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REVIEW

Hyperthermia and Exertional Heatstroke During Running, Cycling, Open Water Swimming, and Triathlon Events

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Abstract: Few previous epidemiological studies, sports medicine position statements, and expert panel consensus reports have evaluated the similarities and differences of hyperthermia and exertional heatstroke (EHS) during endurance running, cycling, open water swimming, and triathlon competitions. Accordingly, we conducted manual online searches of the PubMed and Google Scholar databases using pre-defined inclusion criteria. The initial manual screenings of 1192 article titles and abstracts, and subsequent reviews of full-length pdf versions identified 80 articles that were acceptable for inclusion. These articles indicated that event medical teams recognized hyperthermia and EHS in the majority of running and triathlon field studies (range, 58.8 to 85.7%), whereas few reports of hyperthermia and EHS appeared in cycling and open water swimming field studies (range, 0 to 20%). Sports medicine position statements and consensus reports also exhibited these event-specific differences. Thus, we proposed mechanisms that involved physiological effector responses (sweating, increased skin blood flow) and biophysical heat transfer to the environment (evaporation, convection, radiation, and conduction). We anticipate that the above information will help race directors to distribute pre-race safety advice to athletes and will assist medical directors to better allocate medical resources (eg, staff number and skill sets, medical equipment) and optimize the management of hyperthermia and EHS.

Keywords: heat illness, epidemiology, pathophysiology, thermoregulation, athlete

Introduction

During the transition from rest to exercise, skeletal muscle metabolic rate increases. Depending on the mode (eg, running, cycling, swimming) and intensity of this exercise, human mechanical efficiency (ie, the ratio of external work to the amount that energy production increases) is 25% or less. Consequently, at least 75% of the energy generated during carbohydrate and fat metabolism in active tissue is eventually converted to heat.[1,2] Highly trained endurance runners can produce heat at a rate of 1000–1300 kcal $\cdot$ h^{-1} (1162–1511 W) for 1–3 h.[3,4] This means that the internal body temperature of a hypothetical marathon runner (70 kg body mass) could rise at the rate of 0.3°C$\cdot$$min^{-1}$. At this rate of heat storage, he/she could be at risk for thermal injury within 15 minutes, if heat were not dissipated from internal organs to the environment.[4] The clinical relevance of these observations becomes evident when considering the nature of exertional heatstroke (EHS).

EHS is a medical emergency characterized by hyperthermia (usually > 40°C rectal temperature) with central nervous system disturbances which range from mild personality changes to confusion, delirium, stupor, or unconsciousness.[5–8] The clinical outcomes of EHS are directly attributed to the duration of hyperthermia above the body's critical threshold for cellular damage.[9–12] Thus, the best practice for pre-hospital management of EHS[13,14] includes rapid recognition (ie, nausea, aggressiveness, dizziness, combativeness, staggering while walking/running, or collapse), rapid assessment (ie,

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measuring the athlete's core body temperature with a rectal thermometer and evaluating mental status for disorientation, confusion, altered consciousness, or irrational behavior), and rapid cooling by submerging the athlete in an ice-water bath that is maintained at ≤ 15°C.[6,8,11,15] A "cool first, transport second"[9,11,13] management plan is important because EHS is 100% survivable when core temperature is cooled below 40°C within 30 minutes.[16,17] If whole-body cooling is not applied rapidly, the untoward sequelae of EHS may ensue,[17] and patient management may require critical care interventions for organ and tissue damage, including systemic inflammatory response syndrome and disseminated intravascular coagulopathy.[18–20]

It is perplexing that EHS frequently strikes young, highly motivated individuals (ie, athletes, recreational enthusiasts, soldiers) during activities that they have performed previously, in similar environmental conditions, at the same exercise intensity-duration, and while wearing similar clothing or gear.[21–23] It is tragic that EHS strikes some individuals more than once.[24] For example, Stearns et al[25] reported that 11% of EHS cases spanning 17 years of the Falmouth Road Race sustained a second EHS episode within the next 2 years. Similarly, Abriat et al[26] reported that 15% of EHS patients in the French military experienced EHS recurrence at a later date. Although a few clinicians and physiologists have suggested that EHS is preventable,[27–30] effective prevention has been sought for decades without eradicating this life-threatening illness.[31–33] Today, no method exists to validly predict who will experience EHS during a sport or mass participation event.[34] We propose that this state of affairs exists primarily because the interactive effects of recognized risk factors are unknown and understudied. Further, it is unlikely that the risk of EHS will be eliminated completely[35] because (a) heat storage in deep internal organs is common when prolonged, strenuous exercise is performed in a hot environment,[3,4,36–39] and (b) an athlete's motivation and competitive drive are self-controlled.[30] However, while total primary prevention is not likely, 100% survival from EHS is possible when whole-body cooling reduces internal temperature below 40°C within 30 minutes.[11,16,17] This fact underscores the importance of treatment by the on-site medical team and pre-event planning.[40–43] It also indicates that additional research is warranted.

Individual endurance sports and mass participation events have grown during the past 25 years globally. This includes distance running and sanctioned cycling competitions,[44,45] open water swimming,[46–48] triathlons,[45,49] and the ultra-distance events organized for all of these.[47] Endurance sport participants seek great challenges[44] that often are associated with an increased incidence of serious and life-threatening medical conditions.[50] As a result, meeting the clinical demands of various stressors and venues has become a priority in the realms of sports medicine and mass medical management.[44,51] Relevant to the present review, EHS is included among the possible serious and life-threatening problems that participants report to the event medical team[42,50,52,53] during foot races,[54–57] endurance cycling events,[52,58] triathlons,[43,59,60] and ultra-distance events.[40,52,58] It is especially relevant to triathletes that no previous review article has assessed hyperthermia and EHS across all of these endurance sports. Therefore, the dual purposes of the present review are to clarify the available evidence regarding the recognition of hyperthermia and EHS (a) by medical teams at outdoor running, cycling, open water swimming, and triathlon events; and (b) by professional organizations and writing groups in position statements and consensus documents regarding outdoor endurance activities. Prior to conducting an extensive search of the literature, we hypothesized that this effort would identify gaps in the knowledge base plus event-specific differences which are not widely recognized. We propose that this review will inform and enhance the medical care of those who participate in future endurance sports and mass participation events.

Materials and Methods

Manual searches for relevant articles were performed in the PubMed and Google Scholar databases using advanced search operators (eg, quotation marks, pertinent phrases, "and", "or"). Inclusion criteria included English language, full-text, peer-reviewed articles, without publication year limits and available through March 5, 2024. Combinations of the following key words during literature searches emphasized the associations of hyperthermia and EHS with running, cycling, swimming, and triathlon events: "hyperthermia", "heatstroke", "heat stroke", "cyclist", "cycling", "runner", "running", "triathlon", "triathlete", "swimmer", "swimming", and "open water swimming". All manual searches included "hyperthermia", "heatstroke" and "heat stroke" as keywords; each search excluded articles which contained the keywords "military", "soldier", "industry", "industrial", and "labor" which were beyond the scope of the present review. After removing duplicate records, the abstracts and titles of the remaining records were evaluated to determine which studies should be further assessed for eligibility. We subsequently performed manual searches of each eligible article's reference list, as well as the bibliographies found in germane systematic reviews and meta-analyses. Finally, we investigated full text (.pdf) versions of all remaining articles to ascertain if they fit the purposes of this review.

We sought and organized relevant articles using the following approaches to the existing literature. First, research in the area of exertional heat illnesses is complicated by difficulties with definitions,[61] which vary considerably and are based on non-specific terminology.[62] Thus, we sought publications which described the medical encounters that specifically involved hyperthermia and EHS at outdoor mass participation/large group events, athletic competitions, or training and competition spanning a single season or multiple years. Second, we segregated running, triathlon, cycling, and open water swimming studies. Third, because previous publications have suggested that ambient conditions (ie, hot environments) influence the types and prevalence of illnesses observed at athletic competitions and recreational endurance events,[56,63–67] we sought articles that reported environmental conditions (eg, dry bulb temperature, wet bulb globe temperature, relative humidity) on the day(s) that clinical observations were made. Fourth, because few publications have evaluated hyperthermia and EHS during open water swimming or cycling (eg, as an individual sport or as part of a triathlon event), we sought to identify randomized, controlled investigations regarding the effect of water temperature (swimming) and wind speed (cycling) on body heat balance and core temperature. Fifth, we evaluated the recognition of hyperthermia and EHS by professional organizations and expert panels in published position statements and consensus reports.

Definitions

To clearly describe the medical conditions presented in this review, we have employed definitions published by the International Olympic Committee[68] and other respected sources. The term "medical encounter" is defined as an interaction between the medical team and a race participant that requires medical assistance or evaluation and which occurred between the start of the event and 24 hours after the event.[42] The term "medical team" refers to the officially designated team of medical staff (ie, physicians, first aid providers, registered nurses, physiotherapists, athletic trainers) responsible for the medical care during the event, typically led by a medical director.[42] The "recognition" of hyperthermia and EHS by the medical team refers to an a priori medical staff plan, reports from previous years, or on-site diagnosis. Hyperthermia is defined in the present review as a mild-to-moderate elevation of internal body temperature (eg, 37.7 to 39.4°C [100 to 103°F]) resulting from exercise;[69,70] in trained and heat acclimatized athletes, this mild-to-moderate temperature increase is not dangerous, but it indicates that metabolic heat has been stored in bodily organs and fluids.[71] EHS involves severe whole-body hyperthermia that exceeds 40°C[6,8,14,29,41,72,73] and occurs when a healthy thermoregulatory system is either overloaded by exercise-induced metabolic heat production[74] or when thermoregulation "fails" due to physiological dysfunction of central or peripheral effector responses.[75]

The following four definitions[76] are relevant to hyperthermia and EHS because they refer to heat transfer within the body and at the skin surface. First, heat exchange by convection occurs via the circulation (ie, heat moves from deep organs to the periphery in blood), as well as between the skin and surrounding cool air or water.[77] The temperature gradient between skin and its environment plus the speed of fluid movement determines the amount of heat absorbed or donated by a given mass of air or water. Second, conduction refers to heat transmission from the skin to a solid object (eg, clothing, shoes) or a fluid (eg, water). During running and cycling, conduction accounts for only about 2% of energy transfer. During open water swimming, however, conduction and convection are the primary avenues of heat transfer, and may involve heat gain or loss depending on the temperature gradient between the skin and water.[76,78] The thermal conductivity of water is 24 times that of air; thus, water has a much greater potential for heat transfer, into or out of the body, than air.[11,79] Third, radiation is defined as the transmission of energy in the form of waves. Solar energy from direct sunlight and radiant heat from the ground are relevant examples for outdoor sports. Fourth, evaporation occurs when sweat or water changes its physical state, from a liquid to a gas; this change of state removes energy from the skin and it cools. In a hot-dry environment, evaporation accounts for 85–90% of all heat dissipation during exercise.[80]

Results

Using the keywords and inclusion criteria described above, the manual screenings of 1192 article titles and abstracts and subsequent reviews of full-length pdf versions identified the 80 articles that were acceptable for inclusion in tables and figures. The initial 4 tables indicate if hyperthermia or EHS was recognized by medical personnel who provided care at sport and mass participation events. If "yes" a + symbol appears in that cell, and if "no" the cell is open (blank). This recognition by medical staff was due either to an a priori medical staff plan, reports from previous years, or on-site diagnosis. Column 1 of these tables also includes the number of athlete hyperthermia and EHS medical encounters, if reported by the authors. In some field studies, the potential harm to athletes of a high core body temperature was described, but the term "hyperthermia" was not used; these cases are annotated by footnotes.

Across the 18 featured studies in Table 1, hyperthermia was recognized by medical personnel in 76.5% of endurance running studies, whereas EHS was recognized in 58.8% of these articles; 3 studies (17.6%) recognized neither hyperthermia nor EHS.

Table 1 Medical Team Recognition of Hyperthermia and Exertional Heatstroke in Field Studies That Were Conducted at Outdoor Endurance Running Events

Endurance Running Events	Ambient Conditions During the Event[a,b]	Hyperthermia[c]	Exertional Heatstroke[c]	Source
42.2km road marathon (1982–1994)	12 y DB range, - 4.4 to 20.0°C with humidity of 32 to 100%rh	+	+	[81]
21.1km road race (32 heatstroke cases, 2005–2012)	8 y DB range, 9.4 to 21.7°C with humidity of 57 to 81%rh	+[d]	+	[82]
16.1km road race (1 case of hyperthermia, 1998 to 2004)	6 y dew point range, 6.1 to 17.2°C; (October)	+		[57]
21km and 56km road races (2008–2011)	4 y DB range, 11.5 to 18.2°C with humidity of 77 to 93%rh	+	+	[67]
16.1km road race (29 heatstroke cases, 2017–2019)	3 y DB range, 10.7 to 21.6°C with humidity of 54.4 to 91.3%rh; WBGT, 10.9 to 18.7°C	+	+	[50]
42.2km road marathon (2018)	DB range, 13.9 to 15.6°C with rain	+		[83]
42.2km and 21.1km road races (26 heatstroke cases, 2014–2016)	3 y average annual DB range, 12.2 to 22.2°C with humidity of 73 to 84%rh	+	+	[84]
80km run, rugged terrain (1990)	DB range, 14 to 25°C with humidity of 24 to 44%rh			[85]
21.1km and 56km road races (2008–2015)	8 y range of WBGT, 13.4 to 18.4°C with humidity of 77 to 93%rh			[86]
42.2km road marathon (51 heatstroke cases, 2015–2019)	Across 5 y, all heatstroke cases occurred in the WBGT range of 17 to 22°C	+[d]	+	[54]
90km ultramarathon (7 heatstroke cases, 2014–2019)	6 y DB range, 17.3 to 23.1°C with humidity of 37 to 68%rh; WBGT, 13.8 to 16.8°C	+	+	[53]
11.3km summer road race (180 heatstroke cases, 2012–2019)	Across 8y, all heatstroke cases occurred in the WBGT range of 19.8 to 26.7°C	+ [d]	+	[87]
Nineteen 10km road races (142 cases of hyperthermia and 94 heatstroke cases, 2011–2017)	7 y DB range, 16.7 to 27.8°C with humidity of 38 to 100%rh	+	+	[55]
11.3km summer road race (274 heatstroke cases, 1984–2011)	DB range (all years), 17.2 to 27.7°C with humidity of 47 to 98%rh	+[d]	+	[56]
World 42.2km marathon championships (2019)	DB range, 29.3 to 32.7°C with humidity of 46 to 81%rh	+[d]		[88]
219km, 5-d ultramarathon (2010)	DB range, 32 to 37°C			[89]
Four 7-d, 240km desert and wilderness races (2005–2006)	2 y DB Range, 10 to 48°C	+		[90]
241km, 7-d desert ultramarathon (2009)	Daytime DB, >38°C; night DB, ~0°C		+ [e]	[91]

Notes: [a]Because various environmental indices[92] were reported in these studies (column 2), they are rank ordered approximately from low to high environmental heat stress; [b], meteorological indices are expressed as dry bulb temperature (DB), wet bulb globe temperature (WBGT), dew point, and percent relative humidity (% rh); [c], hyperthermia and exertional heatstroke are defined in the Methods section above and represent a sample of all other illnesses recognized in each publication; [d], the term "hyperthermia" did not appear in these articles but increased core body temperature (ie, >40°C) was recognized; [e], a diagnosis of exertional heatstroke requires confirmation of hyperthermia, but the term "hyperthermia" did not appear in this publication; **+**, this classification was recognized due to an a priori medical staff plan, reports from previous years, or on-site diagnosis; an open (blank) cell in columns 3 and 4 indicates that hyperthermia or EHS was not discussed in the article.

Table 2 Medical Team Recognition of Hyperthermia and Exertional Heatstroke in Field Studies That Were Conducted at Outdoor Triathlon Events

Triathlon Events	Ambient Conditions During the Event [a]	Hyperthermia[b]	Exertional Heatstroke[b]	Source
Multiple triathlon events (10 cases of hyperthermia and 16 heatstroke cases, 2006–2015)	Average DB range, 8.6 to 27.2°C with average humidity range of 60 to 80%rh	+	+	[60]
Medium to long-distance triathlons: 1.5 to 3.9km swim, 40 to 180.3km cycle, 10 to 42.2km run (no cases of heatstroke or hyperthermia as assessed in the axillary region, 2017–2019) [c]	3 y DB range, 9 to 29°C with humidity range of 45 to 100%rh	+	+	[93]
Ironman triathlon: 3.9km swim, 180.2km cycling, and 42.2km run. (1 case of hyperthermia, 2014)	Swimming DB, 17°C with 82% rh; cycling, 20°C, 84%rh; running, 20°C, 82%rh	+		[94]
Deaths and cardiac arrests during USA Triathlon outdoor races (2 heatstroke deaths, 1985–2016)	Average air temperature was 21.9°C (range, 6.7 to 28.9 °C); humidity NR.	+	+	[95]
Eleven triathlon events in the United Kingdom (12 cases of heatstroke, 2010–2016)	NR	+[d]	+	[96]
Half Ironman triathlon: 1.9km swim, 90.1km bike, 21.1km run (no cases of hyperthermia or heatstroke, 2016)	Swimming DB, 22°C with 98% rh; cycling, 25°C, 89%rh; running, 26°C, 84%rh			[43]
Two sprint triathlon events: A, 500m swim, 20km cycle, 5km run; B, 500m swim, 14km cycle, 4km run. (12 cases of hyperthermia, 3 cases of heatstroke, 2006–2007)	DB range (A, 18.3 to 42.1°C; B, 23.0 to 38.5°C) with humidity of (A, 26%rh; B, 38%rh)	+	+	[59]

Notes: [a]Studies are rank ordered approximately from low to high environmental heat stress (column 2); [b], hyperthermia and exertional heatstroke represent a sample of all other illnesses recognized in each publication; [c], axillary temperature does not accurately represent central body temperature; [d], the term "hyperthermia" did not appear in this article but an increased core body temperature was recognized; **+**, this classification was recognized due to an a priori medical staff plan, reports from previous years, or on-site diagnosis; an open (blank) cell in columns 3 and 4 indicates that hyperthermia or EHS was not discussed in the article.
Abbreviations: DB, air dry bulb temperature; NR, data not reported.

Table 2 presents the results of 7 field studies that were conducted at triathlon competitions. Hyperthermia was recognized by medical personnel in 85.7% of studies, whereas EHS was recognized in 71.4% of these articles; only 1 study (14.3%) recognized neither hyperthermia nor EHS.

Table 3 summarizes information from outdoor cycling studies which allow comparisons to the articles presented in Tables 1 and 2. Only 3 of 20 cycling studies (15.0%) recognized both hyperthermia and EHS, confirming that cycling epidemiology is different from running and triathlon events. Few of the studies in Table 3 reported ambient conditions during the event (column 2, n = 4).

Table 3 Few Medical Teams Reported Hyperthermia and Heatstroke in 20 Road and off-Road Cycling Studies

Cyclists and Events (year)	Ambient Conditions During the Event[a]	Hyperthermia[b]	Exertional Heatstroke[b]	Source
Off-road recreational cyclists (1990)	NR			[97]
Elite off-road cyclists (1992 season)	NR			[98]
5-event off-road national championship (1994)	NR			[99]
Recreational cyclists during a 6-day, 549km road tour (1994)	NR			[100]
Amateur & professional cyclists, 7 mountain bike races (1994–1998)	NR			[101]
3 off-road cross-country and downhill races (1995)	NR			[102]
Recreational cyclists during an 8-day, 880km road tour (1 case of heatstroke, 1996)	Range of air temperatures: 15.6 to 37.8°C; humidity NR	+[c]	+	[40]

(*Continued*)

Table 3 (Continued).

Cyclists and Events (year)	Ambient Conditions During the Event[a]	Hyperthermia[b]	Exertional Heatstroke[b]	Source
Mass participation 67.6km Five Boro Bike Tour (1996)	NR			[103]
Recreational & competitive mountain bikers (1998–2000 seasons)	NR			[104]
Elite road cyclists during training and competition (2002–2009)	NR			[105]
Non-professional competitive road cyclists (2002 and 2012 seasons)	NR			[106]
Mass participation 130 or 200km road races (2006–2011)	Air temperature annual average 17–24°C and maximum 24–31°C; relative humidity annual average 63–77%rh			[107]
7-stage mountain bike race (2010)	NR			[108]
Elite cyclists during the Tour de France (2010–2017)	NR			[109]
109km recreational mass-participation event (21 hyperthermia cases, heatstroke NR, 2012–2014)	WBGT range, all years: 12.3 to 19.3°C	+	+	[52]
Recreational 7-day, 563km bicycle tour (2013 and 2014)	NR			[110]
Elite cyclists during a multi-day road race (2015)	NR			[111]
World Road Cycling Finals: Individual and Team (8 cases of heatstroke, 2016)	Average dry bulb temperature 36.9°C; humidity, 24.6%rh; WBGT, 27.1°C	+	+	[58]
USA Cycling road races (2016 season)	NR			[112]
Professional road cyclists' season (2019)	NR			[113]

Notes: [a]Few epidemiological studies conducted at cycling events reported environmental conditions; [b]Hyperthermia and exertional heatstroke represent a small number of all medical encounters at these cycling events; [c]The term "hyperthermia" did not appear in this article but increased core body temperature was acknowledged; **+**, recognized due to an a priori medical staff plan, reports from previous years, or on-site diagnosis; an open (blank) cell in columns 3 and 4 indicates that hyperthermia or EHS was not discussed in the article.
Abbreviations: NR, data not reported; %rh, relative humidity; WBGT, wet bulb globe temperature.

Figure 1 is reproduced from the laboratory research of Saunders et al[114] with the permission of the publisher. This graph is included to illustrate the relationship between increasing air velocity and internal heat storage, during controlled cycle ergometer exercise in a hot environment. Specifically, heat dissipation from the

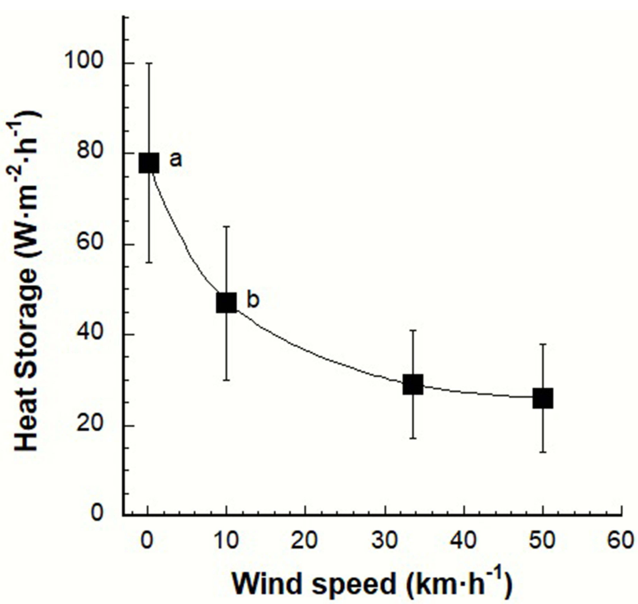

Figure 1 The effect of 4 air velocities on the internal heat storage of 9 men who exercised for 2 h on a stationary cycle ergometer in a controlled hot environment (33.0°C, 59%rh), as reported by Saunders et al.[114] During these 4 repeated experiments, subjects consumed fluids which replaced 58–61% of sweat losses. Redrawn with the permission of the publisher John Wiley and Sons, © 2005 Scandinavian Physiological Society from Saunders AG, Dugas JP, Tucker R, Lambert MI, Noakes TD. The effects of different air velocities on heat storage and body temperature in humans cycling in a hot, humid environment. Acta Physiol Scand. 2005;183(3):241–255.[114] [a]Significantly different from all other data points (P < 0.05 to 0.005); [b]Significantly different from 50 km h^{-1} (P < 0.05).

skin surface increased at higher air velocities (ie, primarily via increased evaporation) and heat storage decreased.

Table 4 presents the 5 open water swimming field studies we identified during extensive manual searches of the literature. Only one of these publications (20.0%) recognized hyperthermia and none (0%) mentioned EHS. We identified so few field studies in Tables 4 that 5 was created to summarize the information from relevant review articles and sport governing body manuals. Contrary to the findings of the studies in Table 4, the potential for hyperthermia during open water swimming was discussed in 92.3% of these articles and manuals in Table 5, whereas EHS was acknowledged in 53.8%.

Figure 2 provides information that clarifies the effect of water temperature on deep body temperature (eg, hypothermia or hyperthermia) in controlled swimming experiments, at different exercise intensities. The vertical dashed line depicts the maximum water temperature (31°C, 87.8°F measured at a depth of 40 cm) for open water swimming competitions that is allowed by World Aquatics, the international sport governing body.[125,129] This figure is original and unique to the present review.

Table 4 Hyperthermia and Exertional Heatstroke, as Reported in 5 Open Water Swimming Field Studies

Swimmers and Event (Year)	Research Study Focus	Ambient Conditions		Hyperthermia	Exertional Heatstroke	Source
		Air	Water			
Elite swimmers competing at the Federation International de Natation (FINA) Open Water Swimming World Championships[a] (2009)	To record and analyze illnesses and injuries	NR	NR			[115]
Elite athletes competing at three FINA Open Water Swimming World Championships[a] (2009, 2013, 2015)	To assess the frequency and characteristics of injuries / illnesses prior to and during events	NR	NR			[116]
Novice, recreational, experienced and master's swimmers competing in open water and triathlon swim segment competitions (2009–2019)	To review characteristics of deaths in open water events in Brazil	NR	NR	+[b]		[117]
Elite athletes competing at the FINA Open Water Swimming World Championships[a] (2013)	To examine injuries among aquatic disciplines, before and during events	NR	NR			[118]
Elite and amateur athletes competing at the FINA Open Water Swimming World Championships[a] (2019)	To assess the frequency and characteristics of injuries and illnesses	NR	NR			[119]

Notes: [a]Other aquatic sports also were contested; [b]the term "hyperthermia" did not appear in this article, but the risk of increased core body temperature was acknowledged; **+**, recognized as a medical condition that occurs in open water swimming; an open (blank) cell in columns 5 and 6 indicates that hyperthermia or EHS was not discussed in the article.
Abbreviation: NR, data not reported.

Table 5 The Risk of Hyperthermia and Exertional Heatstroke for Open Water Swimmers, as Discussed in Review Articles and Sport Governing Body Manuals

Relevant Topics in Review Articles and Manuals	Hyperthermia	Exertional Heatstroke	Source
Hyperthermia in open water swimming, triathlon, and other sports (2012)	+		[120]
EHS risk during long-distance open water swimming (2013)	+	+	[121]
Open water swimming regulations that limit maximum water temperature (2014)	+ [a]	+	[122]
Physiology of open water swimming in warm and cold water (2014)	+		[48]
Hypothetical mechanisms and etiologies of swimming-related deaths in open water swimming and triathlons (2016)	+		[123]
Medical considerations for open water swimming (2019)	+	+	[124]
Fédération International de Natation (FINA) [b] Open Water Swimming Manual (2020)	+		[125]
Analysis of existing literature regarding heat injury in open water swimming, to mitigate risk and develop treatment options (2021)	+	+	[126]

(*Continued*)

Table 5 (Continued).

Relevant Topics in Review Articles and Manuals	Hyperthermia	Exertional Heatstroke	Source
Hyperthermia during open water swimming in warm water (2021)	+[a]		[127]
Medical and physiological considerations for open water swimming, pool swimming, and diving (2021)	+		[128]
Hyperthermia and EHS in 13 sports including triathlons and open water swimming (2023)	+[a]	+	[60]
World Aquatics [b] Competition Regulations (2024)		+[c]	[129]
Mechanisms of death in open water and in swimming pools (2024)	+	+	[130]

Notes: Because these publications did not focus on a specific open water swimming event, ambient conditions were not reported. [a]The term "hyperthermia" did not appear in this article but heat gain and increased core body temperature were acknowledged; [b]World Aquatics (formerly known as FINA) is the international organization that administers competitions in water sports; [c]A diagnosis of exertional heatstroke requires confirmation of hyperthermia, but the term "hyperthermia" did not appear in this publication; **+**, recognized as a medical condition that occurs in open water swimming; an open (blank) cell in columns 2 and 3 indicates that hyperthermia or EHS was not discussed in the article.

Table 6 shows that hyperthermia was recognized in 63.6%, whereas EHS was recognized in 81.8%, of the position statements and reports published by professional sports medicine organizations and consensus writing groups between 2012 and 2023. Only two of these publications (18.2%) did not recognize hyperthermia or EHS.

Discussion

The present review focuses on the available evidence regarding the recognition of hyperthermia and EHS by medical teams at outdoor running, cycling, open water swimming, and triathlon events. Prior to an exhaustive literature search, we hypothesized that this effort would identify event-specific differences which are not widely recognized. Indeed, Tables 1–4 demonstrate that event-specific differences exist in the available literature. For example, Tables 1 and 2 establish that hyperthermia and EHS are recognized by the majority of medical teams at endurance running and triathlon events (range, 58.8 to 85.7%), whereas little recognition is given to hyperthermia and EHS by medical teams at cycling

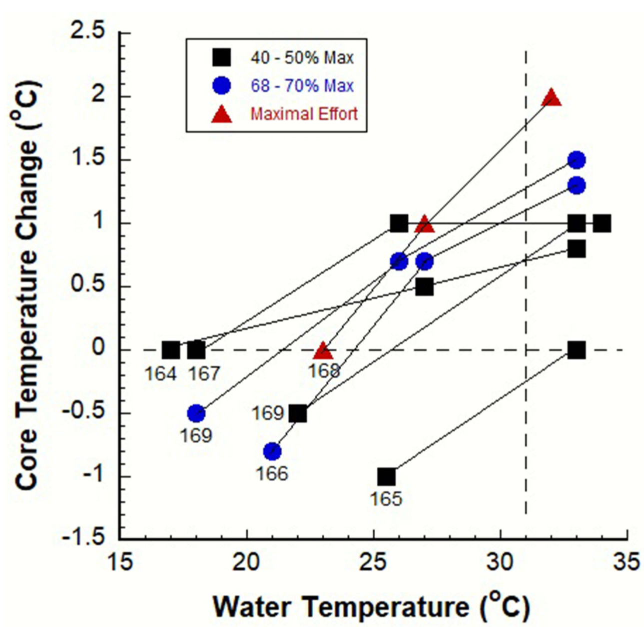

Figure 2 The effect of water temperature on internal body temperature during 20–80 min of swimming performed during 6 controlled research studies.[131–136] Each study is identified in this graph by its reference citation number. These experiments involved a range of exercise intensities (see inset box) and various exercise modes (ie, swimming flume, swimming pool, or tethered to a swim ergometer). The horizontal dashed line represents the border between net heat loss and net heat gain during exercise. The vertical dashed line depicts the maximum water temperature (31°C, 87.8°F) for open water swimming competitions that is allowed by the international governing body World Aquatics.[125,129]

Table 6 Recognition of Hyperthermia and Exertional Heatstroke in Position Statements and Reports of Professional Sports Medicine Organizations and Consensus Writing Groups

Organization or Writing Group	Activities Described[a]	Hyperthermia[b]	Exertional Heatstroke[b]	Source
National Athletic Trainers' Association, preventing sudden death in sports (2012)	All organized high school sports	+	+	[63]
FINA Expert Working Group, consensus statement on injury/illness surveillance in aquatic sports (2015)	Aquatic sports[c]			[137]
National Athletic Trainers' Association, exertional heat illness position statement (2015)	Multiple individual and team sports	+	+	[6]
Wilderness Medical Society, heat illness clinical guidelines (2019)	Multiple outdoor activities	+	+	[12]
Endurance Race Medical Working Group, terms and methods consensus statement (2019)	Mass participation endurance sports		+[d]	[42]
International Olympic Committee, sports injury/illness surveillance methods consensus statement (2020)	Multiple individual and team sports		+[d]	[68]
Competitive Cycling Working Group, methods for recording and reporting epidemiological data (2021)	Cyclists			[138]
Marine Corps Marathon, algorithms for triage and treatment of collapsed runners (2021)	Marathon runners	+	+	[139]
World Triathlon, guidelines for exertional heat illness prevention (2021)	Triathletes	+ [e]	+	[140]
International Olympic Committee, regulations and recommendations for events in the heat (2022)	Multiple individual and team sports	+	+	[7]
American College of Sports Medicine, exertional heat illness consensus statement (2023)	Sports, military, and industrial activities	+	+	[8]

Notes: [a]These articles are included in Table 6 because they considered (one or more of) running, cycling, swimming, or triathlon events; [b], hyperthermia and exertional heatstroke represent a sample of all other illnesses recognized in each publication; [c], including open water swimming; [d], a diagnosis of exertional heatstroke requires confirmation of hyperthermia, but the term "hyperthermia" did not appear in this publication; [e], the term "high core temperature" is discussed but the term "hyperthermia" does not appear in this article; **+**, recognized as a medical condition that occurs in sport; an open (blank) cell in columns 2 and 3 indicates that hyperthermia or EHS was not discussed in the article.

and open water swimming events (Tables 3 and 4; range, 0 to 20%). Thus, the following paragraphs consider the unique features of body heat balance and temperature regulation during these endurance events.

The factors that influence metabolic heat production within contracting muscles, heat transport via blood to internal organs or to the skin, heat transfer to or from the skin, and evaporation of sweat from the skin surface (ie, to dissipate heat to the environment) are described by the following heat balance equation:[92,141]

$$S = M - (W + C + R + K + E + Resp) \quad (1)$$

In this equation, S refers to the rate of heat storage within the body, M is the rate of heat production via muscle metabolism, and W is the work rate (ie, which considers whether energy is released as heat within the body, the mode of exercise, and whether mechanical energy is applied to an external object such as a bicycle or stairs). The following terms refer to heat transfer at the skin surface: C is convection, R is radiation, K is conduction, E is evaporation of sweat or water from the skin (ie, a change of state from liquid to gas), and Resp refers to heat transmission via C and E from the respiratory tract. Energy exchange is typically expressed in terms of Watts but may be conveyed as kilocalories per hour or kilojoules per minute.[141]

During exercise, the brain employs two primary physiological effector responses to maintain a stable internal body temperature (ie, the state in which the rate of metabolic heat production equals the rate of heat loss to the environment; S = 0). The first involves evaporation of sweat and the second involves dilation of superficial cutaneous veins which results in increased skin blood flow; this latter response transports heat from the body core to skin via convection.[141] When the skin is moist, the primary role of increased skin blood flow is to deliver the heat necessary to evaporate sweat. In the absence of sweating (ie, dry skin) or when air water vapor is high (ie, reducing evaporation), the main effect of increased skin blood flow is to increase skin temperature and promote heat loss via convection and radiation. An important detrimental outcome of increased skin blood flow is that central blood volume is diminished. This redistribution of blood limits cardiac filling, stroke volume, and cardiac output,[4] thereby reducing endurance performance in hot environments;[142,143] it also increases the risk of hyperthermia and exertional heat illness.[8,144–147]

Event & Environment Specificity

Our extensive literature search revealed no previous review article that compared either hyperthermia or EHS at endurance running, triathlon, cycling, and open water field studies. The following paragraphs delineate our findings, and provide an analysis of body heat balance and thermoregulation during each of these sports.

As shown in column 1 of Table 1, hyperthermia or EHS cases were recognized in the majority of outdoor endurance running events (52.9 and 58.8%, respectively), across a range of ambient conditions. This indicates that metabolic heat production in these cases exceeded heat transfer from the body surface to the environment. A systematic review of 33 studies by Gamage et al[62] supports this observation, in that distance running was identified as the organized sport with the highest rate (per 100 participants) of exertional heat illnesses.

A majority of triathlon medical teams (71.4%) recognized both hyperthermia and EHS (Table 2, column 1). This finding in triathlon events may be somewhat greater than in running events (Table 1) because of differences in running economy, expressed as the energy cost of running a distance of 1 km (mL $O_2 \cdot kg^{-1} \cdot km^{-1}$).[148] This quantity has been measured in triathletes during both isolated running and "triathlon running" (ie, after swimming and cycling segments). In highly trained triathletes, it is generally reported that the energy cost measured at the end of an Olympic distance triathlon is higher by approximately 10% when compared with an isolated run covering the same distance.[149,150] The theoretical mechanisms that have been proposed to explain this deterioration of running economy in triathlon events include higher oxygen consumption of the respiratory muscles, shifts of circulating fluids (eg, to the extremities), and altered running biomechanics.[149–152]

With regard to outdoor cycling, Table 3 prompts a considerably different conclusion regarding internal heat storage (S). Only 3 of the 20 field studies (15.0%) recognized hyperthermia and EHS during road and off-road events; these involved a spectrum of participant capabilities that ranged from recreational to elite. We propose that this small percentage of hyperthermia and EHS is an indication of the great amount of heat that is dissipated during cycling because the airflow across the skin surface is considerably greater than during running.[153,154] Especially on flat terrains, this rapid air movement facilitates cooling via evaporation and convection, reducing the risk of hyperthermia.[155] This phenomenon is illustrated in Figure 1, which presents data from controlled laboratory experiments involving habitually active, moderately fit men who exercised on a stationary cycle ergometer in a controlled 33°C, 59%rh environment. In combination with additional physiological and perceptual measurements, the authors of this study[114] concluded that airflow greater than 10 $km \cdot h^{-1}$ contributed to reduced physiological and perceptual strain; their calculations indicated that the reduced heat storage was primarily due to enhanced evaporation in this hot environment. Employing a similar repeated measures experimental design (30°C, 50%rh ambient conditions; cycle ergometer exercise), Otani et al[156] reported that test subject thermoregulatory (ie, rectal temperature, heat storage), cardiovascular (ie, heart rate, cutaneous vascular conductance), and perceptual (ie, rating of perceived exertion, thermal sensation) strain decreased, whereas the time to exhaustion increased, as air velocity intensified from 0 to 30 $km \cdot h^{-1}$. The convective heat loss described in these two studies, however, would diminish during outdoor up-hill cycling (ie, as ground speed decreases) or when the air temperature exceeds skin temperature.[7]

Thermal conductivity influences heat storage (Eq. 1 above) in swimmers as they move through water, but affects runners and cyclists minimally as they move through air. The thermal conductivity of water is 24 times that of air.[11] This translates into a great potential for heat transfer (ie, relative to air) into or out of the body, depending on the water-to-skin thermal gradient and the body surface area that is exposed.[76,79] Although none of the field studies in Table 4 described air or water temperatures, we propose that the thermal conductivity of cool water resulted in the scarcity of hyperthermia and EHS among open water swimmers. Figure 2 supports this proposition by depicting the relationship between water temperature and internal body temperature, as reported in 6 controlled research studies. Considering the horizontal dashed line in Figure 2, no cases of net heat gain (and all cases of net heat loss) occurred when the water temperature was ≤26°C (78.8°F), across a range of exercise durations and intensities. The vertical dashed line in Figure 2 is relevant because it depicts the maximum water temperature (31°C, 87.8°F) allowed by World Aquatics[125,129] during open water swimming events in 2024. The purpose of this regulation is to minimize the risk of hyperthermia when open water swimming competitions are conducted in warm water;[122] it requires event organizers to either shorten or reschedule a race at a time that is likely to present a more favorable environment.[126,129] Despite the fact that the field studies in Table 4 provide little evidence of hyperthermia and EHS at outdoor swimming competitions, multiple journal review articles, manuals published by sport governing bodies (Table 5), and online web sites have described the risk of hyperthermia and/or EHS during open water swimming events in warm water.[119,121,122,126,127] We interpret these differences between Tables 4 and 5 to mean that the World Aquatics maximum water temperature (31°C) regulation[129] is valid and that it was employed during the 5 events summarized in Table 4.

Data from multiple endurance sport studies[143,157] indicate that a body water deficit impairs temperature regulation by reducing sweat rate and skin blood flow.[158–161] This detrimental role of dehydration in body temperature regulation has been consistently demonstrated. For each 1% deficit of body weight, rectal temperature increases 0.2–0.4°C (0.36–0.72°F) during controlled laboratory trials.[158,161–165] Thus, a body water deficit increases the risk of hyperthermia and EHS[163,165,166] and this risk is influenced by the unique exercise mode and rehydration regulations of each sport. For example, the transmission of stored body heat to cool air (eg, ambient <20°C) is largely accomplished during high-speed cycling (ie, generating rapid air movement across the skin surface) via convection and radiation – forms of dry heat loss[4,155] that do not result in a body water deficit. We propose that this explains, in part, the scarcity of hyperthermia and EHS in Table 3. However, during high-speed cycling in warm and hot environments (eg, ambient >20°C), evaporation of sweat becomes the predominant avenue of heat loss[114,156] and dehydration progressively influences the rate of heat storage within internal organs. Furthermore, we propose that fluid availability influences the risk of hyperthermia and EHS. During endurance running, fluid intake is limited by the number of aid stations along the race course or by the size of a water bottle in hand. Open water swimmers can expect to be in the water for 2–4 hours during short course events (eg, up to 10 km) and 6–8 hours at distances >25 km; this means that they must rely on their support team to provide fluids from a watercraft.[125] In contrast, cyclists can rehydrate whenever desired, because water bottles are carried in jersey pockets or are attached to the bicycle frame.[142] These event-specific differences influence the hyperthermia and EHS which occur during outdoor endurance events (Tables 1–3).

Previous publications[56,63–67] have suggested that hot environments influence the types and prevalence of illnesses observed at outdoor athletic competitions and recreational endurance events. Prior to our extensive literature search, we anticipated that this concept would be supported by the present data base. However, we were unable to draw conclusions regarding a systematic effect of increasing environmental heat stress on hyperthermia and EHS. This was due to the wide variety of meteorological indices (eg, dry bulb temperature, dew point, WBGT) in Tables 1 and 2 and few reports of ambient conditions in Tables 3 and 4.

Position Statements and Consensus Reports

The second purpose of this review is to clarify the available evidence regarding the recognition of hyperthermia and EHS by professional sports medicine organizations and writing groups in their position statements and consensus documents. Table 6 summarizes 11 such publications and shows that 63.6% of these articles recognized both hyperthermia and EHS. However, the articles, which focused solely on aquatic sports and competitive cycling,[137,138] were the only two that recognized neither hyperthermia nor EHS. This finding agrees with field studies of cycling and open water swimming which involved considerably fewer cases of hyperthermia and EHS (column 1, Tables 3 and 4) than studies that involved endurance running and triathlons (column 1, Tables 1 and 2). In fact, any prolonged activity that involves a large metabolic heat production concurrent with diminished heat transfer to the environment (eg, insulative gear or uniform, air > skin temperature, low air velocity, relative humidity >75%, high solar radiation) may result in hyperthermia or EHS.[7,29,167] Therefore, we recommend that future position statements, consensus reports, and field studies recognize both hyperthermia and EHS, including their inclusion in a priori medical planning and pre-event medical staff briefings.

This recommendation supports medical diagnosis, which begins with an onsite evaluation and history, and then rules out life-threatening disorders such as EHS.[6,139,146,168]

Conclusion

The first purpose of the present review was to clarify the available evidence regarding the recognition of hyperthermia and EHS by medical teams at outdoor endurance races and mass participation events. At endurance running events, the majority of medical teams recognized hyperthermia and EHS (76.5 and 58.8%, respectively). Similarly, the majority of medical teams at triathlon events recognized hyperthermia and EHS (85.7 and 71.4%, respectively). In contrast, little recognition was given to these medical conditions (both hyperthermia and EHS, 15.0%) by the medical teams covering cycling events and open water swimming events (hyperthermia, 20.0, and EHS, 0%). Also, few authors of cycling field studies and no authors of open water field studies described the ambient conditions (eg, air and water temperature) during those competitions. These event-specific differences arise from complex, dynamic interactions of multiple factors. The second purpose of this review was to clarify the recognition of hyperthermia and EHS by professional organizations and writing groups in their position statements and consensus documents. Based on our findings, we recommend that sport governing bodies and on-site medical teams consider the sport-specific incidence of hyperthermia and EHS, to optimize pre-race safety advice provided to athletes, the planning and allocating of medical resources (eg, staff number and skill sets, whole-body cooling supplies), and managing patient care.

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