Journal of Science and Medicine in Sport 27 (2024) 515–524

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Review

The impact of extreme heat on mass-gathering sporting events: Implications for Australia and other countries

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ARTICLE INFO

Article history:
Received 8 November 2023
Received in revised form 21 April 2024
Accepted 29 April 2024
Available online 15 May 2024

Keywords:
Sport
Heatwaves
Exercise
Climate change
Disaster

ABSTRACT

Objectives: As temperatures increase across the globe due to climate change, human exposure to extreme heat is a public health challenge. During sporting events, athletes, officials, spectators, and staff are at risk of heat stress and resulting illness. The objective of this review was to explore the impact of heat on the health outcomes of these groups and the wider health system and discuss implications for outdoor mass-gathering sporting events in Australia.
Design: A systematic review was undertaken to identify literature published from 2010 to 2023.
Methods: Seven databases were searched: Web of Science, SportDiscus, Scopus, Medline, CINAHL, Emcare, and PsychInfo, for relevant key search terms such as heatwave, heat stress, extreme heat, stadium, arena, sports facilit*, sport, athletic, and Olympic. An inductive thematic analysis was undertaken. Articles were quality checked using Joanna Briggs Institute critical appraisal tools and data were extracted, tabulated, and synthesized.
Results: Forty papers were included in the final analysis: 17 quantitative, and 23 descriptive and qualitative (including reviews). Health outcomes explored across the literature included exertional heat illness, exertional heat stroke, hyperthermia, and general heat related illness. Six recommendation themes emerged: planning, mitigation strategies, medical, policy, research, and education.
Conclusions: The impact of heat on health outcomes during sporting events is significant, and should be considered by individuals, coaches, officials, and organizers before, during, and after mass-gathering sporting events. These findings can inform evidence-based preparedness strategies to protect the health of those attending and competing in mass-gathering sporting events now and into the future.

Practical implications

- All sports and sporting events should have a heat policy that addresses players, spectators, and officials.
- For major sporting events, consultation with health services should be part of the planning process.
- With extreme heat events increasing across the globe, sporting bodies may need to alter scheduled events (time/location/breaktimes, etc.) to adequately address heat related challenges.

1. Introduction

The effects of climate change pose a significant threat to human health and well-being.[1,2] Extreme heat events have increased in frequency and magnitude across the globe due to climate change, with the past eight years established as the warmest years on record.[3] Rising temperatures and more frequent heatwaves have increased human morbidity and mortality across the world,[4] with a recent report by the International Panel on Climate Change projecting global temperatures to increase by 1.5 °C between 2030 and 2052.[5]

Prolonged exposure to heat causes significant stress on the human body, which may lead to heat exhaustion and/or the exacerbation of pre-existing health conditions.[2,6] This is particularly concerning for those who spend time outdoors, such as those who participate, spectate, officiate, and volunteer at outdoor sporting events. Increased exposure to extreme heat increases the risk of heat-related illness, which can range from minor symptoms such as cramps and fatigue to potentially fatal conditions such as heat stroke.[2,7] Heat-related illnesses are preventable with appropriate action plans.[8] Therefore, it is crucial to implement measures to mitigate the risks posed by extreme heat during sporting events to ensure the safety and well-being of those participating, officiating, working, and attending.

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https://doi.org/10.1016/j.jsams.2024.04.015
1440-2440/

Exercising in hot conditions increases body core temperature, and excessive humidity prevents the body's ability to regulate this heat load through sweating.[8,9] Athletes who are at greatest risk of heat-related illness include those who are not properly acclimatized to the environmental conditions, have pre-existing health conditions, play high intensity sport, and wear protective equipment that prevents evaporative heat loss.[9–11] During these extreme environmental conditions, officials, spectators, workers, and volunteers may also be in danger as they are required to stand or move in these hot conditions for extended periods of time. During outdoor sporting events, where shade, cooling and ventilation are limited, there is an increased risk of heat-related health events, especially for those unacclimatized to the climate in which an event is being held. Approaches to alleviate the impact of heat on health and performance are crucial to ensure that all who attend are unharmed during these popular sporting events.

The state of Queensland in Australia is set to host many major sporting events, including but not limited to the Lifesaving World Championships (2024), Rugby World Cup (2027 and 2029) and the 2032 Brisbane Olympics and Paralympics. These events will take place among other regularly scheduled international events including the Australian Open, IronMan™ Australia, and long distance runs such as the Gold Coast Marathon. These events will occur at times and/or locations where heat may impact upon the health of competitors, spectators, and support personnel and this must be considered when selecting, designing and developing venues, transport networks, and accommodation. Understanding how extreme heat has historically impacted upon human health and the health systems that manage it at mass-gathering sporting events may assist with planning and actioning strategies for future events, thus reducing impacts on people's health.

The overarching aim of this systematic review was to determine the impact of extreme heat on health outcomes for those who participate, officiate, spectate, volunteer, and work at mass-gathering sporting events. Specifically, this review aimed to: 1) describe the burden of heat on health during mass-gathering sporting events; 2) describe what current indicators are used for measuring the impact of heat on health systems during sporting events and activities; 3) consolidate recommendations for the preparation of sporting events and activities to manage extreme heat; and 4) discuss implications for mass-gathering sporting events in Australia.

2. Methods

A systematic review was conducted to examine literature from January 2010 to June 2023 and was prospectively registered with PROSPERO (#CRD42022360162). The year 2010 was deemed "the year of the heatwave", and to date is the earliest year still in the rankings for the top-ten hottest years on record.[12,13] This timeframe was selected to capture recent and relevant data in the wake of new trends in climate change and technological innovation.[14,15] The review was guided by the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA 2020).[16]

Articles were retrieved from seven databases: Medline (Ovid), Emcare (Ovid), PsychInfo, Web of Science, CINAHL, Scopus, and SportDiscus. Search terms were slightly modified to suit database functionality (see Supplementary file 1 for detailed searches), and key search terms included: heatwave, heat stress, extreme heat, stadium, arena, sports facilit*, sport, athletic, and Olympic.

Original research, policy documents, guidelines, consensus statements, editorials, and commentaries were considered. Articles were included if they explored relationships between, and challenges of, extreme heat on the health of athletes, officials, workers, volunteers and spectators attending large, mass-gathering sporting events.

Large, mass-gathering sporting events are not consistently defined in the literature, and often descriptions of the size of the event and quantification of spectator numbers are not presented. For the purposes of this review, an event was considered large and/or mass-gathering if the terms "mass-gathering", "large", "international", or "stadium" were used. As such assumptions and generalizations have been made in attempting to apply the parameters of inclusion. The size of the event, the standard/caliber of sport being performed (elite, international level) and spectator numbers are all interrelated, thus there is an assumption that events with elite and/or international athletes, in large venues are presumed to be mass-gathering events due to the draw of the sport, capacity for spectators and caliber of athletes.

Articles were excluded if they focused on performance physiology, heat physiology, micro-climates, military operations, non-organized sport, school sport, or community sport. Articles exploring junior sport were also excluded, as children and adolescents may exhibit different physiological responses to heat, have unique vulnerability factors, and necessitate specific health interventions.[17] Articles that did not contain extractable results or recommendations related to the review aims, were not published in English, and were published before 2010 were excluded, noting that data from prior years were included in the review if such studies were published from 2010 forward. Studies that reported on the results of less than five cases of heat illness or exhaustion were also excluded due to limited generalizability, risk of bias, and low statistical power.

Using the Covidence online software platform, articles were screened and selected according to the pre-defined inclusion and exclusion criteria. Dual title and abstract screening and full text screening were completed by a combination of three authors (HM, AP, JK) independently. Conflicts were solved by a third, independent author (RF).

Quality was assessed using the Joanna Briggs Institute (JBI) critical appraisal tools to determine the trustworthiness, relevance, and results of the included articles.[18] Quality assessment scores were converted into a percentage (Supplementary file 1).

Information from the selected articles was systematically extracted into a standardized form (Microsoft Excel) by a combination of four authors (HM, AP, JK, RF). Independent quality control checks of data extraction were completed by a second reviewer for 20 % of the selected articles. The variables extracted for quantitative studies included: country/region, study period, sport, participants (players, officials, spectators or other), study design, heat measure, outcome variable, and key findings. For descriptive and qualitative studies, the variables extracted were county/region, article type, sport, and key findings.

Recommendations were extracted from each article onto a separate sheet, which included presumed or indicated target group, sport, recommendation, level of evidence of the recommendation, and recommendation group and sub-group. Level of evidence was determined by the criteria from the Oxford Centre for Evidence-based Medicine, with a grading scheme of Grade A (high level of evidence) to Grade D (low level of evidence).[19] An inductive approach was taken to deduce the recommendation groups, where categories were formulated throughout the extraction and analytical process.[20]

As the study design for this paper was a systematic review, ethics approval was not required.

3. Results

The search included publications from January 2010 to June 2023 and yielded 1253 articles. Following the removal of duplicates there were 899 unique entries. A total of 40 articles were included in the final review following title and abstract and full text screening (Fig. 1). Of the included articles, 17 were quantitative including descriptive epidemiological studies (n = 8), retrospective cohort studies (n = 5), prospective cohort studies (n = 3), and a cross sectional study (n = 1; Table 1). There were 23 descriptive and qualitative articles identified that included reviews (n = 11), consensus articles (n = 4), position statements (n = 2), commentaries (n = 2), a mixed methods article (n = 1), a policy brief (n = 1), a concept paper (n = 1) and a letter to the editor (n = 1; Table 2).

The overall quality of the included papers was high according to the results of the JBI assessment with an average score of 92.5 %

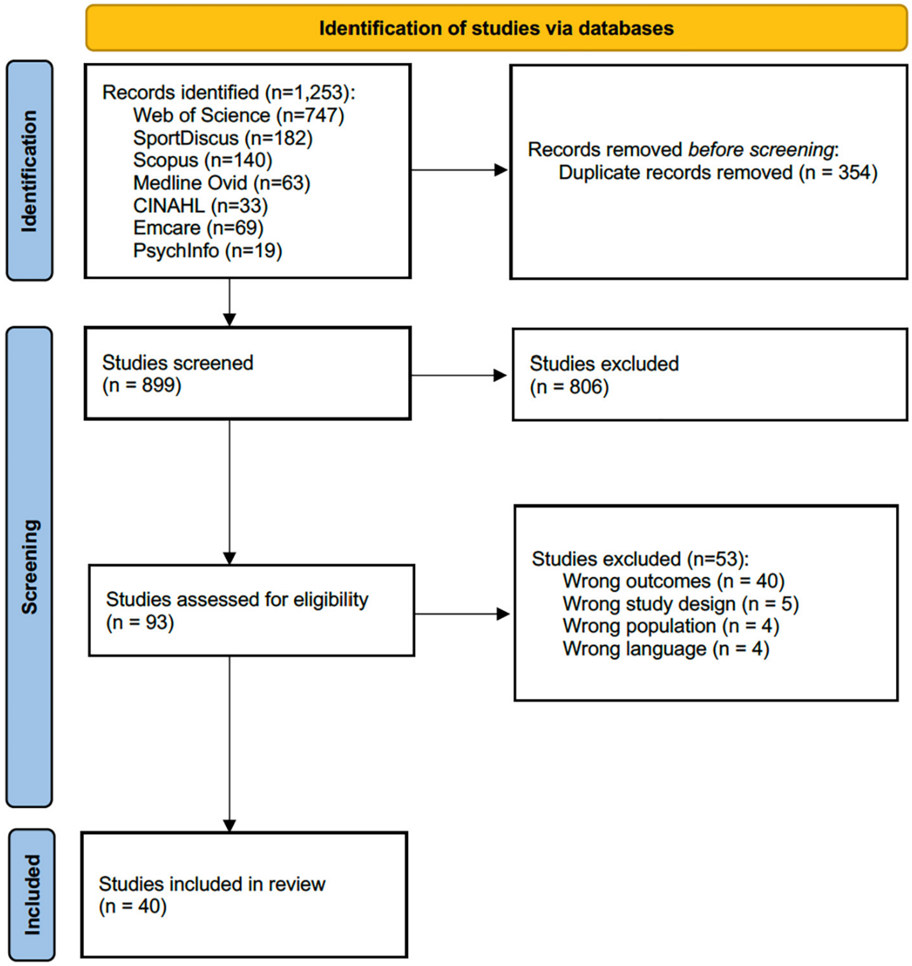

Fig. 1. PRISMA flow diagram.[16]

(Supplementary Table 2). However, it was noted that there were a number of articles (50.0 %) included that would be considered low on the hierarchy of evidence, including non-systematic reviews, commentaries, and editorials.

As there were no randomized controlled trials nor systematic reviews of randomized controlled trials, the possible grade of evidence for recommendations was level B (cohort, ecological or case–control studies). However, due to the large number of non-systematic reviews, commentaries, and editorials, most recommendations were graded as level D (expert opinion; Table 3).

The quantitative articles spanned data from the years 1980–2021 from countries including the United States of America (USA; n = 7), Japan (n = 4), Singapore (n = 1), Qatar (n = 1), the Netherlands (n = 1), and across multiple countries (n = 3). There were no quantitative studies identified that explored Australian sporting events which met the inclusion criteria. A summary of the quantitative studies is provided in Table 1.

The majority of quantitative studies utilized wet bulb globe temperature (WBGT) as the measure of environmental heat load (n = 13) with the daily maximum universal thermal climate index (UTCI, n = 2), ambient temperature (n = 1) and daily maximum temperature (n = 1) also reported. Health outcomes that were explored across the literature were exertional heat illness (EHI),[21–23] exertional heat stroke (EHS),[21,24–26] hyperthermia,[27,28] and more broadly heat related illness.[7,29–35]

For the descriptive and qualitative articles, most (60.9 %) did not focus on a specific region and were deemed international (n = 14). Remaining articles focused on a specific region: three were addressing heat at mass-gathering sport events in Tokyo, Japan; two in the USA; one in Qatar; one in both Qatar and Tokyo; and one in Canada.

Six themes of recommendations with subthemes were developed from the articles including: planning, mitigation strategies, medical, policy, education, and research (Table 3). The planning theme included recommendations that were aimed at being prepared to deliver a mass-gathering sport event. An example of this theme was, "Sports federations should thus consider potential hot and humid conditions when regulating the competition apparel of their athletes"(p. 772).[36] Mitigation strategies were recommendations targeted at mitigating exposure to heat or reducing the impact of heat. An example of this theme was "Ultimately the suspension or cancellation of play can be mandated if the risk is deemed sufficiently high ...." (p. 718).[37] Medical recommendations were those that were directed at medical teams or the medical system. An example of this theme was "...it becomes critical that medical directors evaluate their preparedness from their own historical data to optimize their medical tent operations and needs" (p. 1152).[21] Policy-based recommendations explicitly mentioned policy or guidelines for managing heat, defining heat, or defining cases. An example of this theme was "A heat policy should have a continuous scale of risk categories rather than just a simple dichotomous 'cancellation' threshold. Evidence-based progressive risk mitigation strategies should be included at each of these levels" (p. 2).[38] Recommendations regarding education were for the dissemination of information regarding heat risk and protection. An example of this theme was "Internet-based warning systems can warn users before and during training and competition about climate-induced health risks. Ideally, such applications allow location-specific searches" (p.9).[6] Lastly, research recommendations were those that asked for evidence-based strategies, evaluation, monitoring, and better data. An example of this theme was "Advancing

Table 1
Summary of quantitative articles.

Study setting	Study period	Sport (group)	Study design	Heat measure	Outcome	Article highlights	Author/s (year)[ref]
United States of America (USA)	1980–2009	American football (athletes)	Descriptive epidemiological study	Wet bulb globe temperature (WBGT)	Hyperthermia deaths	Across the study period there were 58 deaths, approximately two per year. Most deaths occurred in the pre-season (August). Deaths occurred on days considered unusually hot and humid.	Grundstein et al. (2012)[27]
Massachusetts, USA	1997, 1998, 2001, and 2013–2016	Road Race (athletes)	Retrospective cohort study	WBGT (ABM model — uses ambient temperature and relative humidity) and WBGT (Liljegren model — uses more variables to estimate WBGT)	Exertional heat stroke and heat exhaustion	The incidence of exertional heat stress was 2.12 per 1000 finishers, and heat exhaustion was 0.98 per 1000 finishers. The incidence of exertional heat stroke increased as the WBGT and the heat alert level increased.	Hosokawa et al. (2018)[21]
Twin Cities, USA	1997–2008	Marathon (athletes)	Retrospective cohort study	WBGT	Unsuccessful marathon starters and medical encounters	A start WBGT of 21 °C+ resulted in midrace cancelations or mass casualty incidents. An area-wide mass casualty incident occurred at a start WBGT of 22 °C+.	Roberts (2010)[59]
Indianapolis, USA	2005–2012	Half marathon (athletes)	Descriptive epidemiological study	Ambient temperature (°F)	Exertional heat stroke	The rate of exertional heat stroke was 1.3 per 10,000 participants. Most cases (78 %) occurred on the three days that had the highest ambient temperature.	Sloan et al. (2015)[24]
Norway, Austria, China, Thailand, Portugal, Turkey, Canada	2009–2011	Beach volleyball (athletes)	Retrospective cohort study	WBGT	Heat-stress related medical forfeiture	One case of medical forfeiture related to heat-stress occurred across 48 events.	Bahr & Reeser (2012)[23]
Singapore	2009–2012	Motor sports (spectators)	Descriptive epidemiological study	Daily maximum temperature	Patient presentations	Up to 19 % of patient presentations were heat-related illnesses. The correlation between the heat index and the patient presentation rate was not significant.	Ho et al. (2014)[34]
Germany, South Korea, Finland, Russia, Switzerland, Netherlands	2009–2018	Athletics championships (athletes)	Prospective cohort study	Daily maximum universal thermal climate index (UTCI)	Heat related illness	The incidence rate of heat related illness across all championships was 11.7 (95 % CI 9.7–13.7) per 1000 athletes. 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) experienced greater risk relative to short-duration disciplines. Higher UTCI temperatures were positively associated with heat related illness.	Hollander et al. (2021)[7]
International	2009–2018	Athletics championships (athletes)	Prospective cohort study	UTCI	Heat related illness	The heat related illness incidence rate increased significantly with temperature increases (0.14 more heat illness per 1000 athletes per °C). Athletes participating in endurance events had significantly higher incidence than those in explosive disciplines by 20-fold (RR = 21.7, 95 % CI 12.0 to 39.2).	Hollander et al. (2021)[29]
USA	2011–2017	10-km road race (athletes)	Descriptive epidemiology study	WBGT	Exertional heat stroke medical encounters	In the medical tent, the most common diagnosis was heat-related illness (1.6 per 1000 finishers). The incidence rate of exertional heat stoke was 1.0 per 1000 finishers.	Breslow et al. (2019)[25]
Qatar	2015	Para athletics (athletes)	Retrospective cohort study	WBGT	Incidence rates of illness	Seven cases of heat-related illness were documented, and three required hospitalizations.	Grobler et al. (2019)[30]
Boston, USA	2015–19	Marathon (athletes)	Retrospective cohort study	WBGT	Exertional heat stroke medical encounters	The incidence rate of EHS was 3.7 per 10,000 starters. There was a significant direct correlation between EHS incidence and WBGT ($R^2 = 0.7688$).	Breslow et al. (2021)[26]
The Netherlands	2017–19	Road race (athletes)	Descriptive epidemiology study	WBGT	Medical encounters	The incidence rate of hyperthermia was 0.46 per 1000 race starters (95 % CI, 0.34–0.62).	Sewry et al. (2022)[28]
USA	2019	American football (officials)	Cross-sectional survey	WBGT	Use of WBGT to assess heat stress	The majority of Football Bowl Subdivision training programs use the WBGT to assess heat stress (72 % compliance with guidelines specifying WBGT use).	Chan & Wagner (2020)[22]
Japan	2019	Rugby World Cup (spectators)	Retrospective cohort study	WBGT	Visits to the spectator medical room	Rates of visits to the spectator medical room for matches held with a WBGT over 25 °C were significantly higher (PPR 4.27) than matches less than 21 °C (PPR 2.04). The incidence rate of heat illness was 0.31/10,000 attendees.	Tajima et al. (2020)[31]
Tokyo, Japan	2016–2020	Olympics and Paralympics (all in attendance)	Descriptive epidemiology study	WBGT	Emergency transports due to heat illness	The number of emergency transfers due to heat illness was the highest in 2018 (n = 6269), decreasing in 2020 (n = 4862). The peak of emergency transportations for heat illness occurred simultaneously with the resurgence of COVID-19 in 2020, presenting a challenge for the 2021 Olympic and Paralympic Games.	Shimizu et al. (2021)[33]

Table 1 (*continued*)

Study setting	Study period	Sport (group)	Study design	Heat measure	Outcome	Article highlights	Author/s (year)[ref]
Tokyo, Japan	2021	Olympic games (athletes and spectators)	Descriptive epidemiology study	WBGT	In-competition medical care	There were 225 incidences of heat-related illness (100 athletes and 125 spectators). Five athletes and one spectator were transported to the hospital. None of the patients were admitted to hospital. Of the 100 heat-illnesses, 50 cases of occurred in *marathon, race waking,* with an incidence of 13.6 %.	Tanaka et al. (2023)[35]
Tokyo, Japan	2021	Olympics and Paralympics (athletes)	Descriptive epidemiology study	WBGT	Heat-related illness	The incidence of heat-related illness across all Olympic and Paralympic athletes was 8.6 per 1000. The odds ratio of heat-related illness in the Olympics for athletics (marathon/race walk) versus all other sport was 13.87 (95 % CI, 9.46–20.33). The odds ratio of heat-related illness in the Paralympics for athletics (track and field/marathon) was 1.81 (95 % CI, 0.94–3.49)	Inoue et al. (2023)[32]

Acronyms: Australian Bureau of Meteorology (ABM), confidence intervals (CI), degrees Celsius (°C), degrees Fahrenheit (°F), exertional heat stroke (EHS), patient presentation rate (PPR), relative risk (RR), wet bulb globe temperature (WBGT), universal thermal climate index (UTCI).

systematic disease surveillance and evaluation systems across a sequence of the Olympic and Paralympic games would be helpful in learning from the past Olympic and Paralympic games" (p. 3).[39]

4. Discussion

As temperatures rise across the globe, it is paramount that organizers and governing bodies of mass-gathering sporting events consider the impact of extreme heat on all individuals who attend, including athletes, officials, spectators, volunteers and workers. The burden of heat on mass-gathering events is wide ranging — from individual physiological responses,[40] to performance,[40] to health service demand,[33] to infrastructure.[6] This review took a population perspective to understand how systems (health, event and sporting organizations) can mitigate health impacts from heat during mass-gathering sporting events, and six thematic areas of recommendations (planning, mitigation, medical, policy, education and research) emerged.

The findings of this review reveal a consistent pattern of heat-related challenges across various sporting events and settings (Table 1). Incidence rates of exertional heat stress, heat exhaustion and heat-related illness varied and, as expected, exhibited a direct relationship with increasing environmental heat.[21,26,29,31] Regarding the type of sport, those participating in endurance sports (i.e. running and cycling) were at higher risk than those participating in short-duration sports.[7,29,41] Participants and spectators experienced elevated risks in events with higher WBGT, leading to midrace cancelations, mass casualty incidents, and medical tent utilization (Table 1). The impact extended beyond the mass-gathering events to include emergency transfers due to heat illness.[35]

Ultimately, there must be awareness of the impact of extreme heat on health at mass-gathering sporting events at the individual (e.g. pre-cooling, drinking breaks), organizational (e.g. time and place of competitions, adjustment of rules and regulations)[42] and infrastructure levels (e.g. instillation of water dispensers, green roofs and facades).[6] The review identified only one study that explored how mass-gathering sporting events affect health service delivery.[33] This study looked at heat illness and the complications of running an event during the COVID-19 pandemic, finding that the double burden of COVID-19 and heat-related illness during the 2021 Olympic and Paralympic games had the potential to overwhelm the healthcare system.[33] In planning for future large events, further research must be undertaken to understand the health system impacts of extreme heat during sporting events to facilitate a prepared and resilient system.

The current review was unable to find any papers that describe indicators used for measuring the impact of heat on health systems during sporting events and activities. Future events may wish to work with their local health system to place a flag on those cases for people who have attended the event and suffered from a heat-related illness. This review identified that many heat-related illnesses (heat stroke, heat cramps, syncope, and indirect impacts relating to dehydration)[43,44] can be managed at the event. The capacity of event medical teams to manage these types of health impacts relies upon event planning, which may have contributed to the limited number of studies exploring impacts on health services.

4.1. Planning

Planning for extreme heat is essential for all organizations involved in mass-gathering sporting events.[31,34] The explicit consideration of heat in event tendering processes is recommended. While plans may evolve and become more specific over time and may be locally or facility-specific, it is important to have clear guidelines in place for scheduling, venue selection, and equipment considerations.[6,24,29] These plans should span all levels, including venue management, health services and providers, and government entities. Having a comprehensive plan enables athletes and spectators to understand potential changes or cancelations of sports. Plans also provide guidelines for facility selection and the amenities provided within a facility, enable the design of pedestrian routes, and guide location and development of new facilities.[6,24,36,39,45] It is also crucial to have plans in place to educate staff about the impacts of heat and ensure they have the necessary training and equipment to manage heat-related issues,[46] and look after their own health in the heat. Further research is needed around food and beverage provision, including the availability of hydration stations and suitable food choices for hot weather conditions, which may involve reducing or removing alcohol or caffeinated beverages.[6,11]

Aspects of planning that were notably absent from the literature are athlete housing and weather forecasting. Organizers of the Paris 2024 Olympics have implemented an underground water cooling system in an attempt to decrease the use of air conditioning and reduce the carbon footprint of the games.[47] Future investigation into the effectiveness of this strategy is warranted, particularly regarding its impact on mitigating heat-related challenges and reducing the environmental footprint of sporting events. Furthermore, the utilization of forecasting, specifically 'feels like' temperatures, in the days leading up to a mass-gathering event may serve as a helpful tool to communicate with those who attend and participate and may be a considerable benefit to health.[48]

4.2. Mitigation strategies

There are three key areas that require consideration when developing mitigation strategies: individual plans, strategies within competition, and strategies pre/post competition. Practicality, feasibility, and effectiveness

Table 2
Summary of descriptive and qualitative articles.

Setting	Design	Sport	Key result	Reference
International	Review	Tennis	An overview of practical knowledge to improve player well-being, performance, and safety in the heat.	Bergeron[40]
International	Review	Road races	Serious life-threatening medical complications including heat stroke are less common than minor and moderate medical complications during road races.	Breslow et al.[60]
International	Review	Organized sports	Endurance events including running, cycling, and adventure races exhibited the highest incidence rates for exertional heat illness.	Gamage et al.[41]
International	Review	All sport	The identification of two distinct heat alleviation themes: chronic and acute heat alleviation techniques.	Gibson et al.[57]
International	Review	Paralympic games	A summary of heat-related issues for Paralympic athletes' thermoregulatory risk, current recommendations, technological advancements.	Griggs et al.[11]
International	Review	All sport	Provides an understanding of the thermal environment to support sustainable opportunities to keep people cooler with optimal interventions for playing sport.	Jay et al.[37]
International	Review	Aquatics, athletics, football, tennis, and triathlon	Outlines environmental health risks that are sport-specific and explores the epidemiology of exertional heat illness	Mountjoy et al.[61]
Qatar and Tokyo	Review	IAAF World Championships and 2020 Olympics	Argues for the use of real-time transmission of physiological, biomechanical and performance data to alert medical teams of indicators of exertional heat stroke.	Muniz-Pardos et al.[62]
Tokyo, Japan	Review	Olympic and Paralympic Games	Describes the health risks and precautions for visitors of the Tokyo 2020 summer Olympics, including the risk of heat-related illness.	Nakamura et al.[63]
International	Review	All sport	Recommends practical strategies that target thermoregulatory and inflammatory causes of heat.	Pyne et al.[49]
USA	Review	All sport	Critically assesses heat stress guidelines established by governing bodies in sport	Hosokawa et al.[64]
International	Consensus Article	Olympics	New thermoregulatory guidelines implemented by the International Olympics Committee Medical Commission and International Sport Federations to mitigate risk further.	Bergeron et al.[36]
International	Consensus Article	Mass participation sporting events using the Olympic Games as an example	A summary of the key components for the prehospital management of exertional heat stroke.	Hosokawa et al.[65]
International	Consensus Article	Paralympics	Describes the adaptations of the exertional heat stroke management framework to be suitable for Paralympic Athletes.	Hosokawa et al.[52]
International	Consensus Article	All sport	Provides recommendations developed by the IOC via a working group, meetings, field experience and a Delphi process. Recommendations are focused on event organization, athlete behaviors, medical management of EHS, and the development on an environmental heat risk analysis.	Racinais et al.[66]
Tokyo, Japan	Commentary	Olympics	There was almost no time zone with an expected low risk of heat illness for the 2020 Olympics. Tokyo had a higher WBGT than any previous three host cities.	Kakamu et al.[46]
International	Commentary	Wheelchair tennis	Current guidelines, research, and preventative countermeasures regarding heat strain in wheelchair tennis.	Girard[67]
Qatar	Policy Brief	International Association of Athletics Federations (IAAF) World Championships	Summarizes the methods used by the IAAF and local committee doctors to analyze and reduce meteorological risk, including heat.	Bermon & Adami[68]
USA	Position statement	National Athletic Trainers' Association	Presentation of the best-practice recommendations for preventing, recognizing, and treating heat illness.	Casa et al.[69]
International	Position statement	All	Details the key considerations for extreme heat policies including four environmental parameters (ambient temperature, humidity, air velocity, and mean radiant temperature) and two personal parameters (activity and clothing).	Chalmers et al.[38]
International	Concept paper	All	Development of the "sports, clubs, and climate change model" (SC3)	Schneider et al.[6]
Tokyo, Japan	Letter to the editor	Tennis, marathon, soccer, archery	Discusses the underlying climate-related problems of Tokyo 2020, and future directions for the Olympic and Paralympic games	Yamasaki et al.[39]
International	Mixed methods	All	Explores insights from sport managers for implementing climate hazard adaptation strategies	Mallen et al.[70]

Note: International refers to those articles that were written by international sport governing bodies or discussed sport, heat, and health without a regional focus.
Acronyms: exertional heat stroke (EHS), International Association of Athletics Federations (IAAF), International Olympics Committee (IOC), Sports, Clubs and Climate Change Model (SC3), wet bulb globe temperature (WBGT).

should guide the formulation of individual plans for athletes, officials, workers, volunteers, and spectators. These plans should address essential factors such as hydration, suitable clothing, sunscreen application, work breaks, and individual health and fitness considerations.[6,11,46,49] The second area of focus is strategies within sporting events. This entails carefully planning breaks, allowing sufficient time between games/events, determining optimal timing for competitions, and establishing the criteria for schedule changes based on specific weather conditions.[6,23] Another important consideration is active cooling techniques. Chalmers et al. tested and recommended three cooling interventions in-play including chilled water consumption, the application of an ice towel around the neck, and an extended half time break.[50] The third area predominantly involves coaches and athletes, and it encompasses strategies to mitigate heat-related risks both before and after competitions. These strategies may include pre-cooling techniques (e.g. cooling vests, ice slurry ingestion, cold water immersion), post-cooling techniques (e.g. cold water immersion, cryotherapy), acclimatization methods, and adapting warm-up routines to align with the prevailing environmental conditions.[27,36,51] By implementing these measures, coaches and athletes can optimize performance while minimizing the potential negative effects of heat.

4.3. Medical

A significant heat event, combined with a mass-gathering event, can have a profound impact on health services, potentially hindering their ability to effectively respond to the increased demand caused by the event.[33] To mitigate these challenges, mass-gathering sporting events must prioritize appropriate resourcing, ensuring the availability of trained staff and allocating medical resources effectively.[21,26,41] It is crucial to provide comprehensive training to medical teams, equipping

Table 3
Summary of recommendations for improved heat-health outcomes during mass-gathering sporting events.

Theme	Sub-theme	Thematic overview	References and level of evidence
Planning	Equipment	Having equipment (including clothing) to keep people cool during the event or if they are experiencing heat stress. This includes body temperature monitoring devices and alert systems when conditions are favorable for heat stroke/illness. It also includes the positioning of cooling devices throughout the venue to promote cooling, such as misting fans.	C,[24,26] D[32,36,37,62,66]
	Venue	Selection of facility and the amenities available within a facility (e.g., air conditioning, shading or window glazing) that reduce exposure. Other considerations include number of relief stations, planning of pedestrian routes, field type (turf, grass, clay), ice provision, space and power supply for cooling devices, and temperature management throughout the event.	C,[24,35] D[6,32,36,39,66,70]
	Scheduling	Includes the modification of training and match times based on heat risk (e.g., in the morning or later in the evening).	C,[32,59] D[6,7,23,36,39,40,46]
	Staff	Having appropriate staff, having staff who are knowledgeable and trained for cooling and first aid (and providing such training).	D[36,46,70]
	Food and beverage	Providing food and beverages that are nutritious and promote hydration, and reducing the availability of food and beverages that dehydrate (e.g., caffeine and alcohol)	D[6,11]
	'Have a plan'	Recommendations to have heat-health plans in place.	C[34], D[28,31,39,40,62]
Mitigation strategies	Individual plan	These are recommendations which are targeted at an individual level. For example, regarding individual plans for athletes, recommendations included electrolytes, evidence-based hydration plans, dietary practices (consideration of carbohydrate, protein, and probiotic intake), and appropriate use of medication. Regarding individual plans for others attending the events (spectators, officials, volunteers, etc.) recommendations included the use of sunscreen, staying hydrated, covering and cooling the skin, limiting time spent outdoors when possible, and considering individual health and medications when taking protective measures.	C[27], D[7,11,32,36,38,40,49,57,63,66,67,70]
	Strategies within competition	Mitigation strategies that can take place during the competition, for example permitting side changes, water breaks, increasing time between games/rallies, reducing the duration of competition, suspending or canceling the competition if necessary, and in competition access to cooling interventions.	C,[7,30,32,59] D[23,36,37,66,70]
	Strategies pre/post competition	Activities to mitigate heat-health outcomes that are undertaken before or after the competition (e.g., acclimatization [training in a hot, natural environment], acclimation [training in a hot, artificial environment], pre and post event cooling, modifying warm-up duration according to conditions).	D[6,7,11,27,36,37,40,46,49,57,59,64,66]
Medical	Resourcing	Includes sufficiently trained staff, resource allocation, first aid stations, best practice EHS treatment and resources (such as equipment for rectal temperature assessment) and establishing a heat deck (dedicated area to manage EHS).	B[26], C,[21,28,32,35] D[11,36,39,41,66]
	Skills	Medical teams should be skilled in the warning signs, diagnosis, and treatment of heat related illness.	C[35], D[7,52]
	Health system	Organizing health service capacity, preparing for increased demand, and liaising with health and emergency services.	C[24], D[33]
	Action	Monitoring, immediately responding and triage systems. This includes spotters or video surveillance throughout events to identify EHS rapidly. It also includes positioning medical facilities close to finish lines.	B[24], D[40,62,63,65,66]
Policy	Heat threshold and warning systems	Recommendations regarding heat guidelines or regulations to proceed, postpone, or cancel an event. Warning systems may include the use of technology (i.e. phone apps).	C,[28,59] D[7,11,22,38,46,66,70]
	Policy development	Considerations for developing policy. This would include recommendations that policies should not be over restrictive, or that they need to include all ages and physical functions, or policies need to be flexible and environment specific.	C[24], D[6,11,38,49,66]
Education	Heat awareness	Recommendations that emphasize the importance of educating participants, coaches, support staff, spectators, and the general public about the risks and prevention of heat-related illnesses	C,[24,26] D[6,11,27,28,33,39,63,70]
Research	Evidence base	Recommendations for the need for evidence-based strategies, evaluation, monitoring of heat incidence rates, better data, more funding, and the provision of historical weather data at the time of bidding for the event.	D[6,7,11,24,26,28,38,39,41,49,62,64,66]

them with the knowledge and skills necessary to recognize warning signs and promptly diagnose and treat heat-related illnesses. [7,52] Furthermore, collaborative planning with health systems should extend across multiple healthcare services. By establishing strong partnerships and communication channels, sporting events can ensure seamless coordination with hospitals, clinics, and emergency response teams. This collaborative approach allows for a comprehensive and integrated response to any health-related issues arising from the event, ensuring the well-being of participants, officials, workers, volunteers, spectators, and the general public. The potential for mass sporting events to become mass heat illness events is apparent, and therefore one that necessitates not only planning and mitigation strategies but also a well-managed, capable and functional health response.

4.4. Heat-health policy in Australian sport

Australian sporting organizations and governing bodies are recognizing and acting on the threat posed by increasing extreme heat events. While these policies are not necessarily published in the literature, the recognition and action taken by Australian sporting organizations demonstrate a commitment to prioritizing the safety and well-being of those who spectate, officiate, and participate in sport. A key example of such policy includes the Extreme Heat Policy issued by Sports Medicine Australia, which provides recommendations for a range of sport and classifies them according to risk (based on exercise intensity and clothing/equipment worn).[10] Each classification corresponds to a specific temperature/humidity graph that can be utilized to assess heat stress, providing a valuable tool to make informed decisions during extreme heat conditions.[10] In another example, the Australian Open launched an evidence-based extreme heat policy in 2019 resulting from research collaboration between Tennis Australia and the University of Sydney.[53] The AO Heat Stress Scale was developed, accounting for air temperature, radiant heat or strength of the sun, humidity, and wind speed.[53] While these policies offer valuable tools for decision-making in extreme heat conditions, it is important to note that there is currently limited evidence on how these measures directly impact the health outcomes of players, spectators, and officials. Further research in this space is crucial to assess the effectiveness and long-term health implications of these policies in the lead up to future mass sporting events, such as the 2032 Summer Olympics.

4.5. Brisbane 2032 Summer Olympics and Paralympics

The 2032 Summer Olympics and Paralympics will be held in Brisbane, Queensland, Australia. Heatwaves claim more than 100 lives in Queensland each year, and are considered the deadliest natural hazard in

Australia.[54,55] Climate projections must be considered to protect the health of athletes, officials, workers, volunteers, and spectators at all future events. The Queensland Government has released the Brisbane 2032 Master Plan (https://www.qld.gov.au/about/Brisbane2032) which is focused on achieving “optimal legacy outcomes over the next 20 years and beyond.” While there is a section dedicated to ‘Climate positive Games’ regarding renewable energy and emissions, considerations for exposure to extreme heat and mitigation strategies have not been mentioned. Though the Olympic Games are scheduled to occur during the Australian winter, this well-known warm climate in conjunction with potentially unseasonably high temperatures may still put people at risk, especially visitors from cooler climates. The northernmost Games location is Cairns in Far North Queensland, where average maximum temperatures during July and August (the months in which the Olympics are scheduled) are approximately 26–27 °C,[56] mirroring summertime temperatures in many European and North American regions. While athletes are likely to undergo acclimatization and acclimation practices, this is unlikely to occur for others attending the event, such as spectators, officials, volunteers, and workers. Therefore, organizers and policymakers must not become complacent about the potential risks to health and safety.

With the Brisbane Olympics nearly a decade away, there is still time to develop heat-resilient infrastructure and cooling refuges to create a comfortable and safe environment for those participating, working, and attending the Olympics and associated activities. Additionally, research must be conducted in the Australian context urgently to properly inform athletes, spectators, officials, volunteers, workers, and medical services about how to prepare for the Olympic and Paralympic games, and other mass-gathering events.

4.6. Strengths, limitations and future directions

In contrast to existing reviews which primarily focus on individual physiological responses to heat among athletes,[57] acclimatization strategies,[58] and exertional heat illness,[41] this systematic review uniquely examined the broader population-level impacts of extreme heat at mass-gathering sporting events. By exploring the health implications extending beyond individual athletes, this review remedies a gap in the literature and provides valuable insights for the preparation and management of such events.

There were a number of recommendations in which the target group was not specified. Future studies exploring heat-health during sporting events should provide specific, measurable, achievable, relevant, and time bound (SMART) recommendations, that clearly outline who needs to take responsibility. These recommendations need to be evaluated to ensure effective solutions for the future. It is recognized that more specific recommendations in relation to events and enhancing future event provision may also be more directly communicated with the organizing committees, conveners and associated partners and thus may not be publicly available.

While effort was made to ensure all relevant data were captured, studies that investigated individual physiological responses were excluded, and these studies may have contained population-level recommendations that were missed. While the focus of this review was to understand the population-level impact of heat during mass gathering, this approach may have overlooked valuable insights from physiological-based research pertaining to evidence-based individual mitigation strategies (e.g. cooling). Furthermore, this review only included papers from 2010 onwards, and recommendations may have been made prior to this date that remain relevant today. There is a need to review the literature and capture new insights on an ongoing basis as extreme heat continues to be experienced by populations worldwide.

One of the limitations of this study was the large number of recommendations that were graded as professional opinion (Level D). While this field of research typically precludes randomized control designs, further observational studies, such as well-designed case studies or cohort studies, are needed to improve the number of evidence-based recommendations for the management of extreme heat during mass gathering sporting events.

In conclusion, this review identified the risk of heat-related health outcomes at mass-gathering sport events globally. Extreme heat during sporting events has the potential to significantly impact the health of all attendees (including athletes, spectators and officials) of mass gathering sporting events. The literature emphasized the importance of adequate preparation, mitigation strategies to reduce heat exposure, the need for medical personnel and resourcing, the development of evidence-based policies and guidelines for mass-gathering sporting events. Further research must be undertaken to facilitate the development of such policies and guidelines, and this work must be conducted urgently to inform preparations for major worldwide events.

Funding information

This work was funded by the Queensland Department of Environment and Science who provided feedback and has approved publication.

Confirmation of ethical compliance

The submitted work is a literature review, and therefore ethical approval was not sought.

CRediT authorship contribution statement

Hannah Mason: Conceptualisation, methodology, analysis, investigation, writing - original draft, writing - review & editing, visualization, project administration. **Jemma King:** Conceptualisation, methodology, analysis, investigation, writing - original draft, writing - review & editing. **Amy Peden:** Conceptualisation, methodology, analysis, investigation, writing- original draft, writing - review & editing. **Anthony Leicht:** Writing - review & editing. **Richard Franklin:** Conceptualisation, methodology, analysis, investigation, writing - original draft, writing - review & editing, visualization, supervision, project administration, funding acquisition.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT in order to check for reference duplicates and for writing organization. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of interest statement

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Richard Franklin reports financial support was provided by Queensland Department of Environment and Science. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Thank you to the Queensland Department of Environment and Science for funding this project and Jyotishma Rajan for providing feedback.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2024.04.015.

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