity duration to provide inputs to the thermophysiological model used to calculate the heat stress risk.[19–21] When sport-specific data were not available in the extant scientific literature, estimates were made based on data available for a sport with the most similar profile (e.g., if data were not available for Rugby League, then Rugby Union data were used, etc.). The assumptions made for each sport are given in Table 1.

Table 1
Sport/activity and associated metabolic rate and clothing used to calculate the heat stress risk. It should be noted that the metabolic rate we used is 25 % lower than the value reported in the respective reference as detailed in the "Selection and characterisation of sports" section.

Sport	I_{cl} (clo)	Intensity (METs)	V ($m \cdot s^{-1}$)	Duration (min)
Abseiling	0.60	5.5	0.50	120
Archery	0.70	4.3	0.50	180
Australian football	0.47	7.5	0.75	45
Baseball	0.70	6.0	0.75	120
Basketball	0.37	7.5	0.75	45
Bowls	0.50	5.0	0.50	180
Canoeing	0.60	7.5	2.00	60
Cricket	0.70	6.0	0.75	120
Cycling	0.40	7.0	5.00	60
Equestrian	0.90	7.4	4.00	60
Field athletics	0.25	7.0	1.00	60
Field hockey	0.60	7.4	0.75	45
Fishing	0.90	4.0	0.50	180
Golf	0.50	5.0	0.50	180
Horseback riding	0.90	7.4	4.00	60
Kayaking	0.60	7.5	2.00	60
Long distance running	0.37	7.5	2.00	60
Mountain biking	0.55	7.5	5.00	60
Netball	0.37	7.5	0.75	45
Oztag	0.40	7.5	0.75	45
Pickleball	0.40	6.5	0.50	60
Rock climbing	0.60	7.5	1.00	45
Rowing	0.40	7.5	2.00	60
Rugby league	0.47	7.5	0.75	45
Rugby union	0.47	7.5	0.75	45
Sailing	1.00	6.5	3.00	180
Shooting	0.60	5.0	0.5	120
Soccer	0.47	7.5	1.00	45
Softball	0.90	6.1	1.00	120
Tennis	0.40	7.0	0.75	60
Touch football	0.40	7.5	0.75	45
Volleyball	0.37	6.8	0.75	60
Walking brisk	0.50	5.0	0.50	180

I_{cl} = estimated intrinsic clothing insulation, MET = estimated metabolic equivalent, V = estimated air velocity, Duration = estimated duration of activity. The wind speeds reported in this table are conservative estimates based on still conditions, accounting for the anticipated self-generated airflow associated with each sporting activity only. When forecasted wind speed exceeds the self-generated value, this forecasted value is used in the model instead.

The modified SMA EHP v2 (2024) is intended to protect generally fit and healthy adults (aged 18 to <60 y) free of chronic disease, participating in community and recreational sports from the development of heat-related illness, and not those engaging in elite-level competition. Consequently, the maximum average metabolic rate is limited to 7.5 MET. The rationale for this decision is that adults engaging in community, or recreational sports are typically able to down-regulate the intensity of self-paced physical activity to compensate for the higher levels of heat stress imposed by the environment[22] and, on average, can sustain lower metabolic rates compared to elite athletes.

2.2. Acquisition of environmental data

The forecasted environmental data (specific to a given postcode) that are used in the web tool are obtained by querying the weather Application Programming Interface (API) provided by Open-Meteo[23] and the Norwegian Meteorological Institute.[24] Two APIs are used to ensure that the web tool is usable even if one API loses functionality. The APIs are free to use and provide hourly concurrent dry-bulb and relative humidity data for a specific geographic location. Users can select any location in Australia. The latitude and longitude of the user is determined by using the postcode centroid. We used the GeoNames[25] database that includes postal codes for 83 countries, including Australia. This database enables us to easily add other countries in the future to allow international use of our web tool. The weather API also provides the forecasted wind speed, cloud cover, and direct solar radiation. Wind speed values provided by the API are representative of air-velocity at 10 m. We then adjust these values to represent ground-level wind speed in accordance with the AS 1170.2-1989 standard (Category 3). This adjusted wind speed value is then used in the model to broadly categorise wind speed as being either low (i.e., below self-generated air speed), moderate (1.5 $m \cdot s^{-1}$ to 3 $m \cdot s^{-1}$), or high (>3 $m \cdot s^{-1}$). It should be noted that wind speed will not be adjusted for sports which have a self-generated air speed higher than 3 $m \cdot s^{-1}$ as we cannot determine the relative air speed (between self-generated air movement and wind) experienced. Table 1 contains the assumed self-generated air speed for each sport.

Estimates of direct solar radiation provided by the API are used to estimate the solar gain to the human body using the Effective Radiant Field.[26,27] This approach allows us to estimate the mean radiant temperature and use it as an input to the thermo-physiological model.

2.3. Thermo-physiological model

Environmental (temperature, relative humidity, mean radiant temperature, and wind speed) and personal variables (clothing and metabolic rates) are used as inputs to the Predicted Heat Strain (PHS) model as defined by ISO 7933:2023.[28] The PHS model is a two-node model for the analytical evaluation and interpretation of the thermal stress experienced by an individual in a hot environment. It can be used for predicting the sweat rate and the core body temperature that a “typical” human body will likely experience in response to environmental stressors, accounting for personal factors. We used the PHS model as it is a well-established internationally used model that allows the estimation of physiological variables as a function of environmental and personal factors and has been similarly used previously to quantify occupational heat stress during moderate to high physical activity.[29] We used the open-source pythermalcomfort v2.10.0 Python library to calculate the results of the PHS model.[30] The code used to develop the web tool has been made publicly available and can be accessed via: https://github.com/FedericoTartarini/tool-sma-extreme-heat-policy (please cite the current paper if this code is used in or adapted for future work).

2.4. Heat stress risk calculation

We used the output of the PHS model to determine the heat stress risk associated with each combination of input conditions. The SMA EHP v2 (2024) uses the same 4 stratified heat stress risk categories as detailed in the SMA EHP v1 (2021), which are “Low”, “Moderate”, “High”, and “Extreme” risk (Table 2).

A sweat rate threshold of 850 mL/h was used to determine the boundary between “Low” and “Moderate” risk. Sweat rates below this threshold will restrict body mass losses to <2 % – above which thermoregulation is negatively affected[31] – in most individuals even with very limited fluid consumption.

We used a predicted core temperature of 39.5 °C to indicate the threshold between “Moderate” and “High” risk as exercise can be broadly safely maintained below this threshold without the development of heat-related illness in a healthy fit person, and the downregulation of self-paced exercise intensity will provide further protection.[32]Additionally, the use of active cooling strategies is not accounted for in the PHS model underpinning the EHP. For individuals adhering to the policy recommendation of utilising active cooling when the heat-stress risk transitions from moderate to high, it can be assumed that core temperature will be ~0.5 °C lower[33,34] further reducing the heat stress risk.

For archery, bowls, fishing, golf, shooting, and walking, a lower predicted core temperature limit of 38.5 °C was used to indicate the transition from “Moderate” to “High” risk as the core temperature threshold for the development of heat-related illness is lower in more sedentary individuals who are more likely to participate in these activities. Therefore, a more conservative heat stress risk score was deemed appropriate.

Table 2
List of evidence-based heat stress mitigation strategies recommended for each heat-stress risk category.

Risk category	Evidence-based heat stress mitigation recommendations
Low	Recommendation: Increase hydration & modify clothing Detailed suggestions: Maintaining hydration through regular fluid consumption and modifying clothing are still simple, yet effective, ways of keeping cool and preserving health and performance during the summer months.[49–52] You should: • Ensure pre-exercise hydration by consuming 6 mL of water per kilogramme of body weight every 2 to 3 h before exercise. For a 70 kg individual, this equates to 420 mL of fluid every 2 to 3 h (a standard sport drink bottle contains 500 mL). • Drink regularly throughout exercise. You should aim to drink enough to offset sweat losses, but it is important to avoid over-drinking because this can also have negative health effects to familiarise yourself with how much you typically sweat and become accustomed to weighing yourself before and after practice or competition. • Where possible, select lightweight and breathable clothing with extra ventilation. Remove unnecessary clothing/equipment and/or excess clothing layers. Reduce the amount of skin that is covered by clothing – this will help increase your sweat evaporation, which will help you dissipate heat.
Moderate	Recommendation: Increase frequency and/duration of rest breaks Detailed suggestions: Increasing the frequency and/or duration of your rest breaks during exercise or sporting activities is an effective way of reducing your risk for heat illness even if minimal resources are available.[47,48] You should: • During training sessions, provide a minimum of 15 min of rest for every 45 min of practice. • Extend scheduled rest breaks that naturally occur during match-play of a particular sport (e.g. half-time) by ~10 min. This is effective for sports such as soccer/football and rugby and can be implemented across other sports such as field hockey. • Implement additional rest breaks that are not normally scheduled to occur. For example, 3 to 5-min "quarter-time" breaks can be introduced mid-way through each half of a football or rugby match, or an extended 10-min drink break can be introduced every hour of a cricket match or after the second set of a tennis match. • For sports with continuous play without any scheduled breaks, courses, or play duration can be shortened. • During all breaks in play or practice, everyone should seek shade – if natural shade is not available, portable sun shelters should be provided, and water freely available.
High	Recommendation: Apply active cooling strategies Detailed suggestions: Active cooling strategies should be applied during scheduled and additional rest breaks, or before and during activity if play is continuous. Below are strategies that have been shown to effectively reduce body temperature. The suitability and feasibility of each strategy will depend on the type of sport or exercise you are performing.[38,40,53–59] You should: • Drink cold fluids and/or ice slushies before exercise commences. Note that cold water and ice slushy ingestion during exercise is less effective for cooling. • Submerge your arms/feet in cold water. • Water dousing – wetting your skin with cool water using a sponge or a spray bottle helps increase evaporation, which is the most effective cooling mechanism in the heat. • Ice packs/towels – placing an ice pack or damp towel filled with crushed ice around your neck. • Electric (misting) fans – outdoor fans can help keep your body cool, especially when combined with a water misting system.
Extreme	Recommendation: Consider suspending play Detailed suggestions: The suspension of exercise/play should be considered. If play has commenced, then all activities should be stopped as soon as possible.[60] You should: • All players should seek shade or cool refuge in an air-conditioned space if available. • Active cooling strategies should be applied.

A predicted core temperature of 40 °C was used for the threshold between "High" and "Extreme" risk as it is well established that above this threshold, the risk of heat exhaustion and heat stroke is markedly elevated[35,36] so the suspension of activity should be recommended.

For each heat stress risk classification, evidence-based heat stress mitigation strategies are recommended. The SMA EHP v2 (2024) uses the same recommendations as the SMA EHP (2021)[13] since they are informed by peer-reviewed scientific evidence from both laboratory and field studies (Table 1). Recommendations are tailored to match the level of heat stress risk experienced. For instance, when the heat stress risk is "Low", simple and minimally disruptive strategies are suggested, such as increasing fluid intake and modifying clothing. As the heat stress risk progressively increases, more intensive cooling measures are recommended, including more frequent rest breaks and the use of active cooling strategies (e.g., ice towels and cold-water immersion), before suspension of play is finally advised. This approach serves to protect athletes from the adverse health effects of heat stress whilst minimising unnecessary disruptions to their activities.

2.5. Web application and data visualisation

The thermo-physiological model, environmental, and personal parameters are then processed by the Python backend of the SMA web application to calculate a personalised heat stress risk rating. The web application is built using Dash, a Python framework to build web analytic applications and data visualisation websites. We used Dash since it is an open-source library released under an MIT licence, and applications built with it can be rendered in any web browser. The SMA web application is, therefore, cross-platform and compatible with the most widely used web browsers. The SMA Extreme Health Policy web tool is free and open-source and can be accessed at: https://sma-heat-policy.sydney.edu.au. A screenshot of the application is presented in Fig. 1.

Fig. 2 provides examples of how the heat stress risk curves vary with air temperature and relative humidity during daytime hours for three example activities (brisk walking, cricket, and cycling). The outputs assume a constant black globe temperature 10 °C higher than the dry-bulb air temperature and a constant sport-specific wind speed (Table 1). The shape of the heat-stress risk curves varies for each of these activities due to differences in metabolic rate, clothing insulation and air velocity exposure. For example, compared with brisk walking (Fig. 2A), the heat stress risk curves for cricket (Fig. 2B) shift left with narrower bands for "low", "moderate" and "high" risk classifications, due to the heavy protective equipment typically worn (e.g. wicket keeper or batters) and the higher average metabolic rate (6.0 vs. 5.0 METs, Table 1). The heat stress risk curves differ more noticeably for cycling (Fig. 2C) due

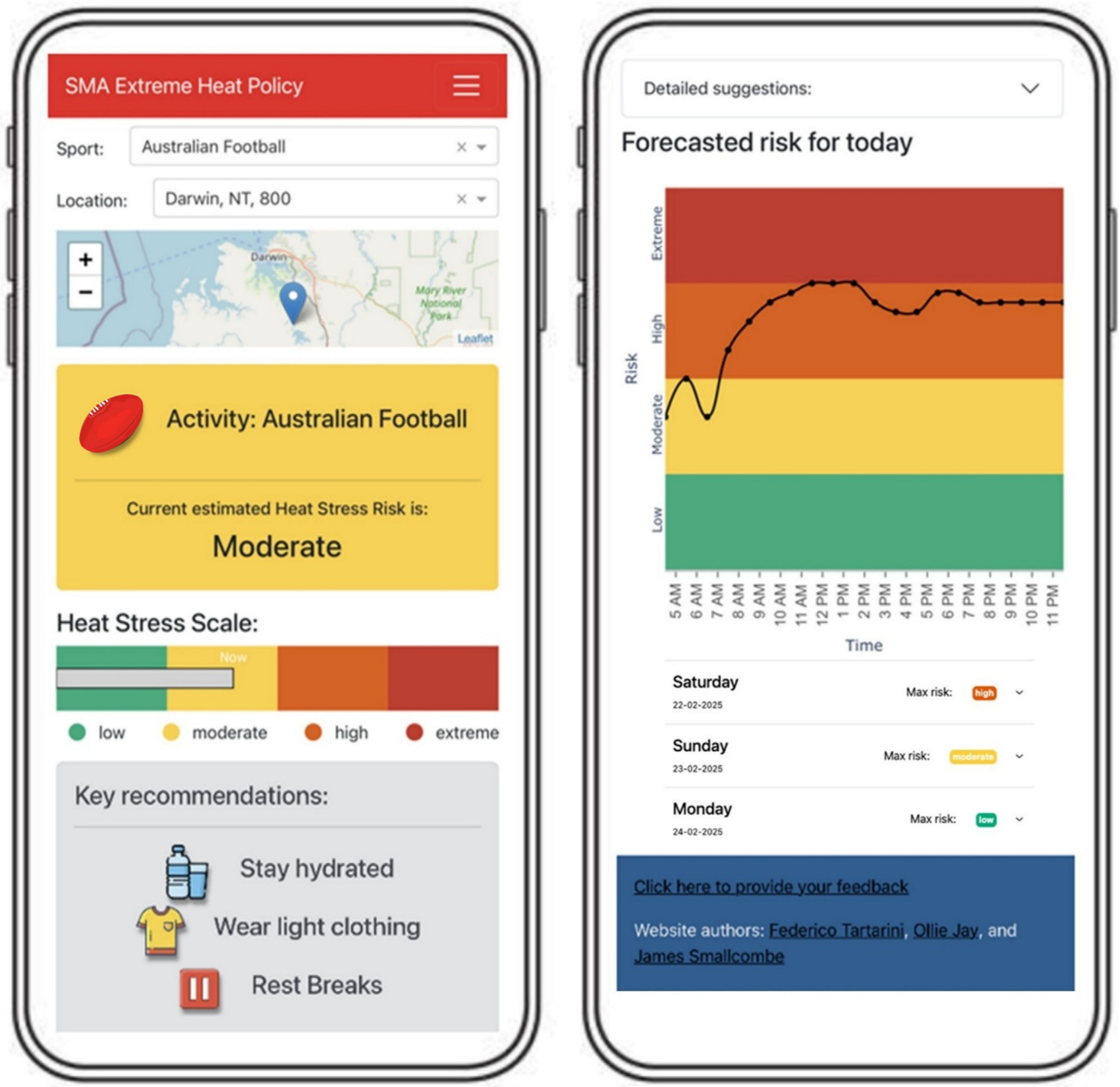


Fig. 1. Screenshot of the SMA web tool display with Australian Football in Darwin presented as an example.

to the influence of high self-generated wind speeds, causing the curves to become steeper. This results in reduced heat stress risk when the air temperature is lower than skin temperature (~35 °C) due to the additional convective heat loss conferred, but higher risk in very hot and dry environments in which convective heat gain is increased by the higher air flow without a corresponding increase in evaporation as the evaporative capacity of the environments already exceeds the physiological capacity to wet the skin.

2.6. Historical data analysis to evaluate the improvements made to the SMA EHP v2 (2024)

Utilising data for a typical meteorological year[37] for three example state capitals in Australia with differing climates (Darwin, Perth, Sydney), we quantified how the SMA policy (2009), SMA EHP v1 (2021), and SMA EHP v2 (2024) differ in the number of hours spent in each heat stress risk category for the example sports: tennis (Fig. 3); soccer (Fig. 4); brisk walking (Fig. 5A); and cycling (Fig. 5B). The major improvements provided by the proposed SMA EHP v2 (2024) are described below.

2.7. Underestimation of heat stress risk in very hot and dry environments

One key limitation of the SMA EHP v1 (2021) was that it underestimated the heat-stress risk in very hot and dry environments which are regularly encountered in places such as Perth and Sydney. Using tennis activity in Perth as an example (Fig. 3), based on a typical meteorological year the SMA EHP v1 (2021) recommends suspension of play for only 5 h annually, despite ambient temperature exceeding 38 °C on 7 days between the months of October and March. Furthermore, the SMA EHP v1 (2021) would not recommend suspending tennis when ambient temperatures reach as high as 40 °C and 43.5 °C at low

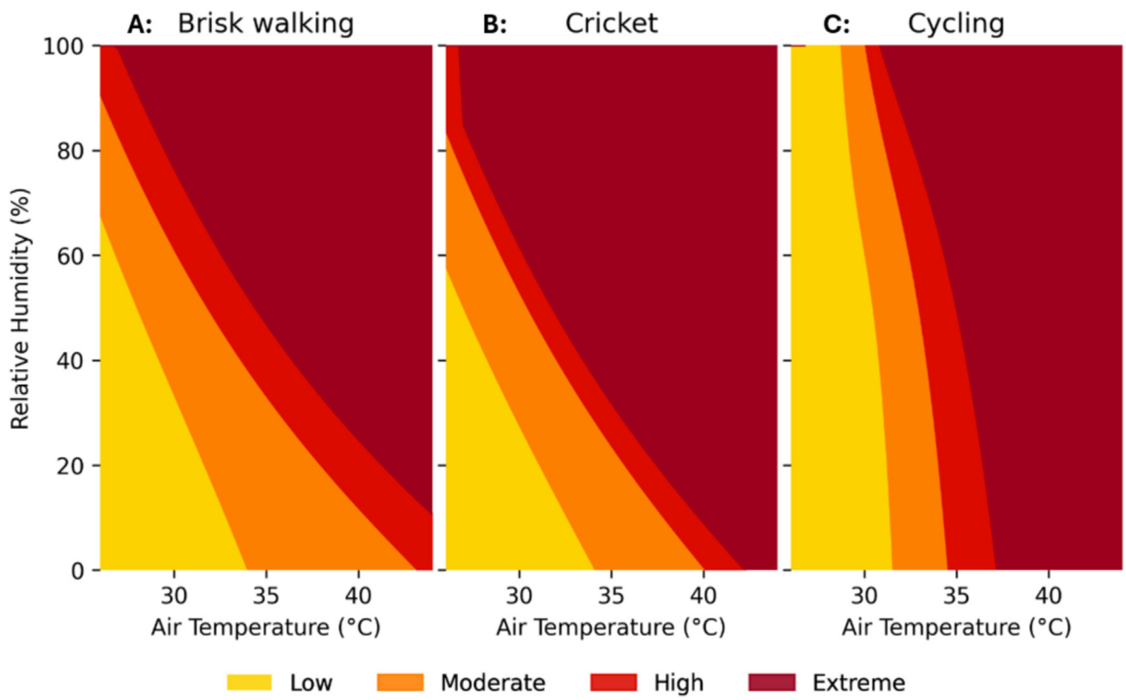
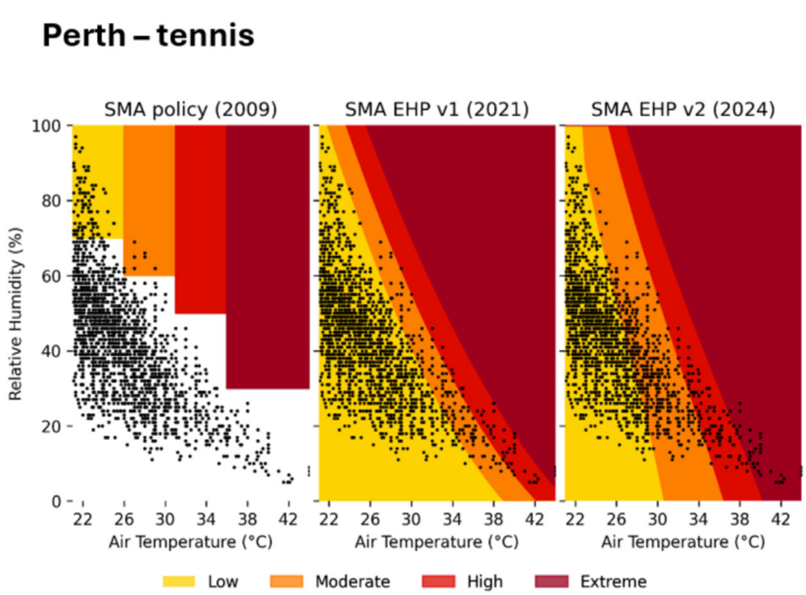


Fig. 2. Examples the risk thresholds for: A) brisk walking; B) cricket; C) cycling as a function of dry-bulb air temperature and relative humidity as visualised on the online web tool. The risk classifications have been generated assuming a globe temperature that is 10 °C higher than the air temperature and a constant wind speed specific to each activity. The wind speeds that were assumed were: 0.5 $m\cdot s^{-1}$ for walking; 0.75 $m\cdot s^{-1}$ for cricket and 5.0 $m\cdot s^{-1}$ for cycling.

humidities (<15 %). In such environmental conditions, people experience large amounts of dry heat gain from the environment which accelerates heat storage, and their capacity to adequately dissipate heat via sweat evaporation is limited by their physiological capacity to secrete sweat, elevating their risk of hyperthermia.[38] To overcome this limitation, the thermophysiological model used in the SMA EHP v1 (2021) was replaced by the PHS model which better accounts for high rates of convective heat gain, dehydration, and the additional cardiovascular strain experienced in very hot, dry environments, resulting in the heat stress risk curves shifting left, offering community users greater protection (Fig. 3). These changes result in the SMA EHP v2 (2024) recommending on average 37 h of tennis suspension annually across 12 days in Perth, with the amount of time spent in the "moderate" (563 h) and "high" (97 h) risk classifications also increasing substantially, providing much improved graded protection via extra rest breaks and the use of active cooling strategies. Notably, the SMA EHP v2 (2024) still represents a marked improvement on the original SMA policy (2009) which failed to recommend any suspensions of play and left 2229 h of hot weather completely unclassified based on the stepwise risk stratification.

2.8. Overestimation of heat-stress risk in warm and humid environments

A second issue with SMA EHP v1 (2021) was that it overestimated the heat stress risk in warm and humid (>50 %RH) environments such as those commonly experienced in tropical climates (e.g., Darwin

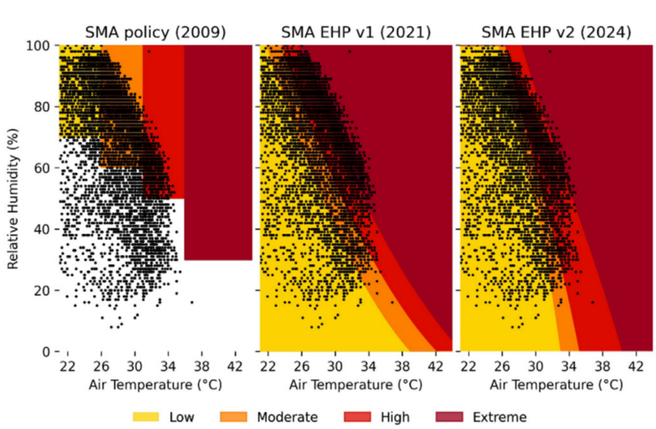


Annual hours spent in risk categories:

Risk	SMA 2009	SMA v1 2021	SMA v2 2024
Low	107	2147	1652
Moderate	13	153	563
High	0	44	97
Extreme	0	5	37
Unclassified	2229	0	0

Fig. 3. A comparison of the hours spent annually in each heat-stress risk classification for tennis in Perth based on the SMA policy (2009), SMA EHP v1 (2021), and SMA EHP v2 (2024).

Darwin – soccer

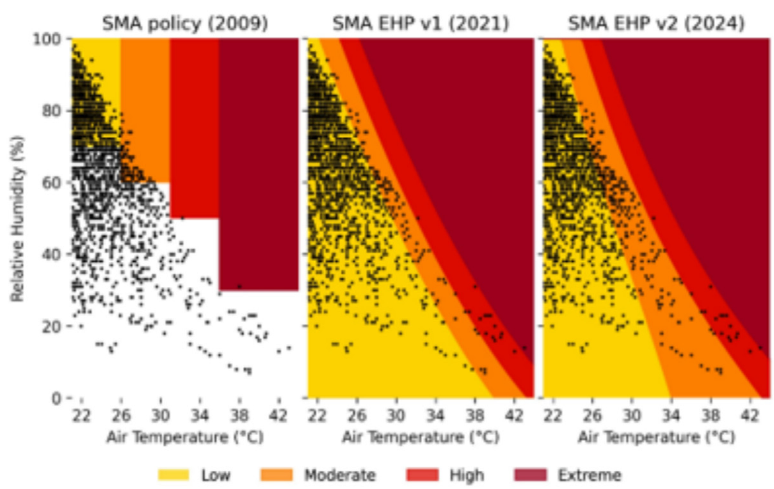


Annual hours spent in risk categories:

Risk	SMA 2009	SMA v1 2021	SMA v2 2024
Low	1692	1721	3956
Moderate	3485	1784	1345
High	1013	2900	2845
Extreme	0	1866	125
Unclassified	2081	0	0

Fig. 4. A comparison of the hours spent annually in each heat-stress risk classification for soccer in Darwin based on the SMA policy (2009), SMA EHP v1 (2021), and SMA EHP v2 (2024).

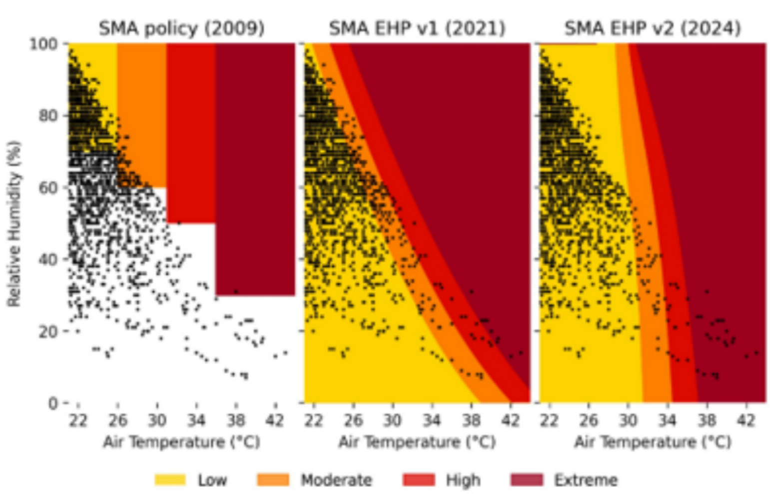
A Sydney – brisk walking



Annual hours spent in risk categories:

Risk	SMA 2009	SMA v1 2021	SMA v2 2024
Low	961	2125	1974
Moderate	125	92	242
High	1	14	16
Extreme	1	1	0
Unclassified	1144	0	0

B Sydney – cycling



Annual hours spent in risk categories:

Risk	SMA 2009	SMA v1 2021	SMA v2 2024
Low	961	1989	2162
Moderate	125	214	35
High	1	20	13
Extreme	1	9	22
Unclassified	1144	0	0

Fig. 5. A comparison of the hours spent annually in each heat-stress risk classification for A: brisk walking and B: cycling in Sydney based on the SMA policy (2009), SMA EHP v1 (2021), and SMA EHP v2 (2024).

and northern Queensland), resulting in regular suspension of play and excessive disruption to scheduled events. This was predominantly due to a low assumed air-velocity for all sports, which led to an underestimation of heat loss via sweat evaporation. Using soccer activity in Darwin during a typical meteorological year as an example (Fig. 4), the SMA EHP v1 (2021) recommends 1866 h of suspended play annually, despite hourly temperatures exceeding 33 °C only 3 % of the time. This translates to play being suspended for at least 1 h on 158 separate days per year, which poses significant scheduling challenges to the community, despite the environmental conditions being commonly encountered. In contrast, the proposed SMA EHP v2 (2024) advises the suspension of soccer events for a total of 125 h across 65 separate days and now preferentially recommends the use of additional rest breaks in conjunction with active cooling (2845 h) under such conditions to reduce the heat-stress risk whilst allowing play to continue safely. Once again, the SMA EHP v2 (2024) provides major improvement compared with the SMA policy (2009), which did not recommend suspending activity at all, with 2081 h of hot weather completely unclassified based on the original stepwise risk stratification.

2.9. Underestimation of heat-stress risk in hot and dry environments at high air velocities

Another limitation of the SMA EHP v1 (2021) is that air velocity is assumed to be constant – and minimal ($0.5\ m \cdot s^{-1}$) – for all sports which does not adequately account for self-generated airflow due to the propulsion of the body through the air and movement of limbs. The proposed SMA EHP v2 (2024) addresses this limitation by incorporating more accurate sport-specific self-generated wind speed estimates as an input to the underpinning thermophysiological model (Table 1). Consequently, for some sports in which the relative motion between the body and the air is limited (e.g., walking, Fig. 5A) the heat stress risk curves have not changed significantly between the SMA EHP v1 (2021) and the proposed SMA EHP v2 (2024) as the estimated self-generated air velocity remains modest (0.5 to $0.75\ m \cdot s^{-1}$). However, for other sports such as cycling (Fig. 5B), during which the self-generated air velocity is much higher, more marked shifts in the risk curves are observed between the two policies due to differences in convective and evaporative heat exchange estimates, with the risk curves becoming steeper. For cycling, this results in more time spent in the "extreme" risk category (SMA EHP v1 = 9 h vs. SMA EHP v2 = 22 h) primarily when it is very hot and dry, providing cyclists additional protection. In contrast, the revised risk curves lead to a reduction in hours spent at "high" and "moderate" risk in cooler but more humid environments due to the larger capacity for heat dissipation when the air velocity is high (Fig. 5B). The importance of providing greater protection in very hot and dry environments during high air velocity activity is evidenced by data that show elite cyclists often experience core temperatures > 40 °C at air temperatures of ~37 °C with low relative humidity of ~25 %.[39] Clearly, such conditions represent an unacceptable level of heat stress risk for community-based sport settings where individuals are far less likely to possess the physiological adaptations needed to tolerate such high core temperatures.

2.10. Forecasting heat-stress risk

Another advancement of the proposed SMA EHP v2 (2024) is the heat risk forecast function which allows users to estimate the likely level of heat stress risk up to seven days in advance, based on automatic extraction of the local weather forecast. Such heat-risk forecasting was difficult to perform using the SMA EHP v1 (2021) as manual input of weather data was required, limiting the ease with which detailed heat stress risk projections could be made. The new forecasting function is designed to further aid organisers in making informed, heat-smart decisions regarding event planning, ensuring physical activity can be avoided when the level of heat stress risk is likely to be highest (e.g., on the hottest days of the week or the peak hours of the day). Importantly, the proposed SMA EHP v2 (2024) - based on historical weather data – never mandates a complete day-long cancellation of sporting activities but instead encourages users to use the forecasting tool to temporarily suspend activities or reschedule them, if feasible, to cooler times of the day to effectively reduce the heat-related health risks.

2.11. Other advantages of SMA EHP v2 (2024)

A key advantage of both the SMA EHP v1 (2021) and the proposed v2 (2024) is the use of a thermophysiological model to inform the development of the heat stress risk curves. Unlike other commonly used heat indices (e.g. WBGT, Heat Index) which only incorporate environmental data, the thermophysiological model used in the SMA EHP also includes sport-specific estimates of metabolic rate and clothing evaporative resistance as inputs.[19–21] Both variables are important moderators of the overall level of heat stress experienced during physical activity due to their impact on internal heat production and heat dissipation to the environment. Additionally, whilst the WBGT has been the most commonly used heat stress index for evaluating heat stress risk in sporting settings to date,[40] its use may be open to misinterpretation as values reported in °C are often lower than the ambient temperature, which may be counterintuitive to users unfamiliar with the use of heat stress indices.[41] The SMA EHP v2 (2024) companion web tool overcomes this issue by automatically integrating the model outputs into a simple 4-point visual scale which is easy for our target audience to understand and use.

2.12. Limitations and future directions

Despite the significant improvements to the proposed SMA EHP v2 (2024), further opportunities for enhancement remain. First, the policy is limited to healthy adults and does not enable users to calculate the risk for older adults (over 60 years) or youth (under 18 years) or those with chronic disease. Separate extreme heat guidelines are not currently provided by SMA for these groups, largely due to the lack of empirical evidence with which such recommendations may be informed. It remains unclear if children are at elevated risk of heat injury during sport participation, however, we intend to update the SMA EHP to cater for youth sports once sufficient high-quality evidence emerges. The SMA heat policy has been designed to be updated and revised as new evidence emerges, ensuring it remains relevant and reliable for all Australians. Secondly, the PHS was developed for activities up to 4 to 5 METs. However, the PHS model is a heat balance model, and its principal equations should remain valid at higher metabolic rates and have been adapted previously to quantify heat stress for moderate- to high-intensity occupational activities.[29] Additionally, previous research has validated the thermoregulatory predictions attained using PHS for use with recreational athletes, concluding that is provided acceptably accurate indicators of physiological heat strain.[42] Furthermore, the PHS has also been validated in the development of other online web tools (e.g. ClimApp) which provide individualised estimates of heat stress and thermal strain.[43,44] However, we acknowledge that additional validation of the PHS model for use in community sport settings would help further optimise the heat-stress risk assessments provided by SMA EHP v2 (2024). The proposed SMA EHP v2 (2024) does not currently account for heat acclimatisation status, which is known to influence physiological strain and heat illness risk[45] – future iterations of the EHP will aim to incorporate estimates of individual levels of heat adaptation based recent weather history to further refine personalised heat stress risk recommendations. Finally, the assumptions made about the mean radiant temperature (estimated assuming a black globe temperature 10 °C higher than ambient temperature which is common on a clear, sunny day) introduces some potential error into the heat stress risk calculations, however errs on the side of caution.

3. Conclusion

The current paper describes a proposed modified version of the SMA Extreme Heat Policy – SMA EHP v2 (2024). This EHP builds upon the SMA EHP v1 (2021) providing important improvements to the underpinning thermophysiological model and the resulting heat stress risk reduction guidance. Notably, the underpinning thermophysiological model has been adjusted to prevent the underestimation of the heat stress risk in very hot and dry environments, whilst also avoiding overestimation of risk in warm and very humid environments. Additional modifications have been made to better account for the impact of self-generated wind speed on human heat exchange with the environment. The revised EHP is designed to protect healthy adults (aged 18 to <60 y) engaging in recreational and community sports from heat-related illness and injury. A free-to-use online web tool has been made publicly available to conveniently assess the heat health risk for more than 30 sports in any location across Australia and access evidence-based heat stress mitigation recommendations.

CRediT authorship contribution statement

The study was designed by OJ, JWS, and CB. The companion web tool presented in the manuscript was developed by FT with input from all other authors. The first draft of the manuscript was written by JWS, FT and OJ and was then edited by CB, TJC and GPL. All authors approved the final manuscript.

Confirmation of ethical compliance

No human participants were involved in this study and, therefore, institutional ethical approval from the human sub-committee was not required.

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Declaration of interest statement

The authors report that there are no competing interests to declare.

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The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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