CLINICAL SCIENCES

Exertional Heat Stroke at the Boston Marathon: Demographics and the Environment

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[1]Department of Othopaedic Surgery, Brigham and Women's Hospital, Boston, MA; [2]Harvard Medical School, Boston, MA; [3]International Institute for Race Medicine, Boston, MA; [4]Boston Athletic Association, Boston, MA; [5]Maine Medical Partners MaineHealth Cardiology, Scarborough, ME; [6]Tufts University School of Medicine, Boston, MA; [7]Division of Sports Medicine, Boston Children's Hospital, Boston, MA; [8]Department of Emergency Medicine, Boston University School of Medicine, Boston, MA; and [9]Cardiovascular Performance Program, Massachusetts General Hospital, Boston, MA

ABSTRACT

BRESLOW, R. G., J. E. COLLINS, C. TROYANOS, M. C. COHEN, P. D'HEMECOURT, K. S. DYER, and A. BAGGISH. Exertional Heat Stroke at the Boston Marathon: Demographics and the Environment. *Med. Sci. Sports Exerc.*, Vol. 53, No. 9, pp. 1818–1825, 2021. **Purpose:** This study aimed to assess associations between exertional heat stroke (EHS) and sex, age, prior performance, and environmental conditions, and report on resources needed for EHS cases at the Boston Marathon. **Methods:** We analyzed participant characteristics, environmental data, and EHS medical encounters during the 2015–2019 Boston Marathon races. **Results:** Among 136,161 starters, there was an incidence of 3.7 EHS cases per 10,000 starters (95% confidence interval, 2.8–4.9), representing 0.5% of all medical encounters. There were significant associations between sex and age ($P < 0.0001$), sex and start wave ($P < 0.0001$), and age group and start wave ($P < 0.0001$). Sex was not significantly associated with increased EHS incidence; however, age younger than 30 yr and assignment to the first two start waves were. All cases occurred at races with average wet bulb globe temperatures of 17°C–20°C. There was a linear correlation between EHS incidence and greater increases in wet bulb globe temperature from start to peak ($R^2 = 0.7688$). A majority of cases (37; 72.5%) were race finishers; nonfinishers all presented after mile 18. Most were triaged 3–4 h after starting, and all were treated with ice water immersion. Treatment times were prolonged (mean (SD), 78.1 (47.5) min; range, 15–190 min); 29.4% (15 cases) developed posttreatment hypothermia, and 35.3% (18 cases) were given intravenous fluids. Most (31 cases; 64.6%) were discharged directly, although 16 cases (33.3%) required hospital transport. There were no fatalities. **Conclusions:** Younger and faster runners are at higher risk for EHS at the Boston Marathon. Greater increases in heat stress from start to peak during a marathon may exacerbate risk. EHS encounters comprise a small percentage of race-day medical encounters but require extensive resources and warrant risk mitigation efforts. **Key Words:** RACE MEDICINE, EVENT MEDICAL MANAGEMENT, HEAT ILLNESS, RUNNING

Exertional heat stroke (EHS) is a serious, life-threatening medical complication of road races. EHS occurs when metabolic heat production exceeds the body's ability to dissipate that heat, leading to dangerous elevations in core body temperature (1). EHS has previously been reported both at shorter-distance races (2–5) and at longer endurance events, including half-marathon and marathon races (6–12). EHS encounters require immediate on-site time- and labor-intensive treatment to prevent multiorgan system failure and death. In addition, effective management of EHS requires community and health care resources. This includes emergency medical services for ambulance transport and hospital facilities with critical care capability. Accordingly, race organizers and medical directors rely on predictors of risk to anticipate staffing needs and resource allocation.

Some studies have shown a positive correlation between warm, humid weather and an increased incidence of all medical complications (13,14), and specifically EHS encounters (2). Others report EHS cases even in seemingly optimal weather conditions (5,6,15), suggesting weather may not be the only factor. Furthermore, although increases in heat stress during a race may increase the risk of EHS, they cannot predict casualties before a race starts. Because of this, investigators have started to identify demographic characteristics of runners that may predict EHS risk, for example, gender and pacing strategies (4,6). However, to truly optimize medical planning, inform standards of care, and mitigate strain on the surrounding community, further exploration of the predictive power for EHS risk of these and other demographic characteristics is needed. In particular, life-threatening events like EHS at large-scale urban marathons with thousands of participants,

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such as the World Marathon Majors, pose significant challenges to participant and community safety given the extensive resources needed to orchestrate effective race medical operations.

One such large-scale event, the Boston Marathon, provides a prime opportunity to study EHS risk. Boston is one of the only marathons to require qualifying times for entry for most participants, yielding a high density of faster-than-average participants, and is frequently characterized by extreme weather conditions, including warm and humid days. Therefore, we aimed to determine if there was an association between EHS and sex, age, and prior race performance by analyzing participant data from the Boston Athletic Association (BAA) over the past 5 yr. We also examined the relationship between EHS incidence and weather conditions by race year during this time period to explore the contribution of environmental conditions. Finally, we describe the most common timing and location of EHS presentation at the Boston Marathon, as well as the staffing and resources needed, and report this information to help guide planning for similar events.

METHODS

Overview. We analyzed participant characteristics, environmental data, and EHS medical encounters for five consecutive BAA Boston Marathon races during the time period spanning from 2015 to 2019.

Institutional approval. All aspects of this study were reviewed and approved by the Partners Human Research Committee, the institutional review board for the Mass General Brigham Healthcare System (Protocol: 2018P000468/PHS).

Demographic characteristics. The BAA organizes the Boston Marathon annually on the third Monday in April. We queried the BAA Salesforce database, which is the race registration database, for the Boston Marathon races from 2015 to 2019 to obtain race starter numbers. As is customary for the Boston Marathon, approximately 80% to 90% of starters gain race entry by meeting qualifying time standards for their age group. The remaining 10% to 20% of participants gain entry using invitational or charity mechanisms. The race has a staggered start divided into four waves, with 25 min between each wave. Qualified runners start in waves 1, 2, and 3, and runners with faster qualifying times start in earlier waves. Runners who gain race entry through a charity or invitational mechanism, and not through qualifying by time, start in wave 4. Within the BAA Salesforce database, we searched for the following variables: total starters, starters by sex, starters by 10-yr age range, and starters by wave. Individuals participating in the wheelchair and handcycle divisions were excluded from all subsequent analyses.

Runner medical records. We reviewed the paper medical encounter forms from each race to identify runners who presented to the finish line or course medical tents with EHS. Medical encounter forms were completed by members of the on-site medical team at the finish line medical tents and at the course medical tents at the time of each race. At the Boston Marathon, runners are diagnosed with EHS and treated with ice water immersion if they have a core body temperature of greater than 104.0°F and evidence of altered mental status (confusion or unresponsiveness). Some medical encounter forms did not contain complete information, and mental status was not documented (four cases). Therefore, we defined EHS as a documented core body temperature of greater than 104.0°F and evidence of altered mental status or treatment with ice water immersion. We excluded runners with heat-related illness that did not meet these criteria. We used race results published on the BAA website (https://www.baa.org/races/boston-marathon/results) to determine finishing times for runners treated for EHS. If we were unable to find a runner in the published list of finishers, or if the medical encounter form documented failure to finish the race or hospital transfer from a course medical tent, we categorized that runner as a nonfinisher.

Environmental conditions. Hourly meteorological data from the course weather station in Natick, MA, between 10 AM and 2 PM were available, as previously described (16). The Natick course weather station is located approximately halfway along the Boston Marathon course. Wet bulb globe temperature (WBGT) is a measurement that combines ambient temperature, relative humidity, and solar radiation and is commonly used to indicate race-day heat stress (1). For each race, hourly measurements of WBGT between 10 AM and 2 PM were used to identify the WBGT at the start of wave 1, to calculate an average WBGT for the time period measured, and to calculate the difference between the peak WBGT and the start WBGT during the time measured. Measured WBGT values do not significantly differ at different locations along the Boston Marathon course (16); therefore, the Natick location measurements were considered representative of the heat stress experienced by runners along the course on each race day. The Natick weather station was damaged by strong winds in 2018, so for that year, WBGT measurements from the Newton, MA, weather station were used.

EHS encounter data. Two authors (R.G.B. and C.T.) retrospectively reviewed all medical encounter forms of runners presenting with EHS from each race. All runners with suspected EHS (i.e., collapsed runners or those with altered mental status) had their core body temperature measured with a rectal thermistor. If the diagnosis was confirmed, runners were treated with ice water immersion until they cooled to a core body temperature of approximately 102.5°F. Two runners treated for EHS presented with initial core body temperatures that did not meet the criteria for EHS. One runner had an initial measurement of 101.7°F, but his core body temperature increased to 105.6°F after 7 min of monitoring; the other runner presented with an initial temperature of 99.3°F but increased to 105.0°F after 10 min of monitoring. Both of these runners were included in our analysis. Runners presenting to the finish line medical tent with EHS were transferred to a dedicated area, the "Heat Deck," for this treatment; however, all 26 course medical tents were also equipped to provide ice water immersion.

For each EHS encounter, we entered deidentified demographic data as well as information about the runner's clinical presentation and treatment course into a REDCap electronic data capture tool (17) hosted at Brigham and Women's Hospital. We collected the following variables: triage time, presenting temperature (°F), ice water immersion time (minutes), temperature on removal from ice water immersion (°F), posttreatment low temperature (°F), fluid resuscitation method (if any), total treatment time (minutes), and disposition. Runners were considered to have mild hypothermia if their posttreatment low core body temperature was between 95°F and 97°F, and significant hypothermia if their posttreatment low core body temperature was less than 95°F. Individuals whose core body temperature remained between 97°F and 102.5°F for 30 min posttreatment, without evidence of altered mental status, were discharged into the care of family or friends. EHS cases with persistent altered mental status after treatment, evidence of compromised renal function, or abnormal electrolytes on iSTAT laboratory testing, or who were unable to be discharged into the care of friends or family were transported to a local emergency room via emergency medical services once core body temperature was consistently measured less than 102.5°F for 30 min after treatment.

Data analysis. We generated descriptive statistics on participant characteristics and EHS encounter variables. For continuous variables, we present both mean and median values to illustrate central tendency and data skew, respectively. We calculated the incidence of EHS for each race as the number of events divided by the number of starters and reported incidence as EHS cases per 10,000 starters for each race year and cumulatively over the 5-yr period. We used Poisson regression to simultaneously assess the association between age, sex, and starting wave on EHS incidence. Participants missing age ($n = 1$) and start wave ($n = 1$) were excluded from the regression models. We then calculated both unadjusted and adjusted incidence ratios to compare EHS incidence between groups. For this analysis, runners younger than 30 yr and older than 70 yr were grouped together because of small sample sizes.

To examine the relationship between weather conditions and EHS incidence, we plotted EHS cases per 10,000 starters against start WBGT, average WBGT, and delta WBGT (defined as the difference between the peak WBGT and the start WBGT) (18). We fit models with linear and logarithmic terms and used the R^2 value to choose the line of best fit. To further evaluate the effect of temperature, we categorized the temperature for each race as warm (≥14°C average WBGT) versus cool (<14°C average WBGT) and categorized warm race days by whether the temperature rose or fell over the course of the day. We assessed the association between warm versus cool days and temperature change with EHS using Fisher's exact test.

RESULTS

Race characteristics. There were a total of 136,161 Boston Marathon starters at the 2015 through 2019 races. There were 11,001 medical encounters at the 5 races and 51 cases of EHS, for an incidence of 3.7 EHS cases per 10,000 starters (95% confidence interval [CI], 2.8–4.9). EHS encounters represented 0.5% of all medical encounters.

Runner characteristics. The overall mean (SD) starter age on race day was 43.3 (11.3) yr, and the overall mean (SD) qualifying time was 3:22:15 (0:25:17). There were 61,773 female starters (45.4%) and 74,388 male starters (54.6%). The mean (SD) ages were 41.0 (10.5) yr for female starters and 45.2 yr (11.6) yr for male starters. The mean (SD) qualifying time for females was 3:34:33 (0:18:45), and that for males was 3:12:29 (0:25:31). Start wave qualifying time ranges for each race year are shown in Supplemental Digital Content Table 1, http://links.lww.com/MSS/C286. There were significant associations between runner sex and age ($P < 0.0001$), sex and start wave ($P < 0.0001$), and age group and start wave ($P < 0.0001$), shown in Table 1. Compared with female runners, male runners tended to be in earlier start waves and were more likely to be in older age groups. Runners in younger age groups tended to be in earlier start waves.

Runner characteristics and incidence of EHS. The unadjusted incidence of EHS by sex, age, start wave, and race year is presented in Table 2. See Tables, Supplemental Digital Content 2, for univariate subgroup analysis for sex by age, sex by start wave, and start wave by age, http://links.lww.com/MSS/C287. The effects of sex, age, and starting wave on EHS incidence are presented in Table 3. Males had a 1.3 times increased unadjusted incidence of EHS (95% CI, 0.7–2.3), but this was not statistically significant ($P = 0.38$). Age less than 30 yr was significantly associated with an increased incidence of EHS compared with other age groups ($P < 0.0001$). Overall,

TABLE 1. Distribution (%) of race starters by sex by start wave, sex by age group, and start wave by age group, Boston Marathon, 2015–2019.

	Sex		
	Female	Male	*P*
Start wave			
1	2753 (4.5%)	30,784 (41.4%)	<0.0001
2	14,452 (23.4%)	18,820 (25.3%)	
3	25,703 (41.6%)	8006 (10.8%)	
4	18,865 (30.5%)	16,778 (22.6%)	
Age group, yr			
<30	12,822 (20.8%)	8559 (11.5%)	<0.0001
30–39	17,397 (28.6%)	16,544 (22.2%)	
40–49	19,070 (30.9%)	22,954 (30.9%)	
50–59	9855 (16.0%)	17,830 (24.0%)	
60–69	2426 (3.9%)	7527 (10.1%)	
70+	203 (0.3%)	974 (1.3%)	

Age Group, yr	Start Wave 1	2	3	4	*P*
<30	7197 (21.5%)	4901 (14.7%)	2189 (6.5%)	7094 (19.9%)	<0.0001
30–39	13,621 (40.6%)	6231 (18.7%)	5898 (17.5%)	8191 (23.0%)	
40–49	10,263 (30.6%)	11,461 (34.5%)	12,128 (36.0%)	8172 (22.9%)	
50–59	2287 (8.3%)	9606 (34.7%)	8576 (31.0%)	7216 (26.1%)	
60–69	163 (1.6%)	1001 (10.1%)	4744 (47.7%)	4045 (40.6%)	
70+	6 (0.5%)	72 (6.1%)	174 (14.8%)	925 (78.6%)	

There were significant associations between sex and age group, sex and wave, and age group and wave for Boston Marathon starters. Female runners tended to be younger. Younger runners and male runners tended to be in earlier start waves. See Table, Supplemental Digital Content 1, http://links.lww.com/MSS/C286, for all qualifying time ranges for each start wave by race year. The 2019 qualifying time ranges are representative and were as follows: wave 1, less than 3:07:27; wave 2, 3:07:28 to 3:27:17; wave 3, 3:27:18 to 3:56:54; and wave 4, greater than 3:56:55. $P < 0.05$ was considered to be statistically significant.

TABLE 2. Incidence of EHS by sex, age, start wave, and year (environment), Boston Marathon, 2015–2019.

	EHS Cases, No. (%)	Race Starters, No. (%)	Incidence per 10,000 Starters	Lower 95% CI	Upper 95% CI
Total	51	13,6161	3.7	2.8	4.9
Sex					
Male	31 (60.8)	74,388 (54.6)	4.2	2.9	5.9
Female	20 (39.2)	61,773 (45.4)	3.2	2.1	5.0
Age, yr[a]					
<20	1 (2.0)	346 (0.3)	28.9	4.1	205.2
20–29	23 (46.0)	21,035 (15.5)	10.9	7.3	16.5
30–39	6 (12.0)	33,941 (24.9)	1.8	0.8	3.9
40–49	13 (26.0)	42,024 (30.9)	3.1	1.6	5.3
50–59	7 (14.0)	27,685 (20.4)	2.5	1.2	5.3
60–69	0	9953 (7.3)	0	—	—
70–79	0	1117 (0.8)	0	—	—
80+	0	60 (0.04)	0	—	—
Start wave[a]					
1	19 (38.0)	33,537 (24.6)	5.7	3.6	8.9
2	19 (38.0)	33,272 (24.5)	5.7	3.6	9.0
3	6 (12.0)	33,709 (24.8)	1.8	0.8	4.0
4	6 (12.0)	35,643 (26.2)	1.7	0.8	3.7
Year (average WBGT)					
2015 (6.8°C)	0	27,182 (20.0)	0	0.0	1.4
2016 (19.7°C)	4 (7.8)	27,578 (20.2)	1.5	0.4	3.7
2017 (18.8°C)	21 (41.2)	27,226 (20.0)	7.7	4.8	11.8
2018 (6.1°C)	0	26,885 (19.8)	0	0	1.4
2019 (14.4°C)	26 (51.0)	27,290 (20.0)	9.5	6.2	14.0

See Table, Supplemental Digital Content 1, http://links.lww.com/MSS/C286, for all qualifying time ranges for each start wave by race year. The 2019 qualifying time ranges are representative and were as follows: wave 1, less than 3:07:27; wave 2, 3:07:28 to 3:27:17; wave 3, 3:27:18 to 3:56:54; and wave 4, greater than 3:56:55.
[a]Age was unknown for one EHS patient, and start wave was unknown for one EHS patient.

starting wave was significantly associated with EHS incidence (P = 0.002). Runners in the first wave had a significantly higher EHS incidence compared with runners in waves 3 (P = 0.013) and 4 (P = 0.01), and runners in wave 2 had a significantly higher EHS incidence compared with runners in waves 3 (P = 0.01) and 4 (P = 0.009).

Environmental conditions. Hourly WBGT for each race day are shown in Figure 1A. Race-day weather conditions were variable during the study time period (see Supplemental Digital Content Table 3 for environmental conditions at the Boston Marathon 2015–2019, http://links.lww.com/MSS/C288). Figures 1B–D illustrate the relationship between EHS incidence and starting WBGT, average WBGT, and delta WBGT, respectively. For the two cool race days, 2015 and 2018, there was an EHS incidence of 0.0 per 10,000 (95% CI, 0–0.7); 2016, 2017, and 2019 were warm race days, with an EHS incidence of 6.2 per 10,000 (95% CI, 4.6–8.2; P < 0.0001). Among the warm race days, 2017 and 2019 had a rise in temperature and had an average EHS incidence of 8.6 per 10,000 (95% CI, 6.3–11.5), whereas 2016 had a steady decrease in temperature and had an EHS incidence of 1.5 per 10,000 (95% CI, 0.4–3.7; P < 0.0001).

EHS case presentation. There were 37 EHS cases who were race finishers, and all were triaged at or near the finish line. There were 14 nonfinishers, and the location of collapse was documented for 13 of these (all after mile 18): tent 12 at mile 18.3 (1 runner), tent 13 at mile 19.3 (1 runner), tent 14 at mile 19.9 (1 runner), tent 17 at mile 21.1 (3 runners), tent 21 at mile 22.8 (1 runner), tent 23 at mile 23.9 (3 runners), tent 25 at mile 24.8 (2 runners), and tent 26 at mile 25.5 (1 runner). The elapsed times from start to triage for EHS cases are pictured in Figure 2. The mean (SD) initial rectal temperature was 106.5°F (1.7°F), and the median was 106.6°F (range, 99.3°F–109.0°F).

EHS treatment course. All cases of EHS were treated with ice water immersion. Duration of ice water immersion was documented in 30 of the 51 cases, with a mean (SD) time immersed of 16 min (6.7 min) and a median time of 15 min (range, 7–41 min). In 32 cases, core body temperature prompting removal from the ice bath was documented, with a mean (SD) temperature for removal of 102.3°F (0.6°F) and a median temperature of 102.5°F (range, 100.9°F–103.4°F). Posttreatment low temperatures were documented in 44 cases, with a mean (SD) of 98.3°F (3.0°F) and a median of 98.4°F (range, 91.8°F–102.6°F). In 7 cases (13.7%), there was significant hypothermia (mean (SD) core body temperature, 93.6°F (1.0°F); median, 93.9°F (range, 91.8°F–94.9°F)) and mild hypothermia in 8 cases (15.7%; mean (SD) core body temperature, 95.8°F (0.6°F); median, 95.7°F (range, 95.0°F–96.8°F)). Intravenous fluids were administered to 18 runners (35.3%); the remainder received oral fluids (9 runners; 17.7%) or no fluids (24 runners; 47.1%). Total treatment times were variable, with a mean (SD) of 78.1 min (47.5 min) and a median of 66 min (range, 15–190 min). A majority of runners treated for EHS were released (31 runners; 64.6%), but 16 runners (33.3%) required hospital transport. Final disposition was not documented for four runners. There were no fatalities.

DISCUSSION

We found that over a 5-yr period at the Boston Marathon, the incidence of EHS was 3.7 cases per 10,000 starters. There

TABLE 3. Effects of sex, age, and start wave on EHS incidence, Boston Marathon, 2015–2019.

	Unadjusted			Adjusted[a]	
	Incidence per 10,000 (95% CI)	IR (95% CI)	P	IR (95% CI)	P
Sex					
Female	3.2 (2.0–5.0)	Reference	0.2342	Reference	0.2819
Male	4.6 (3.2–6.5)	1.4 (0.8–2.5)		1.6 (0.7–3.6)	
Age, yr					
<30	11.2 (7.5–16.7)	4.4 (1.9–10.3)	<0.0001	5.5 (2.0–15.3)	<0.0001
30–39	1.5 (0.6–3.5)	0.6 (0.2–1.8)		0.7 (0.2–2.4)	
40–49	3.1 (1.8–5.3)	1.2 (0.5–3.1)		1.3 (0.5–3.3)	
50–59	2.5 (1.2–5.3)	Reference		Reference	
Wave					
1	5.7 (3.6–8.9)	3.5 (1.3–9.4)	0.0039	3.0 (1.03–8.6)	0.0122
2	5.9 (3.8–9.3)	3.6 (1.4–9.7)		4.3 (1.6–11.8)	
3	2.1 (0.9–4.6)	1.3 (0.4–4.2)		2.2 (0.6–7.8)	
4	1.6 (0.7–3.9)	Reference		Reference	

[a]We used a multivariable Poisson regression model to simultaneously assess the association between age, sex, and wave on incidence of EHS. Age younger than 30 yr and assignment to the first two start waves were significantly associated with increased EHS risk in both unadjusted and adjusted analyses. For this analysis, we excluded cases that did not have complete data on all covariates. Runners younger than 30 yr and older than 70 yr were grouped together for this analysis because of small sample sizes, and incidence ratios were not calculated for runners in age groups greater than 60 yr because of the small sample size and 0 events. P < 0.05 was considered statistically significant.
IR, incidence ratio.

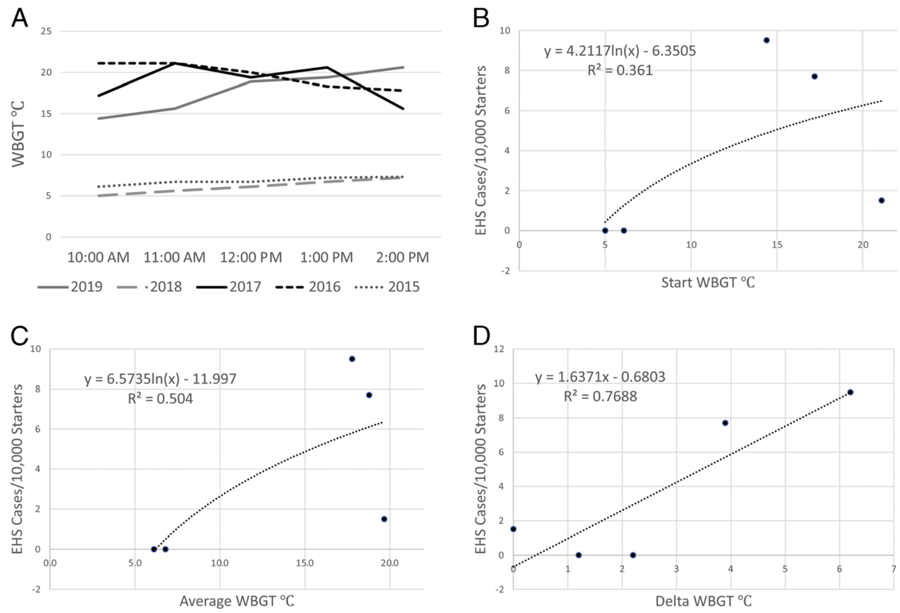

FIGURE 1—Relationship between WBGT and EHS incidence. A, Hourly WBGT measurements between 10 AM and 2 PM on the day of each race, 2015–2019. There is a modest positive association between higher start WBGT (B) and higher average WBGT (C) and EHS incidence. D, There is a strong linear relationship between the delta WBGT, defined as the difference between the peak WBGT and the start WBGT, and EHS incidence.

was no significant effect of sex on EHS incidence, which were highest among runners younger than 30 yr and those who started in the first two starting waves (indicating runners with faster qualifying times), even when adjusted for sex, age, and starting wave. EHS cases all occurred on warm, humid race days in which average WBGT ranged from 17°C to 20°C. Greater increases in start to peak WBGT also strongly correlated with increased EHS incidence. Most EHS cases collapsed at the finish line or during the last quarter of the race and were triaged approximately 3 to 4 h after the race start. A substantial number of cases were given intravenous fluid resuscitation, and nearly one-third developed posttreatment hypothermia. Two-thirds of cases were discharged directly, and there were no fatalities.

The overall incidence of EHS in our study is similar to that reported by Roberts (8) at the Twin Cities Marathon, which was 3 cases per 10,000 entrants over a 12-yr period. However, Divine et al. (6) reported a much higher incidence of 13 cases per 10,000 full-marathon finishers over a 3-yr period at the Cincinnati Flying Pig Marathon. EHS incidence across other race distances also displays variability; for example, we recently reported 10 EHS cases per 10,000 runners at 10-km races in New England over an 8-yr period (5), whereas a series of studies conducted at the Falmouth Road Race (a similar

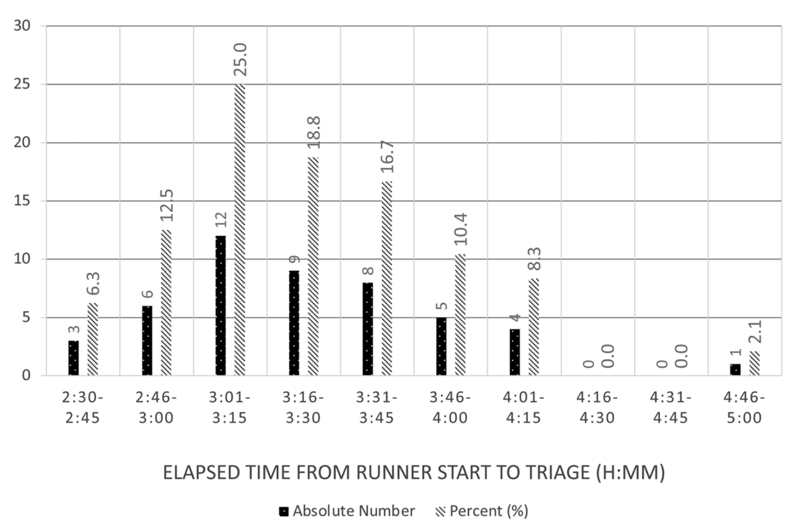

FIGURE 2—Time elapsed from runner start to triage for EHS cases at the Boston Marathon, 2015–2019. Time elapsed from runner start to triage for 37 finishers and 14 nonfinishers with EHS. Most cases presented between 2:45 and 3:45 h after starting the race. A knowledge of peak time of presentation for specific medical issues assists with planning and resource allocation.

distance race of 11.3 km) found 18 to 21 EHS cases per 10,000 runners over two decades of study (2–4,19). Half-marathon (21.1 km) races such as the Two Oceans Races in South Africa (10) and the Indianapolis Half Marathon (11) have an EHS incidence of 1 per 10,000 runners, whereas other half marathon races such as the Great North Run in Northern England have an EHS incidence of 10 per 10,000 runners (7). This variability suggests that the formula for predicting EHS risk combines both participant and race-level characteristics that are potentially unique and specific for each race. However, close examination of how each of these components may affect EHS risk at a given race may improve our ability to predict it more accurately.

Male sex has previously been associated with an increased incidence of EHS in marathon runners. At the Cincinnati Flying Pig Marathon and Half-Marathon, there were 20 cases per 10,000 finishers in male marathon runners compared with approximately 4 cases per 10,000 finishers in female marathon runners (6). Furthermore, a recent systematic review examining gender differences in exertional heat illness in the armed forces found that among United States army personnel, men have a higher incidence of EHS than women (0.22–0.48 per 1000 person-years for males versus 0.10–0.26 per 1000 person-years for females) (20). In our study, we did not find a significant difference in EHS incidence between male and female starters over the past 5 yr at the Boston Marathon, with 4.2 cases per 10,000 male starters versus 3.2 cases per 10,000 female starters, and no statistically significant associations between the groups in adjusted or unadjusted analyses. This may be due to intrinsic differences in race conditions or participant demographics between the Cincinnati Flying Pig Marathon and the Boston Marathon. This could also be due to the fact that we were underpowered to detect modest effect sizes. With a total sample size of 136,161 starters and relatively equal sex distribution of EHS cases (45% female, 55% male), we were powered to find risk ratios of approximately 2, and the EHS incidence for male starters in our study was only 1.3 times greater than that of female starters. Another possibility that could account for the sex difference in EHS incidence is the effect of race performance level, which (as discussed hereinafter) is a significant risk factor for EHS: many more men than women were in the faster start waves (67% of men vs 28% of women in waves 1 and 2).

Although we were unable to detect significant sex differences, we did find a significantly increased EHS incidence in runners younger than 30 yr, which persisted when adjusted for sex and wave. To our knowledge, this has not previously been reported for runners participating in road races, but other studies have identified younger adults as a high-risk age group for EHS, particularly in the context of sports or exercise. In one large registry of young adult athletes in the United States (mean age, 19 ± 6 yr of age), EHS was the fourth leading cause of death (21). In another study of exertional heat-related injuries treated in US emergency departments over a 10-yr period, patients 19 yr or younger accounted for 46.7% of all heat-related injuries, and more than 75% were associated with sport or exercise participation (22). This suggests that younger adults planning to participate in marathons, especially on warm and humid days, should be counseled on EHS risk and on strategies to avoid heat illness.

We also found that race performance level is a significant risk factor for EHS. During marathon running, core body temperature elevation is largely determined by metabolic rate (23,24), and faster runners might be expected to generate higher levels of metabolic heat. However, some individuals within this group of runners may be unable to pace themselves appropriately and/or lose their ability to thermoregulate. This was recently suggested by a study of runners with EHS at the Falmouth Road Race, which has an average rate of 15 cases per year (4). That study found that runners with EHS ran at a faster-than-average pace than those who did not and did not slow their pace in warmer conditions. Although we were unable to determine pacing strategy with the available data in our study, our findings support the idea that faster run times among recreational marathoners might contribute to higher EHS risk. Thus, it is important to educate higher performers on appropriate pacing strategies, particularly on race days when extreme environmental conditions may exacerbate EHS risk.

Environmental heat stress did elevate EHS risk during the 2015 to 2019 Boston Marathon races. We found a modest positive association between start and average race-day WBGT and EHS incidence (Figs. 1B, C), and all of the EHS cases in our study occurred during warmer race years where the average WBGT was between 17°C and 20°C. However, both the 2017 and 2019 race years saw greater than 20 cases compared with 2016, which had a much lower number (4 cases) in spite of having the highest start and average WBGT of the races we examined. This may be due to the fact that the WBGT during the 2016 race remained relatively constant, and even decreased, during the race, whereas the 2017 and 2019 races experienced increases in WBGT from start to peak by nearly 4°C–6°C. This suggests runners may be less able to adjust to greater changes in WBGT from start to peak and therefore more vulnerable to EHS on such days. Although the relationship between changes in WBGT and EHS incidence has not previously been examined in the context of marathon races, studies in military recruits have revealed higher rates of exertional heat illness during early morning hours when WBGT increases most rapidly (25). Whether or not this might explain variation in EHS risk on marathon race days with moderate WBGT merits further exploration at future Boston Marathon and other races.

A knowledge of which groups of runners are at highest risk for EHS has important clinical implications in that it allows more precise planning for staffing and resource allocation. Figure 2 illustrates that a majority of EHS cases in our series were triaged in the relatively narrow time window between 2:45 and 3:45 h after their race start. This is similar to what has been reported by Roberts (8) at the Twin Cities Marathon, where the peak volume of admissions with exercise-associated collapse occurred 3.5 h after the race start. Collapsed runners, and particularly those with EHS, require labor-intensive and time-consuming treatments. At the Boston Marathon, each ice water immersion tub is manned by four to six medical staff to ensure the safety of the runner, adequate circulation of the water, and documentation of clinical status. The mean immersion time was 16 min, although some runners needed more prolonged immersion, and more than one-third were given intravenous fluid resuscitation. All runners required a period of observation and recovery once they were adequately cooled, and a subset required further care for hypothermia. On average, runners with EHS spent more than 1 h receiving care in the medical tent. Based on these findings, we would recommend at least 4 ice water immersion tubs per 10,000 starters at a large-scale urban marathon, with the capability of scaling up to 8 to 10 tubs per 10,000 starters on warmer, more humid days. We would also recommend staffing with at least 16 to 24 licensed personnel trained to manage EHS per 10,000 starters, again with the capability for expansion on warm and humid days and during the expected peak admission time range. At least 1 medical personnel per 10,000 starters should be proficient in placing an intravenous catheter.

Because of the retrospective nature of our study, we were limited to the information documented on the medical encounter forms and were unable to control for the effects of other potential risk factors associated with EHS, such as training background, acclimatization, athletic history, antecedent viral illness, or other medical history (26). A further limitation was that documentation of the clinical course of some runners was incomplete. Quality improvement measures to address these deficiencies are currently in progress and will enable greater compliance with documentation and capability for prospective data collection for future studies. Studies exploring factors that influence suboptimal outcomes, such as overcooling and hypothermia, are also currently under way. Efforts to enhance education and outreach to runners deemed high-risk for life-threatening conditions, like EHS, will inform future health and safety initiatives at the Boston Marathon.

CONCLUSIONS

Younger and faster runners are at higher risk for EHS at the Boston Marathon. Greater changes in start to peak WBGT may exacerbate risk. EHS encounters comprise a small percentage of race-day medical encounters but require time- and resource-consuming treatments and warrant risk mitigation efforts.

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