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Physiological Response and Adaptation to Heat Stress Among Florida Agricultural Workers in Hot and Cool Environments

By

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Environmental Health

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

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PURPOSE: Relationships between climate and health are of particular interest in the context of projected global temperature changes. A growing body of literature calls for the study of heat-related illnesses (HRI) in outdoor agricultural workers, whose jobs regularly involve strenuous activities in hot conditions. The aims of this study were to (1) compare physiological heat stress responses between Florida agricultural workers in hot and cool environments and (2) characterize differences in workers' use of adaptive strategies (clothing and fluid choices) to address heat stress in hot and cool conditions.
METHODS: Data were collected from 11 Florida fernery workers in winter and summer of 2015. In both seasons, participants wore heart rate monitors during three workdays and swallowed thermometers that tracked core temperatures for the same period. Participants answered questions about clothing and fluid choices. Paired t-tests and McNemar's tests were used to compare data by season. Clustered Cox regression was used to compare, by season, the time participants took to reach the Occupational Safety and Health Administration heat stress risk threshold (core temperature of 38°C) on each workday.
RESULTS: Physiological heat stress responses—as measured by average maximum core body temperatures and heart rates—did not differ by season (all $p>0.05$). The hazard of reaching the heat stress threshold also did not differ in the summer [HR 1.1 (95% CI 0.3-3.3)] compared to the winter. All participants reached the threshold at some point in the study, and equal numbers (9) of participants reached it in both seasons. Only work hours and reported use of wide-brimmed hats differed. In winter, participants reported working longer hours [8.2 (SD 1.5) vs. 6.0 (SD 1.0); $p<0.01$]. In summer, participants more often reported wearing wide-brimmed hats ($p=0.02$).
CONCLUSION: This study is the first to quantify and compare agricultural workers' physiological heat stress responses, and—despite its small sample size—its results reveal a nuanced relationship between climate and health. Although environmental temperatures in the winter and summer portions of this study were significantly different, participants' heat stress responses were largely the same; thus, vulnerability to HRI is determined by more than just high temperatures.

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Introduction

In the Southeastern region of the United States, average temperatures are expected to increase between 2.2 and 4.4°C during the next century (Petkova, Ebi, Culp, and Redlener, 2015). The relationship between climate and health is of particular interest in the context of this projected change, and the etiology of heat-related illnesses (HRI)—especially in vulnerable populations—requires further understanding (Barrow & Clark, 1998; Balbus & Malina, 2009; Spector & Sheffield, 2014; Gutierrez & LeProvost, 2016; USGCRP, 2016).

A growing body of literature calls for the study of HRI in outdoor agricultural workers, whose jobs regularly involve strenuous activities in hot conditions (Bethel & Harger, 2014; Spector & Sheffield, 2014; Kjellstrom, Holmer, and Lemke, 2009). Fernery workers in the state of Florida, for example, work under shade cloths in moist, humid environments and are paid according to a piece rate. No federal heat hazard regulations are in place to protect such workers, though the Occupational Safety and Health Administration (OSHA) recognizes that workers should not continue working when their core body temperature exceeds 38°C (Jackson & Rosenberg, 2010). Some agriculturally productive states, notably California and Washington, have implemented employer training and planning programs to protect agricultural workers from the effects of heat stress, but others, like Florida, have no HRI-preventive regulations. Addressing HRI in this population is critical, given workers' already high levels of chemical and pesticide exposures and low levels of health care access (Hansen & Donohoe, 2003).

A Vulnerability to Heat Hazards Framework informs the relationship between climate and health in this population of interest (Romero Lankao & Tribbia, 2009).

Vulnerability to HRI is determined by exposure to high temperatures but also by work intensity; both may alter core body temperatures. The higher blood perfusion rates that result from physical activity are associated with metabolic heat generation (Seng et al., 2016). Physiological responses to heat stress can trigger HRI through cellular damage, endotoxin release, and organ dysfunction. An individual's sensitivity—their demographic characteristics, acclimatization, and body composition—and adaptive capacity—their clothing choices, work practices, and fluid preferences—also interactively influence heat stress responses (Romero Lankao & Tribbia, 2009; Fleischer et al., 2013; Kwon, Park, Kim, and Lee, 2015).

Existing studies of heat stress in agricultural workers describe the prevalence of self-reported heat-related symptoms, including diarrhea, dizziness, headache, irritability, loss of coordination, and nausea. In independent studies in South Georgia, North Carolina, and Oregon, all conducted during summer months, upwards of 36% of surveyed farmworkers reported experiencing at least one HRI symptom; in one case, more than a third of the participants experienced three or more symptoms in the previous week (Fleischer et al., 2013; Mirabelli et al., 2010; Bethel & Harger, 2014). Literature also documents workers' use of adaptive strategies to manage the impacts of heat stress. Ninety-four percent of participants in the Oregon study, for instance, reported wearing baseball caps as head protection, 73% drank water at least once per hour, but 27% did not use any cooling measures in the past week (Bethel & Harger, 2014). In North Carolina, almost all participants reported drinking more water as an HRI prevention strategy, and others rested in shade or changed their work activities. Between 53.5% and 62.6% of participants in the South Georgia study reported drinking more juices and sodas when working in hot conditions, though sugary beverages—many of which are diuretics—are not encouraged for use as hydrators (Fleischer et al., 2013).

While previous studies assess workers' self-reported HRI symptoms and adaptive strategies, they do not explore physiological responses to heat stress, evaluate the potential for heat stress impacts in seasons other than summer, or compare the use of adaptive strategies under different meteorological conditions. Monitoring physiological responses in different seasons provides opportunities to isolate the impact of weather on heat stress and to better understand HRI within the Vulnerability to Heat Hazards Framework. This study aims to fill research gaps by (1) comparing physiological heat stress responses between agricultural workers in hot and cool environments and (2) characterizing differences in workers' use of adaptive strategies to address heat stress in hot and cool environments.

Methods

Data for this study were collected in an ongoing community-based participatory research project led by Emory University and the Farmworker Association of Florida (FWAF).

Subjects

Promotoras (community health workers) were hired by FWAF to recruit fernery workers from Pierson, FL. Data on 12 fernery workers were collected over 6 days in January 2015 to capture cool—or "winter"—working environment, and data on the same workers were collected over 13 days in May and June 2015 to capture hot—or "summer"—working environment. Participants were recruited for four days; baseline information was collected on the first day, and additional data were collected on the three following workdays. Participants reported to the testing station in the morning prior to traveling to their worksite. Heart rate and core body temperature monitoring devices were donned by the participants. At the end of the work shift, participants returned to the testing station, where all monitoring equipment was retrieved by study personnel.

Variables

To obtain environmental data, researchers compiled wet-bulb globe temperatures for the study periods from the Florida Automated Weather Network (Florida Automated Weather Network, 2015).

Promotoras collected information about participants' age, gender, body mass (BMI), body fat, work history, and marital status from survey questionnaires. Surveys additionally assessed workers' heat-protective behaviors, including workers' decisions to consume more water, alcohol, coffee, energy drinks, juice, soda, and sports drinks and their decisions to wear loose clothing, long-sleeved shirts, long pants, and wide-brimmed hats in hot, humid weather. Participants indicated in baseline questionnaires whether they "Always," "Usually," "Sometimes," "Rarely," or "Never" engaged in these adaptive practices. Dichotomous variables were created from these responses; the former three options were grouped into one category.

At baseline, each participant in the study swallowed an ingestible CorTemp® Sensor (HQInc., Palmetto, FL) that provided measurements of core body temperature (T_{ret}) every 30 seconds. During the workday, participants wore a heart rate monitor to detect heart rate (HR_t), also at 30 second intervals. These variables measure heat stress response and were used in the calculation of the Physiologic Strain Index (PSI), a composite heat stress indicator (Moran, Shitzer, and Pandolf, 1998):

$$PSI = 5(T_{ret} - T_{re0})x(39.5 - T_{re0})^{-1}+5(HR_t - HR_0)x(180 - HR_0)^{-1}$$

Initial heart rate (HR_0; standing or sitting) and body temperature (T_{re0}; orally or internally depending on pill presence) were measured each morning. At the beginning and end of each workday, researchers determined if temperature sensors had been excreted, and, if so, participants were given another pill.

Analyses accounted for the lag between the time workers began wearing their heart rate monitors and the start of their workday and for the period between the end of their workday and their removal of heart rate monitors; only observations between the first concurrent core body temperature and heart rate measurement plus 30 minutes and the last concurrent core body temperature and heart rate measurement minus 30 minutes were used in this study. Core body temperature measurements were excluded when the sensor battery died, the pill had been excreted, and on days when the percent of missing observations was high. Core body temperature monitoring times for each day were determined based on these restrictions.

A dichotomous variable was created to record whether an individual reached or exceeded the OSHA heat stress risk threshold (at least two consecutive core body temperature values at or above 38°C) on each study day. The time participants took to reach the threshold, the time spent at or above it, and the percent of total monitoring time spent at or above or the threshold were calculated for each study day.

Analysis

Baseline descriptive statistics were determined for both discrete variables—ethnicity, nationality, gender, and marital status—and continuous variables—age, years of school, and years worked in agriculture in the US.

Maximum wet-bulb globe temperatures were identified for each study date, averaged by season, and compared by season using a one-sided independent samples t-test. Two-sided paired t-tests were used to compare average workday durations, average BMI, and average percent body fat. For these tests, pairs were comprised of the same worker in hot and cool weather environments (i.e. a worker in the summer was paired with his/herself in the winter).

Maximum PSI values, core body temperatures, and heart rates over all three study days were determined, and the averages of these values were compared by season with paired t-tests as well. Average monitoring times, average maximum core body temperatures, and average heart rates were also compared by season on *each* study day, and pairs were comprised of the same worker on the same workday for these stratified paired t-tests. Assumptions for all statistical tests were assessed by examining the normality of the data. Exceedance of the OSHA heat stress risk threshold was compared by season using McNemar's test. Average time to threshold, average time above or at the threshold, and average percent of monitored time above or at the threshold were determined for each study day. Cox regression was used to compare the hazard rate of reaching or exceeding the threshold on each study day. The time to the first instance of threshold exceedance was included as a time variable, and observations were grouped by season. Because participants contributed both winter and summer observations, each person was considered a cluster in the analysis (Lee, Wei, and Amato, 1992). The proportional hazards assumption was evaluated by a correlation analysis of Schoenfeld residuals and ranked follow-up time.

The small sample size in this study inhibited multivariate regression analyses, but relationships between maximum core temperature and maximum heart rate and gender, age, BMI, percent body fat, and environmental temperature were explored visually.

Adaptive practices for the workers in hot and cool environments were compared using McNemar's tests.

All analyses were completed in SAS, version 9.4 using an alpha level of 0.05.

Results

Eleven workers (92% retention) participated in both portions of the study. Table 1 presents demographic characteristics of the study participants. All 11 participants claimed Mexican nationality and identified as Hispanic or Latino. Six were women, and 6 were married. The average age of participants was 38.6 years (SD 9.5). Participants had an average of 6.4 years of schooling (SD 3.4), and had worked in agriculture in the US for an average of 15.6 years (SD 6.7).

The mean of maximum summer wet-bulb globe temperatures, measured over 13 days, was significantly higher than the mean of maximum winter wet-bulb globe temperatures, measured over 6 days [25.6°C (SD 1.2) vs. 13.3°C (SD 4.6); $p<0.01$] (Table 2).

Participants' physiological differences in the winter and summer are described in Table 2. Average BMI did not differ significantly in the two seasons ($p=0.85$). Average percent body fat, however, was significantly higher in the summer [30.3% (SD 6.7)] than the winter [27.6% (SD 7.29)].

According to participants' self-report, the average days worked per week were similar in the winter and summer [5.0 (SD 0.0) vs. 4.6 (SD 0.8); $p=0.2$], but hours worked per day were greater in the winter season compared to the summer season [8.2 (SD 1.5) vs. 6.0 (SD 1.0); $p<0.01$] (Table 2).

Monitoring time of participants' core body temperatures was significantly less in the summer ($p \leq 0.02$), reflecting this difference in workday duration. Average monitoring times ranged from 7.0-7.6 hours (SD 0.3-0.6) in the winter and 4.5-5.5 hours (SD 1.1-2.11) in the summer, depending on the study day (Table 2). Temperature data for all 11 participants were available for at least one day over the three-day study period, but since participants were excluded based on missing observations or expelled sensors, the number of participants monitored varied by day. Data were not available on the first study day for one participant in the summer because of a high percent of missingness. Data for 10, 8, and 7 pairs were available for first, second, and third study days, respectively.

When maximum workday core body temperatures were averaged—with maximum readings considered both over individual study days and over the entire three-day study period—summer and winter temperatures did not differ significantly (all $p>0.05$) (Table 2). The mean of participants' maximum core body temperatures over the study period was 38.2°C (SD 0.2) in the winter and 37.8°C (SD 1.2) in the summer. Figure 1 presents maximum core body temperatures in relation to daily maximum wet-bulb globe temperatures. Most observed maximum core body temperatures were to 38°C, though more variation was found at higher temperatures.

Average maximum workday heart rates tended to be higher in the winter than the summer, but differences were not significant (all $p>0.05$) (Table 2). Heart rates did not appear to vary with maximum wet-bulb globe temperatures (Figure 2).

Temperature and heart rate measurements were originally intended for use in the calculation of a physiological strain index (PSI), but daily baseline measurement of these parameters was not standardized, and PSI values were falsely negative (data not shown).

Tables 3 and 4 summarize participants' exceedance of the OSHA heat stress risk threshold (38°C). All participants reached or exceeded the threshold in either the winter or the summer; 7 participants reached or exceeded the threshold in both the winter and the summer; and a total of 9 participants and 9 participants in the winter and summer, respectively, reached or exceeded the threshold (Tables 3 and 4). These results collectively suggest no seasonal difference in participants' exceedance of the threshold.

Because the number of pairs exceeding the threshold on each study day represent only a subset of monitored pairs, pairwise statistical comparisons of mean time to threshold, mean time spent at or above the threshold, and mean percent of monitored time spent at or above the threshold by season were not attempted. Mean time to threshold was between 1.9-3.8 hours (SD 0.5-1.7) in both seasons. Participants spent an average of over three hours at or above the threshold on two of three study days in the winter and close to one hour at or above the threshold in the summer, though variances for these means and the mean percent of monitored time spent at or above the threshold were high (Table 4).

On Day 1, the hazard rate of reaching or exceeding the threshold was not significantly different in the summer compared to the winter [HR 1.1 (0.3-3.3)] (Table 4). Data were sparse and/or did not meet the proportional hazards assumption on the second and third study days; therefore, hazard ratios on these days are not reported (data not shown).

Relationships between individual characteristics and physiological heat stress responses were explored visually. Maximum core body temperatures did not appear to vary by age, BMI, or percent body fat, and these factors do not appear to modify the impact of season on stress responses. Maximum heart rates did not appear to vary by these factors, either (Figures S2-S7). Gender did not appear to influence differences in summer and winter maximum core body temperatures, though more variation in the differences was observed among males (Figure 3). Summer maximum heart rates were higher in the summer among women, whereas little or positive differences between heart rates in the summer and winter were found among men (Figure 4).

Adaptive practices were alike in the winter and summer (Table 5). In both seasons, all participants reported drinking more water during hot and humid weather, and none reported drinking alcoholic beverages or coffee during the workday (data not shown). Season did not influence differences in participants' consumption of juice, soda, or sports drinks during hot and humid weather, nor did it determine differences in participants' decisions to wear long-sleeved shirts in hot and humid weather (all $p>0.05$). All participants reported wearing light, loose-fitting clothing in both seasons (data not shown). Significant ($p=0.02$) differences in participants' use of wide-brimmed hats in hot and humid weather were observed in the winter and the summer; 7 participants reported "Always," "Usually," or "Sometimes" wearing wide-brimmed hats in the summer and "Rarely" or "Never" wearing them in the winter.

Discussion

While physiological heat stress responses and adaptive practices were largely similar among participants in the winter and the summer, the results presented here may offer directions for public health professionals, outdoor workers, and their employers. All 11 participants in this study reached or exceeded the OSHA heat stress risk threshold (a core body temperature of 38°C) on at least one workday. Seven of the 11 participants reached or exceeded the threshold in both the winter and the summer, and the hazard rate of reaching or exceeding the threshold did not differ by season. The regularity with which participants reached or exceeded the threshold—in both hot and cool conditions—is cause for concern, and the results suggest the importance of factors other than environmental temperature in the development of heat-related illnesses. Participants' greater self-reported use of wide-brimmed hats in the summer, for example, may have mediated the relationship between working conditions and physiological heat stress responses. Participants also worked longer hours in the winter, and it is possible that the intensity of their work in cooler conditions yielded metabolic heat generation comparable to the added environmental heat exposure in the summer.

Agricultural workers have previously reported changing work hours or activities to prevent HRI (Mirabelli et al., 2010). Of the 11 Florida fernery workers surveyed in this study, however, 8 (72%) said they never change their hours to combat heat stress (data not shown). Seasonal differences in work hours may rather reflect demand for ferns, which may be higher in weeks leading up to holidays like Valentine's Day and lower in the summer. In both seasons, workers are paid according to a piece rate, and extra rest and hydration breaks are not mandated, which may lead to physiological overextertion. While workers may be able to pursue adaptive practices to minimize heat stress, they may not be able to alter other conditions, and the limits of their control over workplace environments should be acknowledged (Kwon et al., 2015; Lam et al., 2013).

This study has several strengths. It is the first to compare agricultural workers' physiological heat stress responses in hot and cool environments. In one study of fruit and vegetable harvesters in central Italy, researchers used ambient weather conditions, participants' clothing choices, and workers' physical activity to calculate a predicted heat strain (PHS) (Cecchini, Colantoni, Massantini, and Monarca, 2010). Rectal temperatures did not exceed the heat stress risk threshold when modeled using this approach, though projections for only 5 participants were made. The present study directly measured core body temperatures and heart rates with innovative real-time monitoring methods. The use of matched pairs in this study allowed each participant to serve as his or her own cool-weather "control," and comparisons of physiological heat stress responses in the summer and winter thus implicitly account for some demographic confounders. The multi-day study design additionally provided opportunities to stratify results by study day and to collect more measurements for each participant. This study is also the first to consider differences in workers' use of adaptive practices in these different working conditions. This research thus importantly addresses participants' vulnerability, sensitivity, and adaptability to heat stress—albeit separately.

This study also has several limitations. Its small sample size impeded multivariate regression analyses, and it may not have had sufficient power to detect any true differences that exist between seasons. Missing temperature observations further restricted sample sizes, and pairwise comparisons of seasonal differences could not always be completed. In addition, interviewer bias may have been present; participants received educational materials about HRI prevention from *promotoras*, and their answers to questions about adaptive practices may reflect knowledge rather than actual behaviors.

Results may not be generalizable for these reasons. Inconsistent baseline temperature and heart rate measurements, furthermore, prevented the calculation of accurate physiological strain index (PSI) values. The PSI and similar indices, which incorporate core temperature and heart rate into a single measurement, have been used in studies of athletes and military personnel, and researchers consider them comprehensive ways to evaluate dynamic and interrelated heat stress responses (Seng et al., 2016; Dehghan & Sartang, 2015).

Despite these limitations, the results of this study should be consulted in the creation of heat protection policies and regulations, especially in states like Florida, where no state-level standards exist. Heat protection recommendations—taking breaks, resting in shade, staying hydrated, and wearing light clothing and hats—should be emphasized in hot *and* cool conditions. Employers should also be held responsible for creating work atmospheres that prioritize workers' health over productivity, since work intensity may contribute to heat stress responses regardless of environmental temperatures. Increased advocacy for (im)migrants' rights may improve these work atmospheres and ultimately benefit workers' health and safety (Dutta et al., 2015).

In the ongoing study, researchers will evaluate the agreement of workers' self-reported symptoms with these physiological data to better understand workers' perceptions of heat stress. As enrollment increases, multivariate analyses can be used to better characterize nuanced relationships between environmental temperature, potential confounders and effect modifiers—like work intensity, adaptive practices, gender, physical characteristics, workplace tasks, and ergonomic behavior—and physiological heat stress outcomes.

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Tables

Table 1. Demographic characteristics of study participants.

Characteristic (overall N=11)	
	N (%)
Hispanic or Latino	11 (100%)
Mexican nationality	11 (100%)
Female	6 (55%)
Married	6 (55%)
	Mean (SD)
Age	36.8 (9.5)
Years of school	6.4 (3.4)
Years worked in agriculture in the US	15.6 (6.7)

Table 2. Environmental conditions, work characteristics, and physiological differences in the winter and summer.

	N (pairs)*	Winter	Summer	
		Mean (SD)		p-value**
Maximum wet-bulb globe temperature (°C)***		13.3 (4.6)	25.6 (1.2)	<0.01
Body composition				
BMI	11	28.4 (2.5)	28.5 (2.8)	0.85
% Body Fat	11	27.6 (7.3)	30.3 (6.7)	<0.01
Work characteristics				
Days worked per week (self-reported)	11	5.0 (0.0)	4.6 (0.8)	0.2
Hours worked per day (self-reported)	11	8.2 (1.5)	6.0 (1.0)	<0.01
Hours monitored for core temperature readings				
Day 1	10	7.1 (0.5)	5.5 (1.6)	0.01
Day 2	8	7.0 (0.3)	4.8 (2.1)	0.02
Day 3	7	7.6 (0.6)	4.5 (1.1)	<0.01
Core stress responses				
Maximum workday core temperature (°C)****	11	38.2 (0.2)	37.8 (1.2)	0.36
Day 1	10	38.0 (0.2)	37.6 (1.3)	0.34
Day 2	8	38.0 (0.2)	37.6 (1.3)	0.37
Day 3	7	37.9 (0.2)	37.4 (1.6)	0.45
Maximum workday heart rate (beats per minute)****	11	188.0 (23.0)	180.3 (19.3)	0.14
Day 1	11	183.8 (21.5)	162.0 (28.7)	0.10
Day 2	11	165.6 (32.0)	166.7 (21.8)	0.91
Day 3	11	153.9 (20.2)	149.4 (23.6)	0.39

*After accounting for expelled or malfunctioning temperature sensors.
**From paired t-test unless otherwise indicated.
***A one-tailed independent samples t-test was used to compare winter and summer means. A total of 6 days were observed in the winter, and 13 days were observed in the summer.
****Row represents maximum values over all 3 study days.

Table 3. Winter-Summer pairs exceeding the Occupational Safety and Health Administration (OSHA) heat stress risk threshold (38°C) on any of up to 3 study days.

	Reached or exceeded threshold in winter	**Did not reach or exceed threshold in winter**	Total
Reached or exceeded threshold in summer	7	2	9
Did not reach or exceed threshold in summer	2	0	2
Total	9	2	11
McNemar test statistic (p-value)			0.0 (1.0)

Table 4. Exceedance of Occupational Safety and Health Administration (OSHA) heat stress risk threshold (38°C).

	Winter	**Summer**	
	N/Total Monitored* (%)		
Individuals reaching or exceeding threshold**	9/11 (82%)	9/11 (82%)	
Day 1	5/11 (45%)	5/10 (50%)	
Day 2	6/9 (67%)	6/10 (60%)	
Day 3	3/10 (30%)	4/7 (57%)	
	Mean (SD)		
Time to threshold during each workday (hours)***			
Day 1	1.9 (1.0)	3.6 (1.5)	
Day 2	3.8 (1.5)	2.5 (1.4)	
Day 3	2.6 (0.5)	3.0 (1.7)	
Time spent at or above threshold during each workday (minutes)***			
Day 1	185.1 (88.8)	46.7 (34.4)	
Day 2	62.4 (52.0)	72.8 (54.5)	
Day 3	191.8 (166.7)	50.1 (57.8)	
% of monitored time spent at or above threshold***			
Day 1	44.9 (23.3)	13.7 (8.6)	
Day 2	14.9 (13.3)	24.0 (17.9)	
Day 3	38.4 (32.3)	17.0 (20.7)	
	Hazard Ratio (95% CI)		**p-value**
Reached or exceeded threshold during Day 1	1.0 (referent)	1.1 (0.3-3.3)	0.88

*After accounting for expelled or malfunctioning temperature sensors.

**Row represents any exceedance over the 3-day study period.

***Among those who reached or exceeded the threshold.

Table 5. Adaptive practices among participants in the winter and summer.

Table 5a. Participants' responses to "do you drink MORE juice during hot and humid weather?"

	Responded "Yes" in winter	**Responded "No" in winter**	Total
Responded "Yes" in summer	0	1	1
Responded "No" in summer	3	7	10
Total	3	8	11
McNemar test statistic (p-value)			1.0 (0.63)

Table 5b. Participants' responses to "do you drink MORE soda during hot and humid weather?"

	Responded "Yes" in winter	**Responded "No" in winter**	Total
Responded "Yes" in summer	5	0	5
Responded "No" in summer	3	3	6
Total	8	3	11
McNemar test statistic (p-value)			3.0 (0.25)

Table 5c. Participants' responses to "do you drink MORE sports drinks during hot and humid weather?"

	Responded "Yes" in winter	**Responded "No" in winter**	Total
Responded "Yes" in summer	3	1	4
Responded "No" in summer	2	4	6
Total	5	5	10
McNemar test statistic (p-value)			0.3 (1.00)

Table 5d. Participants' responses to "in GENERAL, while working or spending time outside in hot and humid weather, do you wear long-sleeved shirts?"

	Responded "Always," "Usually," or "Sometimes" in winter	**Responded "Rarely" or "Never" in winter**	Total
Responded "Always," "Usually," or "Sometimes" in summer	8	0	8
Responded "Rarely" or "Never" in summer	2	1	3
Total	10	1	11
McNemar test statistic (p-value)			2.0 (0.50)

Table 5e. Participants' responses to "in GENERAL, while working or spending time outside in hot and humid weather, do you wear a wide-brimmed hat?"

	Responded "Always," "Usually," or "Sometimes" in winter	**Responded "Rarely" or "Never" in winter**	Total
Responded "Always," "Usually," or "Sometimes" in summer	3	7	10
Responded "Rarely" or "Never" in summer	0	1	1
Total	3	8	11
McNemar test statistic (p-value)			7.0 (0.02)

Figures

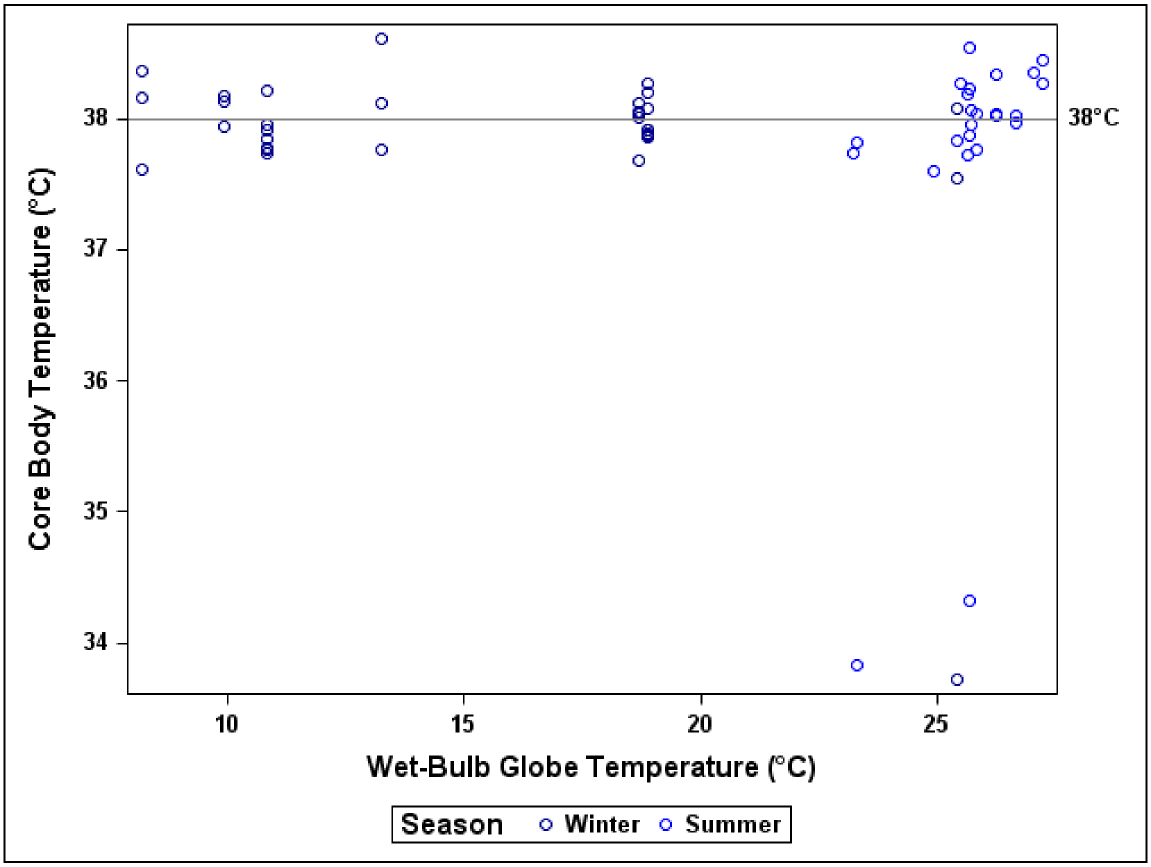

Figure 1. Relationship between maximum daily wet-bulb globe temperature and maximum workday core body temperature by season.

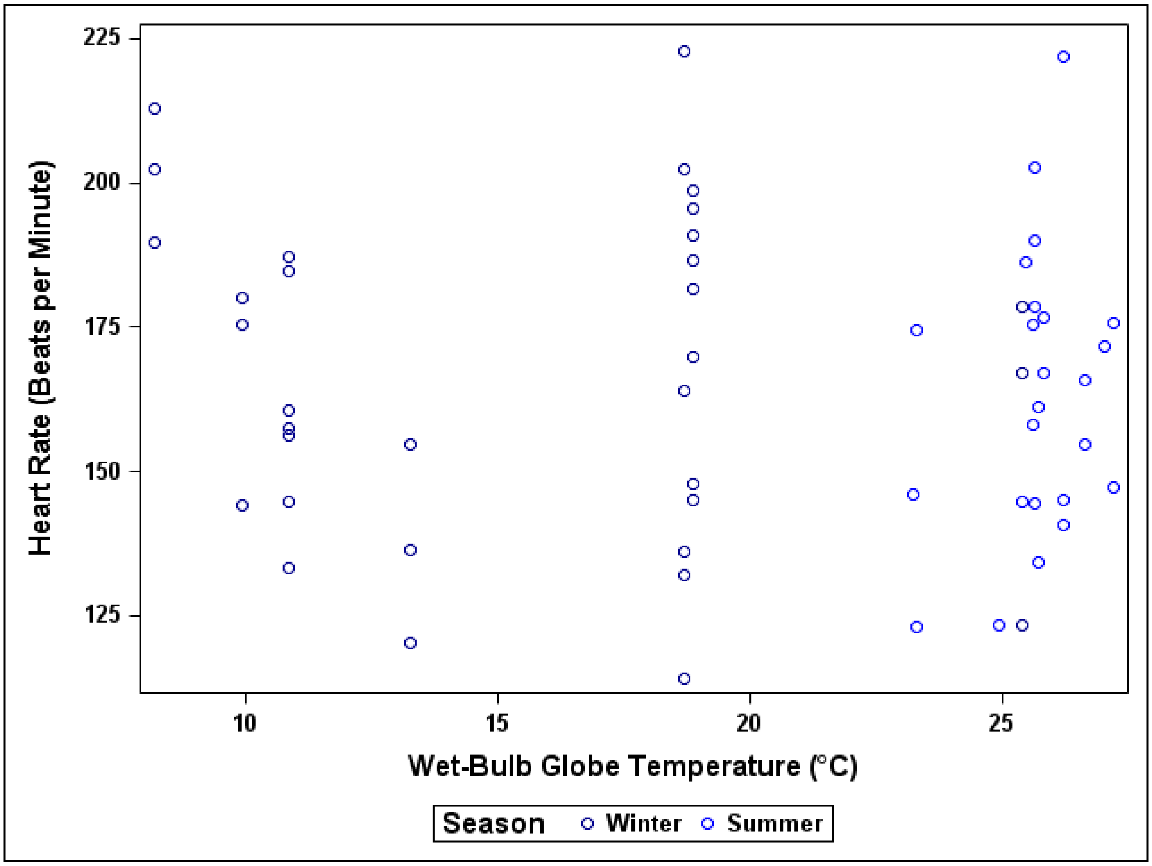

Figure 2. Relationship between maximum daily wet-bulb globe temperature and maximum workday heart rate by season.

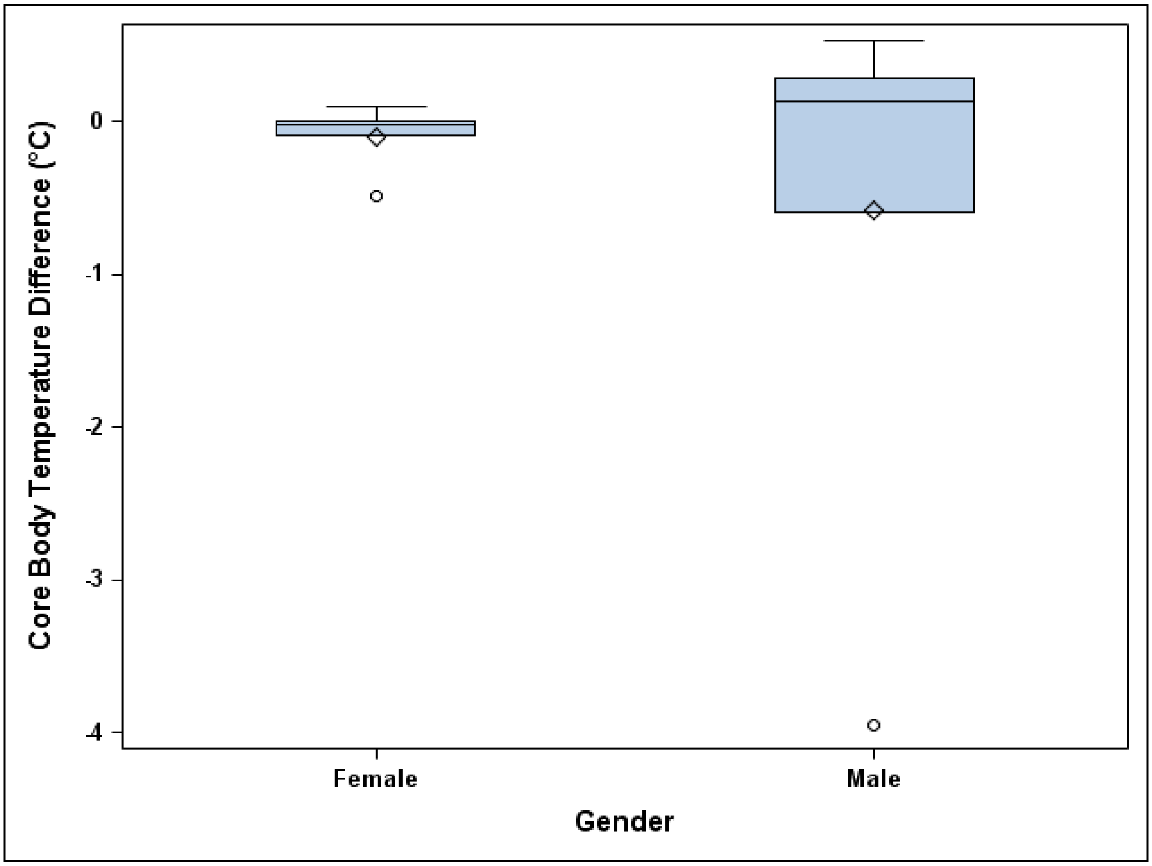

Figure 3. Differences (summer-winter) in overall maximum workday core body temperature by gender.

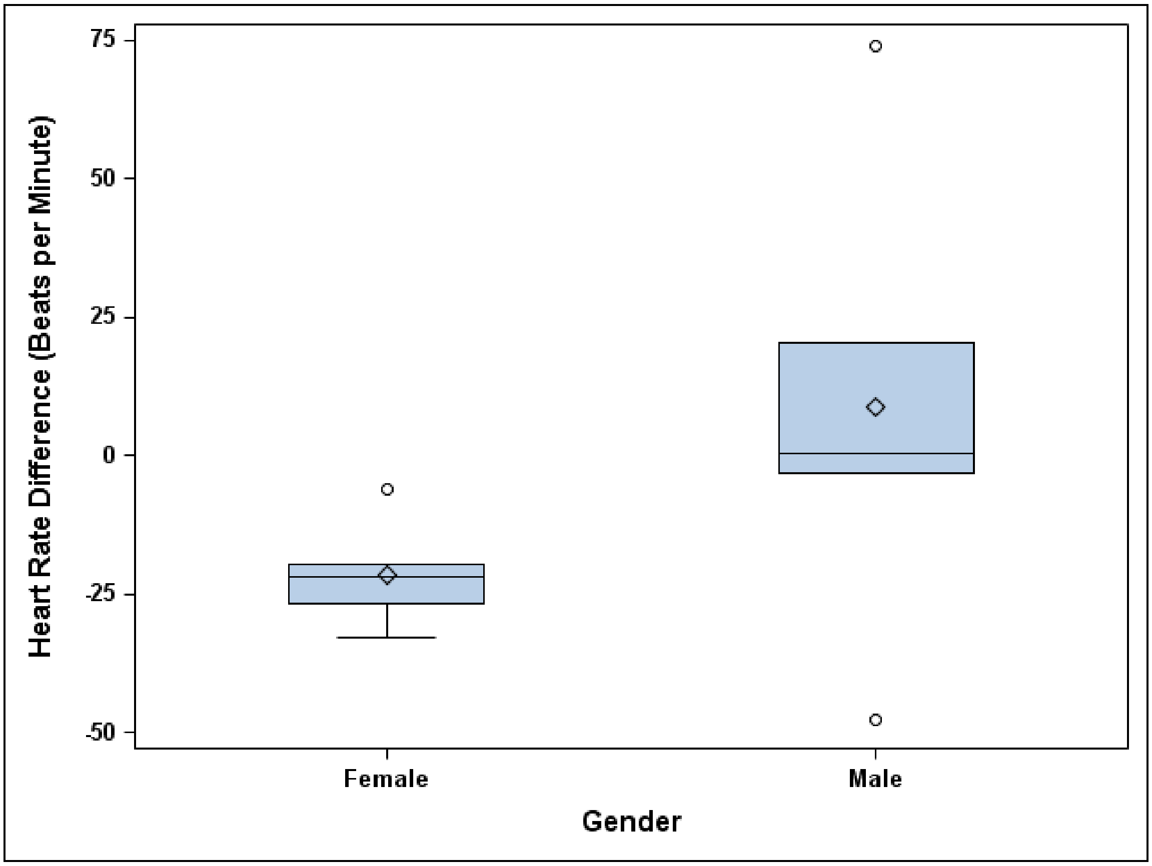

Figure 4. Differences (summer-winter) in overall maximum workday heart rate by gender.

Supplementary Figures

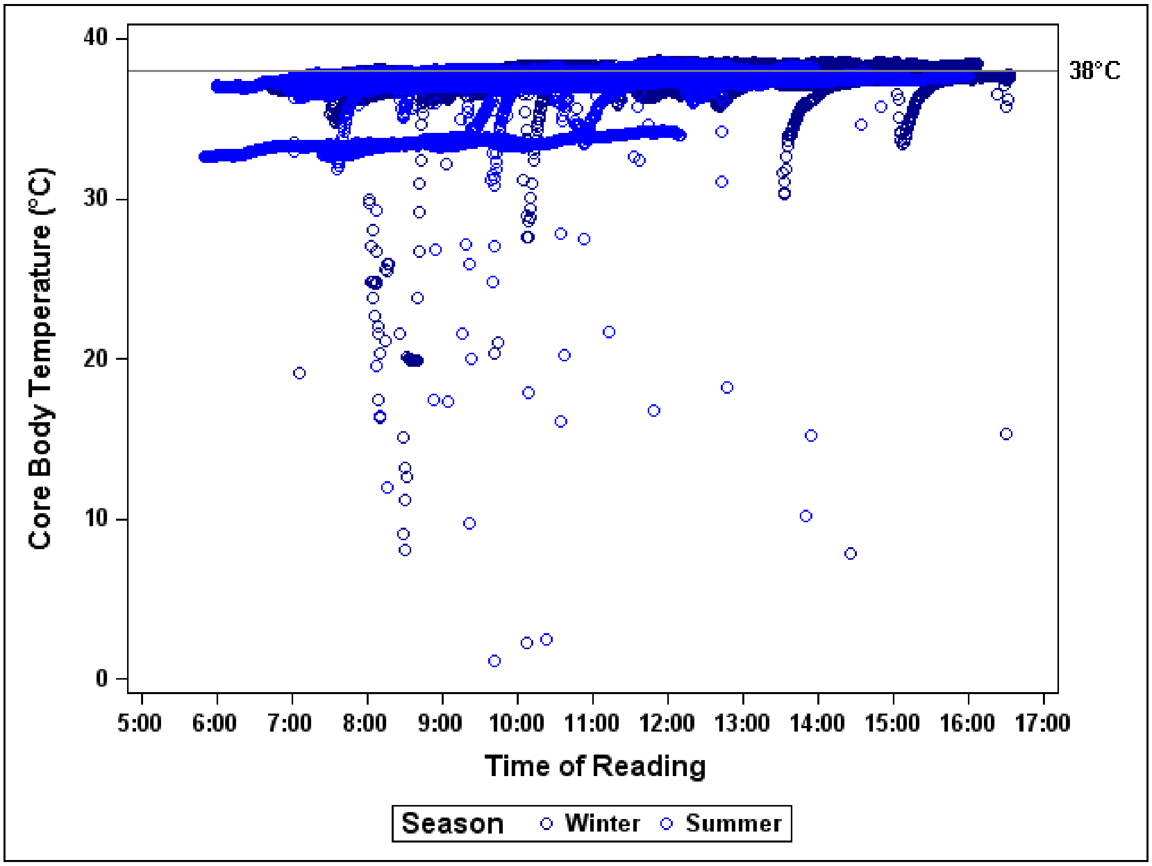

Figure S1. Relationship between time of day and core body temperature during the workday by season.

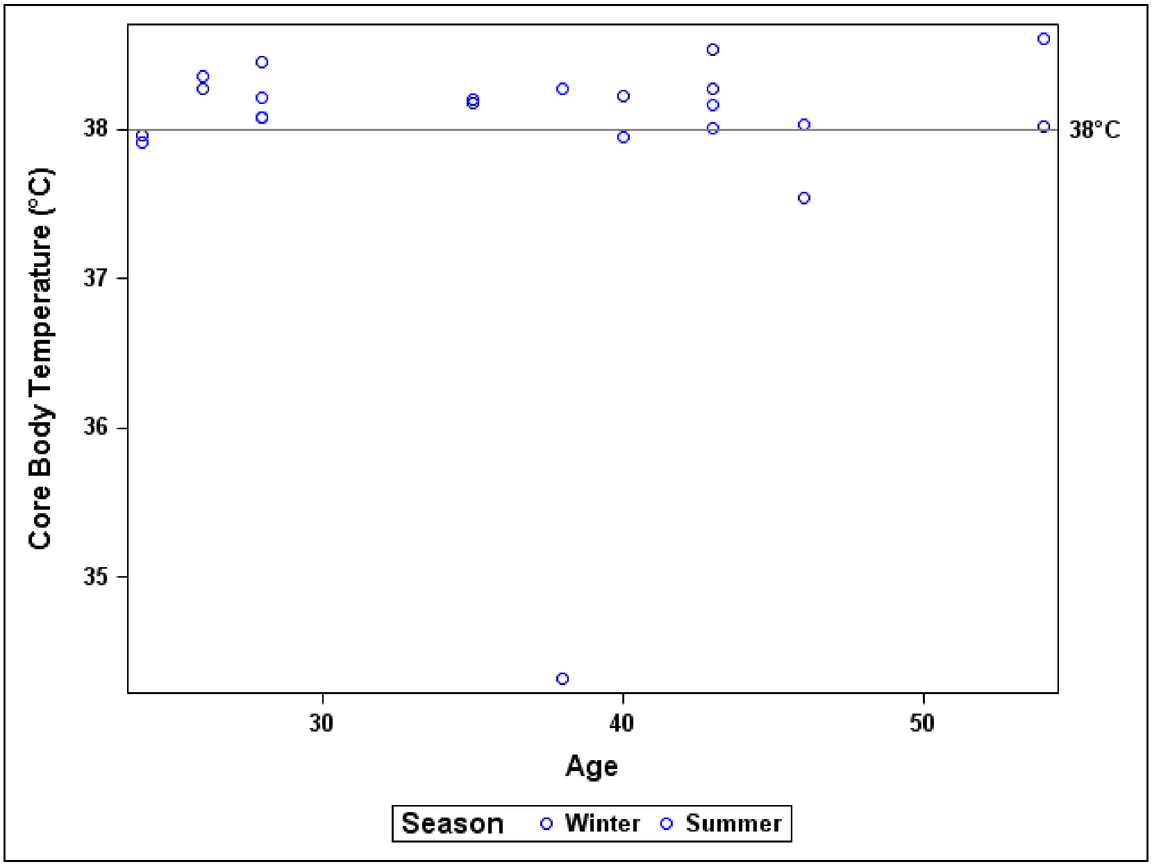

Figure S2. Relationship between age and overall maximum workday core body temperature by season.

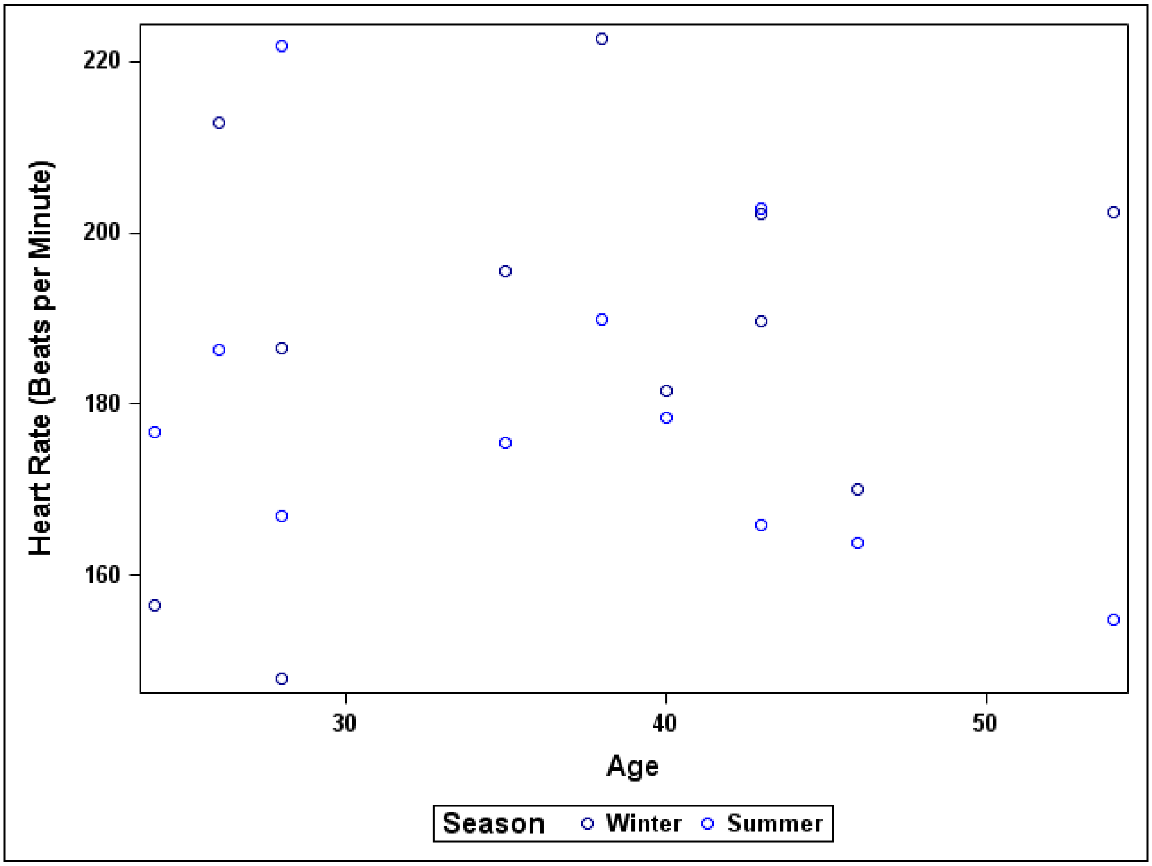

Figure S3. Relationship between age and overall maximum workday heart rate by season.

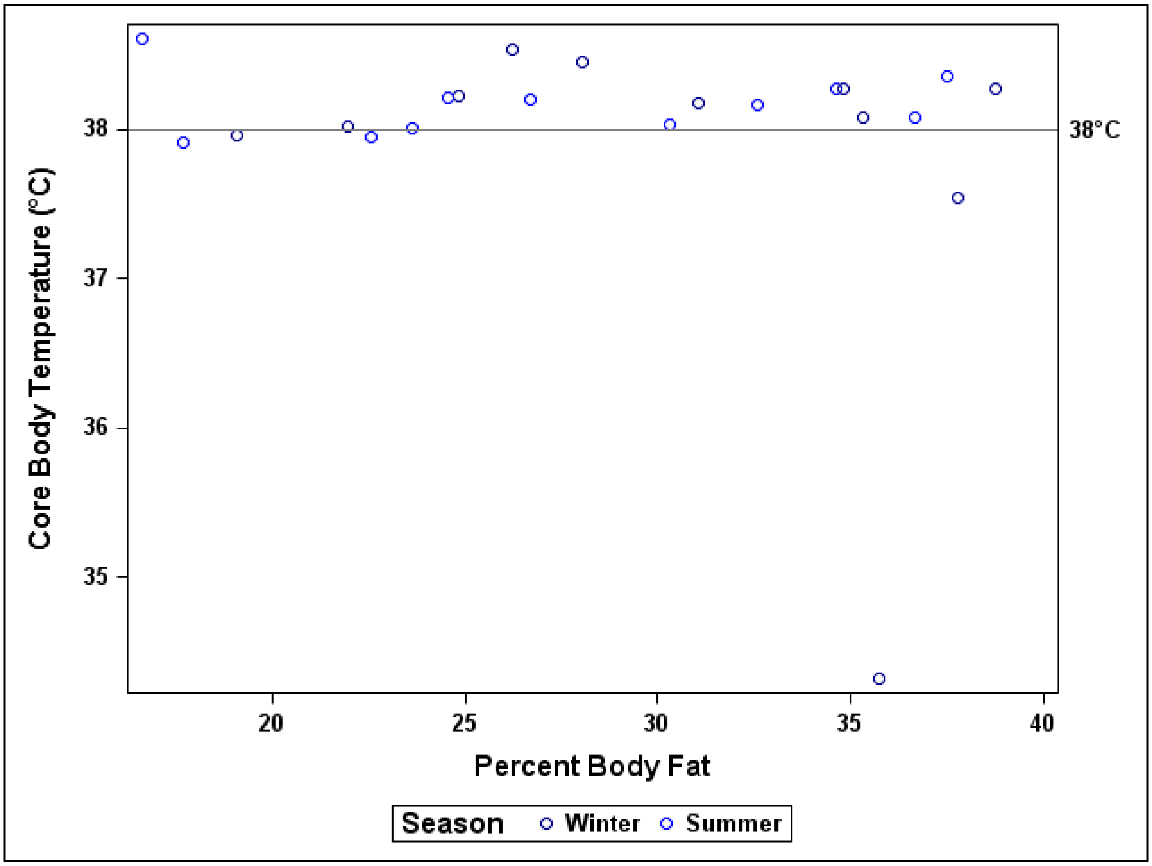

Figure S4. Relationship between percent body fat and overall maximum workday core body temperature by season.

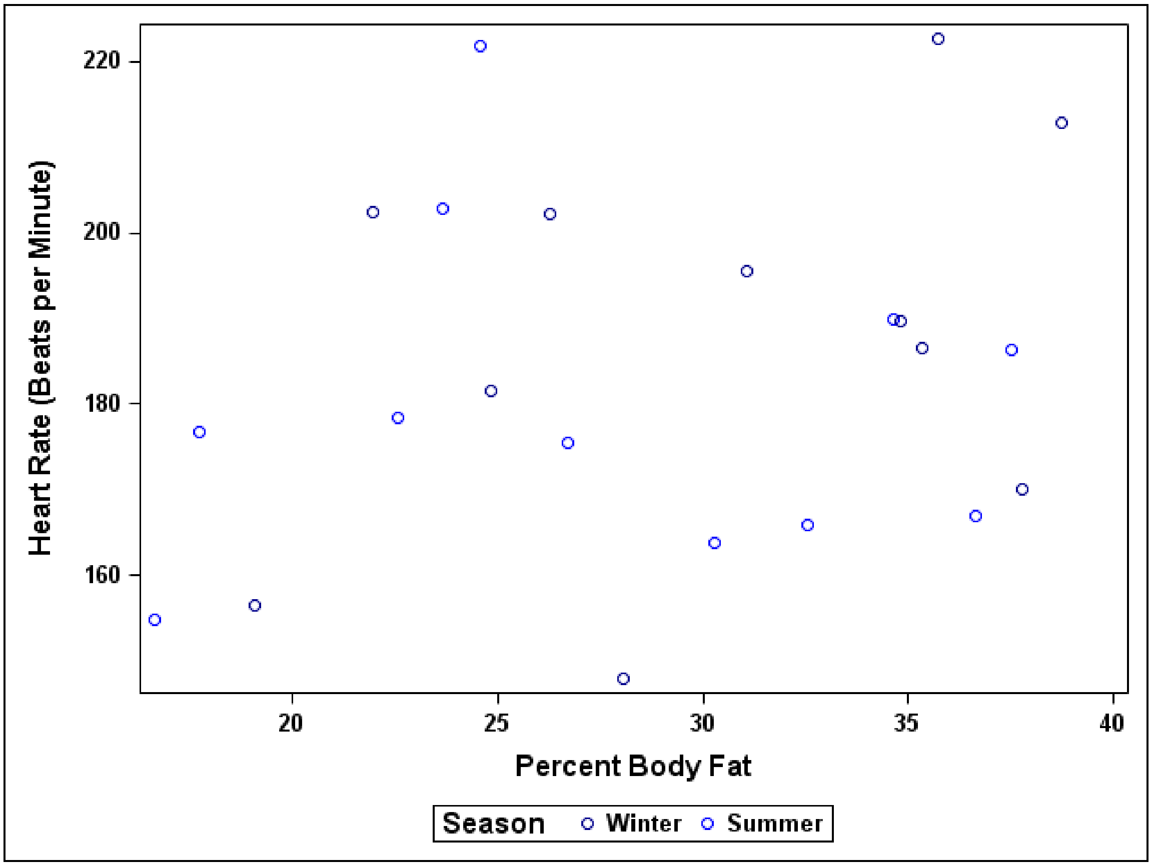

Figure S5. Relationship between percent body fat and overall maximum workday heart rate by season.

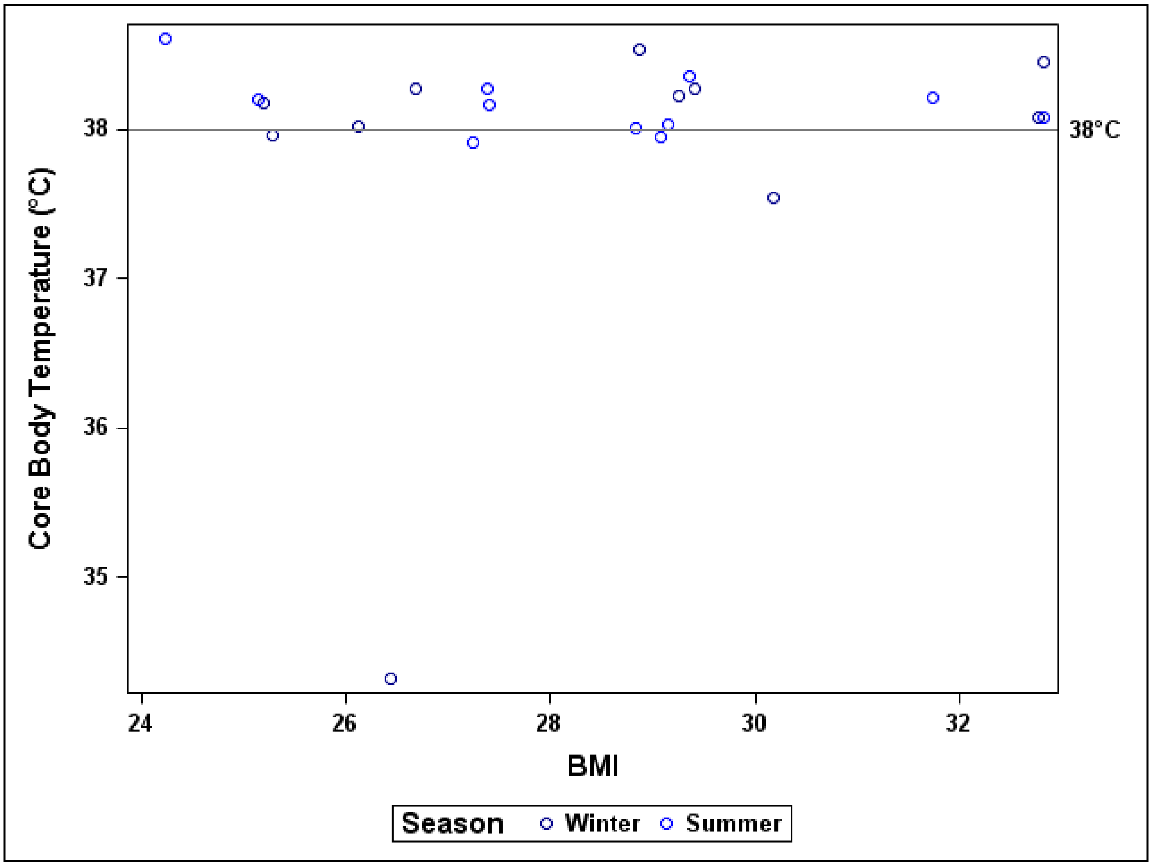

Figure S6. Relationship between BMI and overall maximum workday core body temperature by season.

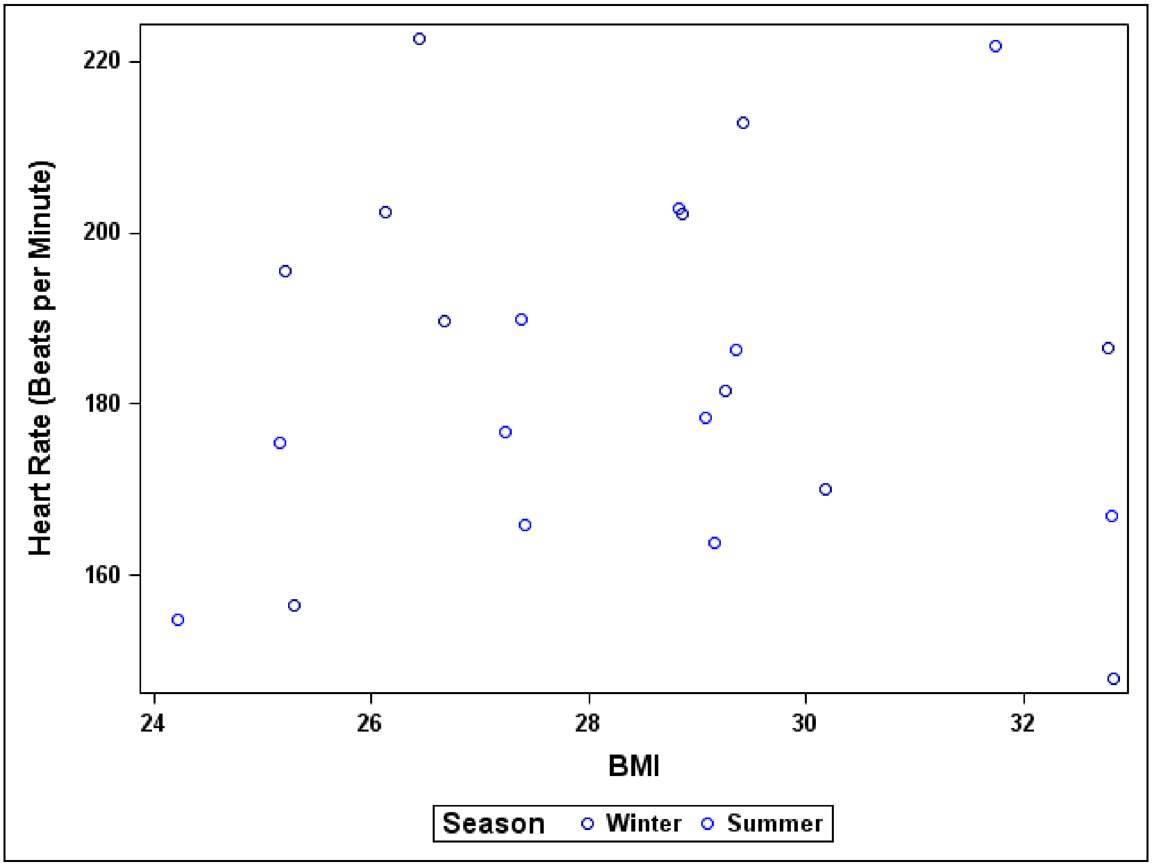

Figure S7. Relationship between BMI and overall maximum workday heart rate by season.