AMERICAN JOURNAL OF PHYSIOLOGY
REGULATORY, INTEGRATIVE AND COMPARATIVE PHYSIOLOGY

Am J Physiol Regul Integr Comp Physiol 324: R15–R19, 2023.
First published November 7, 2022; doi:10.1152/ajpregu.00168.2022

RESEARCH ARTICLE

Don't Deny Your Inner Environmental Physiologist: Investigating Physiology with Environmental Stimuli

Body mass index, but not sex, influences exertional heat stroke risk in young healthy men and women

Gabrielle E. W. Giersch,[1] Kathryn M. Taylor,[2] Aaron R. Caldwell,[1] and Nisha Charkoudian[1]

[1]*Thermal and Mountain Medicine Division, United States Army Research Institute of Environmental Medicine, Natick, Massachusetts and* [2]*Military Performance Division, United States Army Research Institute of Environmental Medicine, Natick, Massachusetts*

Abstract

Exertional heat stroke (EHS) remains a persistent threat for individuals working or playing in the heat, including athletes and military and emergency service personnel. However, influence of biological sex and/or body mass index (BMI) on the risk of EHS remain poorly understood. The purpose of this study was to retrospectively assess the influence of sex and BMI on risk of EHS in the active-duty US Army. We analyzed data from 2016 to 2021, using a matched case-control approach, where each individual with a diagnosis of EHS was matched to five controls based on calendar time, unit ID, and job category, to capture control individuals who were matched to EHS events by location, time, and activity. We used a multivariate logistic regression model mutually adjusted for sex, BMI, and age to compare 745 (n = 61 F) individuals (26 ± 7 yr) with a diagnosed EHS to 4,290 (n = 384 F) case controls (25 ± 5 yr). Group average BMI were similar: 26.6 ± 3.1 (EHS) and 26.5 ± 3.6 kg/m^2 (CON). BMI was significantly ($P <$ 0.0001) associated with higher risk of EHS with a 3% increase in risk of EHS for every unit increase in BMI. Notably, sex was not associated with any difference in risk for EHS (P = 0.54). These data suggest that young healthy people with higher BMI have significantly higher risk of EHS, but, contrary to what some have proposed, this risk was not higher in young women.

exercise; heat illness; military; thermoregulation; women

INTRODUCTION

Exertional heat stroke (EHS) is a potentially fatal condition that affects individuals in many domains, including the military, athletes, and emergency service personnel. A recent estimate suggests that ∼500 US military personnel are affected by EHS each year (1). Factors that put individuals at an increased risk for EHS have been long discussed and aggregated by governing bodies (2, 3). Body mass index (BMI) is a population-based index that is used to approximate body size by providing a ratio between body height and weight. Although not indicative of body composition, BMI is often used as a measure to infer health risk on a population basis. It is well understood that older adults are at an increased risk for passive heat stroke, often attributed to blunted heat dissipation capacity (4, 5) but there has been some debate on the influence of age on EHS risk, with investigations finding younger individuals with higher risk during exercise heat stress (6).

From a biophysical perspective, objects (including people and animals) with larger size have lower surface area-to-mass ratio (SA:mass). Metabolic heat is generated based on body mass (for example, contracting skeletal muscle mass during weight-bearing exercise) and is dissipated based on body surface area (BSA, via skin blood flow, sweating, etc.). Thus, all else being equal, a lower BSA-to-mass ratio makes it more difficult to dissipate metabolically generated body heat in most circumstances. A study of Marine Corps recruits at Parris Island in the late 1980s and early 1990s demonstrated that higher BMI was associated with a significantly increased risk of exertional heat illness (7). Although BMI itself does not quantify body composition or fitness status, for the general population factors related to body size, composition, and fitness may impact the ability of the body to dissipate heat in an exercise and heat stress scenario (8). Average BMI has increased substantially in both the general population and in the US military in the decades since the Parris Island study (9–12), and it is not clear how this has affected individual risk of exertional heat illness (EHI) or exertional heat stroke (EHS), particularly in a military cohort.

Risk for EHI/EHS has often been suggested to be elevated in women (13); however, the physiological basis for that

Correspondence: G. E. W. Giersch (gegiersch@gmail.com).
Submitted 30 June 2022 / Revised 21 October 2022 / Accepted 26 October 2022

Table 1. *Demographics and measurement characteristics for EHS and Controls included in the analysis*

	EHS *n* = 745 (61 Women)	Controls *n* = 4,290 (384 Women)
Age, yr	26 ± 7 [17–47]	25 ± 5 [17–58]
BMI (kg·m^{-2})	26.6 ± 3.1 [15.4–39.9]	26.5 ± 3.6 [14.0–43.4]
Average time since last weigh-in, days	78 [0–180]	86 [0–180]

Data presented are means ± SD and [range]. BMI, body mass index; EHS, exertional heat stroke.

increased risk has not been clear. More recent evidence suggests that women do not appear to be at an increased risk for developing EHS relative to their male counterparts (6, 14). The purpose of the present study, therefore, was to use a retrospective analysis of population-level data (US Army) to assess the influence of BMI and biological sex on risk for developing EHS. A secondary purpose was to evaluate whether increasing age (within this young group of Soldiers) altered risk of EHS.

METHODS

We conducted a population-level, retrospective, matched case-control analysis of information related to heat illness, sex, body size, and body composition in the US Army using the Soldier Performance Health and Readiness (SPHERE) Database at the US Army Research Institute of Environmental Medicine (USARIEM). The USARIEM SPHERE is a population-level data repository composed of existing Army-wide medical, administrative, and performance databases. Medical record data in the form of International Statistical Classification of Diseases 10th Revision Codes were extracted from the MHS Data Repository (MDR). The MDR database is a comprehensive database for all medical encounter data where a soldier was treated in a military treatment facility or where Tri-care insurance was used. Cases identified as having any ICD-10 codes associated with EHS (T67.02XA, T67.02XD, T67.02XS) were risk set-matched with replacement to five controls based on calendar time, unit ID, and military occupational specialty (MOS = job category) to capture control individuals who were at the same location at the same time and conducting similar activities as the EHS cases. This investigation was conducted using deidentified data, thus does not constitute human subjects research per the US Army Research Institute of Environmental Medicine Human Research Protection Program (exempt from IRB review).

Statistical Analysis

We used conditional logistic regression models to evaluate the relationship between BMI and EHS risk in the matched population. Within the analysis, we used the closest BMI measurement to the EHS event for the cases and to the match date for the controls. Those who did not have height and weight measurement within 180 days of the index date were excluded from further analysis. We considered additional covariates for the final models including sex, age, race, and rank. In addition, we considered interaction terms between covariates to test for effect modification. Akaike's information criterion (AIC) was used as a measurement of model goodness-of-fit to select the best-fit model. With using this method, the final model selected was the model mutually adjusting for sex, age, and BMI. Race and rank did not improve the fit of the models so were excluded from the final model. Analyses were conducted with SAS software (v 9.4; SAS Institute) and R statistical software (v 4.2.0; R Development Core Team).

RESULTS

In the US Army from 2016 to 2021, 745 soldiers (n = 61 women) collapsed during activities in the heat and were subsequently diagnosed with EHS. Table 1 shows a demographic summary of the soldiers included in the present analysis. As an important note, all soldiers included in this analysis met the physical and health requirements for entry into the Army. Whereas group-average BMI was in the normal to overweight range (>24 and <28), we found a statistically significant relationship between BMI and risk of developing EHS. In particular, each unit increase in BMI was associated with a statistically significant ∼3% increase in risk for developing EHS. There were no differences between groups for age or BMI.

As shown in Fig. 1, increasing BMI was associated with significantly increased risk of EHS (P < 0.001), whereas there was no influence of biological sex (men vs. women) on EHS risk. Interestingly, despite a relatively young population, increasing age was associated with decreased risk of EHS. In addition, during model selection, there was a significant interaction between BMI and age (P = 0.02), indicating that the effects of increasing BMI on EHS were worse in younger individuals. We note that the best-fit model did not include this interaction and results are reported for the model without the interaction term.

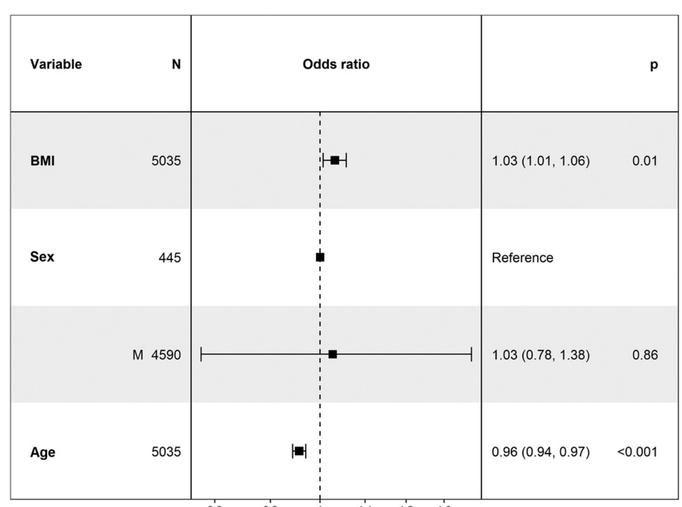

Figure 1. Forest plot of factors associated with EHS risk. BMI is body mass index. Data from n = 5,035 (n = 445 women) analyzed using a logistic regression. EHS, exertional heat stroke.

Figure 2 shows the relationship between BMI and probability of EHS in our group of Soldiers, showing the increased risk with increasing BMI. Also seen in Fig. 2 are density plots of EHS (top of graph) and control (bottom of graph) individuals from the group. Although there were no differences between the mean BMI between groups (shown in Table 1), the distribution of BMI was skewed toward higher values in the EHS group (Fig. 3).

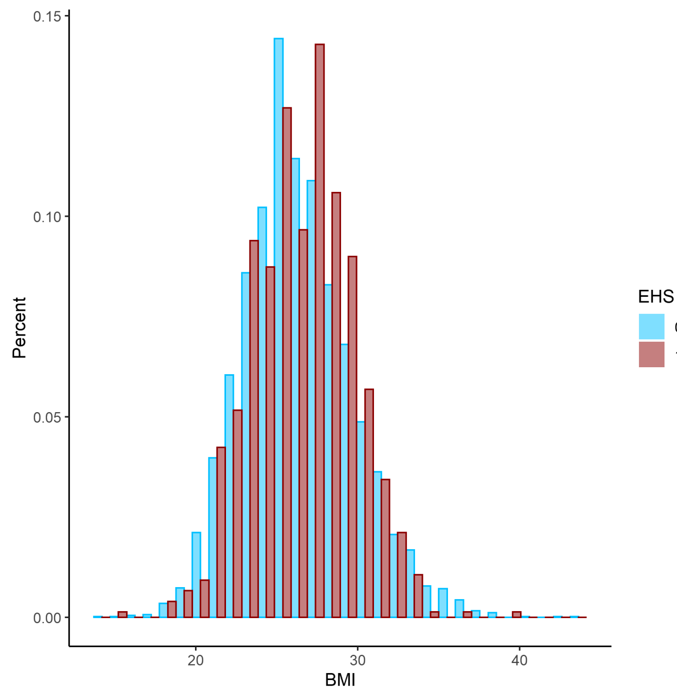

Figure 3. Distribution of BMI between EHS group and matched controls. 0 (blue bars) denotes control group, 1 (red bars) denotes EHS group. Data from n = 5,035 (n = 445 women). BMI, body mass index; EHS, exertional heat stroke.

DISCUSSION

The major new findings of the present study were that increasing BMI was significantly associated with increased risk for EHS across a group of 7,650 male and female Soldiers in the US Army. Specifically, we found a 3% increase in risk for every unit increase in BMI, based on the odds ratio. Importantly, we found no significant difference in EHS risk between men and women. Previous research over a 22-year period, using a similar US Army database found women had an increased prevalence of EHS relative to men (13). However, this earlier Army-wide investigation did not account for differences in body size on analysis. In our present analysis that was mutually adjusted for age, sex, and BMI, there was no impact of sex on EHS risk, leaving only BMI and age as significant predictors of EHS risk. This is in direct contrast with previous assertions that women are at an increased risk for EHS compared with men of similar age and health status (15, 16). Specifically, our data indicate that a woman has a similar risk for EHS compared with a man of similar BMI.

Although BMI was significant in this model, it is unclear whether the impact relies more on physical characteristics of body size (BSA, BSA:mass) or body composition (muscle mass, subcutaneous fat mass, etc.). Importantly, the cohort in this analysis was US military personnel. We do not have body composition data on these subjects, so it is unclear if those with elevated BMI were actually overweight or obese or if they had higher muscle mass. Fitness status is also an important consideration that was not evaluated in this model, although previous investigations show limited impact of aerobic fitness on thermoregulation independent of other physical factors (17) or independent of possible adaptation to the heat (18). US military personnel undergo routine physical training and thus are possibly more fit than the average population; however, a comparison between soldiers and those of the general population with similar BMI scores was not conducted in this analysis.

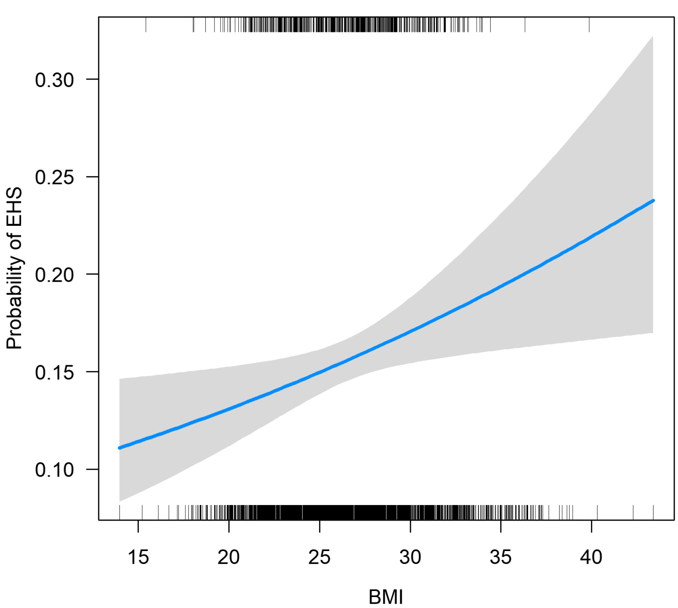

Figure 2. Relationship between BMI and probability of developing EHS. Density bar on the top of the graph represents the EHS group. Density bar on the bottom represents control group. Data from n = 5,035 (n = 445 women) analyzed using a logistic regression. BMI, body mass index; EHS, exertional heat stroke.

Although not directly analyzed in this investigation, BSA-to-mass ratio (BSA:mass) is an important factor for the biophysics of heat exchange as heat is produced from body mass (largely skeletal muscles) and dissipated from the skin (surface area) (8). If more heat is being produced than can be dissipated (i.e., from lower BSA:mass), in certain environmental conditions like hot dry environments, more heat will be stored. This is consistent with previous investigations showing smaller individuals (with larger BSA:mass) have an "advantage" over larger individuals with a lower BSA:mass (19, 20). However, this is inconsistent with previous findings on the influence of body size in thermoregulation (21, 22), and a previous investigation found no differences in thermoregulatory function in individuals with drastically different BSA:mass, suggesting a possible influence of body mass as a whole, rather than an influence of BSA:mass (23). Thus, more research directly assessing the possible influence of BSA:mass on EHS risk is warranted.

Body composition is another factor that may influence thermoregulation and can be associated with BMI. Although the Army population in this study was relatively young, healthy, and fit, it is possible that increased body fat percentage was present in the individuals with higher BMI. Increased body fat percentage is often suggested as a means of increasing heat storage during exercise in the heat. In this context, recent, available evidence suggests that any possible effect of increased subcutaneous or visceral body fat on increasing heat storage is negligible (24). The influence of fat mass has long been thought to be related to increased insulation from subcutaneous fat. Interestingly, recent data suggest that it is not an insulative effect, but rather an effect of differences in specific heat of body tissues that may cause differences in heat storage in people with different amounts of fat mass (25).

Over the past several decades, work from our laboratory (26–29) and others (30–34) has shown that thermoregulatory mechanisms are similar in men and women. Although there are distinct influences of female reproductive hormones on mechanisms of cutaneous vasodilation and sweating (35–37), these do not appear to influence the overall ability to dissipate heat or to maintain body temperature during exercise in a hot environment. The only exception to this appears to be in very hot, dry environments at very high exercise loads (very unusual situations not often encountered), where women may exhibit slightly lower heat dissipation via sweating (38, 39). Nonetheless, there is a persistent idea in some areas of the literature that women are somehow at a "disadvantage" when it comes to thermoregulation in the heat (13, 40). The present analysis of almost 8,000 data points does not show any significant differences in the risk of EHS between men and women. Therefore, we believe statements within the scientific literature that women are at a disadvantage in the heat are unwarranted and contradicted by the best scientific evidence available at this time.

Somewhat unexpectedly in the present analysis, age was a significant predictor of EHS risk, with younger individuals demonstrating a higher risk for EHS. At first glance, this appears to contrast with the well-established dogma that increasing age is associated with increased risk of heat stroke (4, 5, 41–43). However, based on the population studied, we interpret these data from a behavioral perspective, rather than a biological effect of age per se, in two main ways. First, the higher-risk events (ruck marches, timed runs) are more likely to be completed by soldiers of a younger age and/or lower rank. Second, older soldiers (more likely to be officers or senior enlisted, since age and rank are positively correlated) have likely developed better behaviors and/or strategies that prevent EHS. Third, there is the possibility the results were affected by collider bias wherein those at high risk for EHS are less likely to have long careers in the Army thereby producing a misleading effect of age-reducing EHS risk (44). Thus, we do not feel the significant age predictor is reflective of an underlying physiological effect. It is clear that heat tolerance decreases with age (e.g., reduced sweat gland function with age), and we do not feel our findings contradict that evidence (4, 45).

A major strength of the present study was the large sample size (US Army population), but such population-based analyses also come with inherent limitations. Although a useful approximation, BMI is not a very accurate indicator of body size or body composition. In future work, additional measures of body size and/or composition would be beneficial in determining the contributing factors within BMI as it relates to EHS. In particular, BSA:mass may be a more useful tool for estimating EHS risk and is worth investigating further. We also were not able to obtain information related to fitness status of the individuals in each group. Across such a large group, and in particular a military cohort, fitness status would likely be linked to increased muscle mass and possibly to decreased body fatness, which can still lead to increased BMI. However, these additional analyses were not possible in the present study.

Perspectives and Significance

In summary, we demonstrate in the present analysis that across the active-duty US Army soldiers, BMI was a significant predictor of EHS risk, whereas biological sex was not. Within our relatively young, healthy group of soldiers, age was a negative predictor, likely based on behavioral and activity-related factors rather than biological age per se. These findings lead to important follow-up questions regarding specific contributors to risk including body size and body composition, which will be important areas for future work.

DISCLAIMERS

The views, opinions, and/or findings contained in this article are those of the authors and should not be construed as an official US Department of the Army position, or decision, unless so designated by other official documentation. Approved for public release, distribution unlimited. Citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

G.E.W.G., K.M.T., and N.C. conceived and designed research; K.M.T. analyzed data; G.E.W.G., K.M.T., A.R.C., and N.C. interpreted results of experiments; K.M.T. prepared figures; G.E.W.G., K.M.T., A.R.C., and N.C. drafted manuscript; G.E.W.G., K.M.T., A.R.C., and N.C. edited and revised manuscript; G.E.W.G., K.M.T., A.R.C., and N.C. approved final version of manuscript.

REFERENCES

1. **Armed Forces Health Surveillance Branch.** Update: heat illness, active component, U.S. Armed Forces. *MSMR* 26: 15–20, 2018.
2. **Roberts WO**, **Armstrong LE**, **Sawka MN**, **Yeargin SW**, **Heled Y**, **O'Connor FG.** ACSM expert consensus statement on exertional heat illness: recognition, management, and return to activity. *Curr Sports Med Rep* 20: 470–484, 2021. doi:10.1249/jsr.0000000000000878.
3. **Casa DJ**, **DeMartini JK**, **Bergeron MF**, **Csillan D**, **Eichner ER**, **Lopez RM**, **Ferrara MS**, **Miller KC**, **O'Connor F**, **Sawka MN**, **Yeargin SW.** National Athletic Trainers' Association Position statement: exertional heat illnesses. *J Athl Train* 50: 986–1000, 2015 [Erratum in *J Athl Train* 52: 401, 2017]. doi:10.4085/1062-6050-50.9.07.
4. **Kenney WL**, **Craighead DH**, **Alexander LM.** Heat waves, aging, and human cardiovascular health. *Med Sci Sports Exerc* 46: 1891–1899, 2014. doi:10.1249/MSS.0000000000000325.
5. **Kenney WL**, **Hodgson JL.** Heat tolerance, thermoregulation and ageing. *Sports Med* 4: 446–456, 1987. doi:10.2165/00007256-198704060-00004.

6. **Belval LN**, **Giersch GEW**, **Adams WM**, **Hosokawa Y**, **Jardine JF**, **Katch RK**, **Stearns RL**, **Casa DJ.** Age- and sex-based differences in exertional heat stroke incidence in a 7-mile road race. *J Athl Train* 55: 1224–1229, 2020. doi:10.4085/1062-6050-539-19.
7. **Gardner JW**, **Kark JA**, **Karnei K**, **Sanborn JS**, **Gastaldo E**, **Burr P**, **Wenger CB.** Risk factors predicting exertional heat illness in male Marine Corps recruits. *Med Sci Sports Exerc* 28: 939–944, 1996. doi:10.1097/00005768-199608000-00001.
8. **Cramer MN**, **Jay O.** Biophysical aspects of human thermoregulation during heat stress. *Auton Neurosci* 196: 3–13, 2016. doi:10.1016/j.autneu.2016.03.001.
9. **Krueger PM**, **Coleman-Minahan K**, **Rooks RN.** Race/ethnicity, nativity and trends in BMI among U.S. adults. *Obesity (Silver Spring)* 22: 1739–1746, 2014. doi:10.1002/oby.20744.
10. **Flegal KM**, **Carroll MD**, **Kuczmarski RJ**, **Johnson CL.** Overweight and obesity in the United States: prevalence and trends, 1960–1994. *Int J Obes Relat Metab Disord* 22: 39–47, 1998. doi:10.1038/sj.ijo.0800541.
11. **Foulis SA**, **Hughes J**, **Spiering B**, **Walker L**, **Guerriere K**, **Taylor K**, **Proctor S**, **Friedl K.** US Army basic combat training alters the relationship between body mass index and per cent body fat. *BMJ Mil Health*. In Press. doi:10.1136/bmjmilitary-2021-001936.
12. **McGraw LK**, **Turner BS**, **Stotts NA**, **Dracup KA.** A review of cardiovascular risk factors in US military personnel. *J Cardiovasc Nurs* 23: 338–344, 2008. doi:10.1097/01.JCN.0000317437.75081.e7.
13. **Carter R 3rd**, **Cheuvront SN**, **Williams JO**, **Kolka MA**, **Stephenson LA**, **Sawka MN**, **Amoroso PJ.** Epidemiology of hospitalizations and deaths from heat illness in soldiers. *Med Sci Sports Exerc* 37: 1338–1344, 2005. doi:10.1249/01.mss.0000174895.19639.ed.
14. **Millard-Stafford M**, **Sparling PB**, **Rosskopf LB**, **Snow TK**, **DiCarlo LJ**, **Hinson BT.** Fluid intake in male and female runners during a 40-km field run in the heat. *J Sports Sci* 13: 257–263, 1995. doi:10.1080/02640419508732235.
15. **Alele F**, **Malau-Aduli B**, **Malau-Aduli A**, **Crowe M.** Systematic review of gender differences in the epidemiology and risk factors of exertional heat illness and heat tolerance in the armed forces. *BMJ Open* 10: e031825, 2020. doi:10.1136/bmjopen-2019-031825.
16. **Kazman JB**, **Purvis DL**, **Heled Y**, **Lisman P**, **Atias D**, **Van Arsdale S**, **Deuster PA.** Women and exertional heat illness: identification of gender specific risk factors. *US Army Med Dep J*: 58–66, 2015.
17. **Smoljanić J**, **Morris NB**, **Dervis S**, **Jay O.** Running economy, not aerobic fitness, independently alters thermoregulatory responses during treadmill running. *J Appl Physiol (1985)* 117: 1451–1459, 2014. doi:10.1152/japplphysiol.00665.2014.
18. **Ravanelli N**, **Coombs GB**, **Imbeault P**, **Jay O.** Maximum skin wettedness after aerobic training with and without heat acclimation. *Med Sci Sports Exerc* 50: 299–307, 2018. doi:10.1249/MSS.0000000000001439.
19. **Ravanelli N**, **Cramer M**, **Imbeault P**, **Jay O.** The influence of body morphology on changes in core temperature during exercise in an uncompensable environment. *Extrem Physiol Med* 4: A143, 2015. doi:10.1186/2046-7648-4-S1-A143.
20. **Marino FE**, **Mbambo Z**, **Kortekaas E**, **Wilson G**, **Lambert MI**, **Noakes TD**, **Dennis SC.** Advantages of smaller body mass during distance running in warm, humid environments. *Pflugers Arch* 441: 359–367, 2000. doi:10.1007/s004240000432.
21. **Shvartz E**, **Saar E**, **Benor D.** Physique and heat tolerance in hot-dry and hot-humid environments. *J Appl Physiol* 34: 799–803, 1973. doi:10.1152/jappl.1973.34.6.799.
22. **Haymes EM**, **Buskirk ER**, **Hodgson JL**, **Lundegren HM**, **Nicholas WC.** Heat tolerance of exercising lean and heavy prepubertal girls. *J Appl Physiol* 36: 566–571, 1974. doi:10.1152/jappl.1974.36.5.566.
23. **Ravanelli N**, **Cramer M**, **Imbeault P**, **Jay O.** The optimal exercise intensity for the unbiased comparison of thermoregulatory responses between groups unmatched for body size during uncompensable heat stress. *Physiol Rep* 5: e13099, 2017. doi:10.14814/phy2.13099.
24. **Cramer MN**, **Jay O.** Explained variance in the thermoregulatory responses to exercise: the independent roles of biophysical and fitness/fatness-related factors. *J Appl Physiol (1985)* 119: 982–989, 2015. doi:10.1152/japplphysiol.00281.2015.
25. **Dervis S**, **Coombs GB**, **Chaseling GK**, **Filingeri D**, **Smoljanic J**, **Jay O.** A comparison of thermoregulatory responses to exercise between mass-matched groups with large differences in body fat. *J Appl Physiol (1985)* 120: 615–623, 2016. doi:10.1152/japplphysiol.00906.2015.
26. **Moran DS**, **Shapiro Y**, **Laor A**, **Izraeli S**, **Pandolf KB.** Can gender differences during exercise-heat stress be assessed by the physiological strain index? *Am J Physiol Regul Integr Comp Physiol* 276: R1798–R1804, 1999. doi:10.1152/ajpregu.1999.276.6.R1798.
27. **Kolka MA**, **Stephenson LA.** Effect of luteal phase elevation in core temperature on forearm blood flow during exercise. *J Appl Physiol (1985)* 82: 1079–1083, 1997. doi:10.1152/jappl.1997.82.4.1079.
28. **Giersch G**, **Garcia C**, **Stachenfeld N**, **Charkoudian N.** Are there sex differences in risk for exertional heat stroke? A translational approach. *Exp Physiol* 107: 1136–1143, 2022. doi:10.1113/EP090402.
29. **Yanovich R**, **Ketko I**, **Charkoudian N.** Sex differences in human thermoregulation: relevance for 2020 and beyond. *Physiology (Bethesda)* 35: 177–184, 2020. doi:10.1152/physiol.00035.2019.
30. **Notley SR**, **Park J**, **Tagami K**, **Ohnishi N**, **Taylor NAS.** Variations in body morphology explain sex differences in thermoeffector function during compensable heat stress. *Exp Physiol* 102: 545–562, 2017. doi:10.1113/EP086112.
31. **Gagnon D**, **Dorman LE**, **Jay O**, **Hardcastle S**, **Kenny GP.** Core temperature differences between males and females during intermittent exercise: physical considerations. *Eur J Appl Physiol* 105: 453–461, 2009. doi:10.1007/s00421-008-0923-3.
32. **Gagnon D**, **Crandall CG**, **Kenny GP.** Sex differences in postsynaptic sweating and cutaneous vasodilation. *J Appl Physiol (1985)* 114: 394–401, 2013. doi:10.1152/japplphysiol.00877.2012.
33. **Gagnon D**, **Kenny GP.** Does sex have an independent effect on thermoeffector responses during exercise in the heat? *J Physiol* 590: 5963–5973, 2012. doi:10.1113/jphysiol.2012.240739.
34. **Gagnon D**, **Kenny GP.** Sex differences in thermoeffector responses during exercise at fixed requirements for heat loss. *J Appl Physiol (1985)* 113: 746–757, 2012. doi:10.1152/japplphysiol.00637.2012.
35. **Charkoudian N**, **Johnson JM.** Modification of active cutaneous vasodilation by oral contraceptive hormones. *J Appl Physiol (1985)* 83: 2012–2018, 1997. doi:10.1152/jappl.1997.83.6.2012.
36. **Charkoudian N**, **Jm J.** Altered reflex control of cutaneous circulation by female sex steroids is independent of prostaglandins. *Am J Physiol Heart Circ Physiol* 276: H1634–H1640, 1999. doi:10.1152/ajpheart.1999.276.5.h1634.
37. **Charkoudian N**, **Stachenfeld N.** Sex hormone effects on autonomic mechanisms of thermoregulation in humans. *Auton Neurosci* 196: 75–80, 2016. doi:10.1016/j.autneu.2015.11.004.
38. **Gagnon D**, **Jay O**, **Lemire B**, **Kenny GP.** Sex-related differences in evaporative heat loss: the importance of metabolic heat production. *Eur J Appl Physiol* 104: 821–829, 2008. doi:10.1007/s00421-008-0837-0.
39. **Gagnon D**, **Kenny GP.** Sex modulates whole-body sudomotor thermosensitivity during exercise. *J Physiol* 589: 6205–6217, 2011. doi:10.1113/jphysiol.2011.219220.
40. **Epstein Y**, **Yanovich R**, **Moran DS**, **Heled Y.** Physiological employment standards IV: integration of women in combat units physiological and medical considerations. *Eur J Appl Physiol* 113: 2673–2690, 2013. doi:10.1007/s00421-012-2558-7.
41. **Kenny GP**, **Stapleton JM**, **Yardley JE**, **Boulay P**, **Sigal RJ.** Older adults with type 2 diabetes store more heat during exercise. *Med Sci Sports Exerc* 45: 1906–1914, 2013. doi:10.1249/MSS.0b013e3182940836.
42. **Notley SR**, **Poirier MP**, **Hardcastle SG**, **Flouris AD**, **Boulay P**, **Sigal RJ**, **Kenny GP.** Aging impairs whole-body heat loss in women under both dry and humid heat stress. *Med Sci Sports Exerc* 49: 2324–2332, 2017. doi:10.1249/MSS.0000000000001342.
43. **Armstrong CG**, **Kenney WL.** Effects of age and acclimation on responses to passive heat exposure. *J Appl Physiol (1985)* 75: 2162–2167, 1993. doi:10.1152/jappl.1993.75.5.2162.
44. **Rohrer JM.** Thinking clearly about correlations and causation: graphical causal models for observational data. *Adv Methods Pract Psychol Sci* 1: 27–42, 2018. doi:10.1177/2515245917745629.
45. **Kenny GP**, **Yardley J**, **Brown C**, **Sigal RJ**, **Jay O.** Heat stress in older individuals and patients with common chronic diseases. *CMAJ* 182: 1053–1060, 2010. doi:10.1503/cmaj.081050.