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Probability of hyperthermia in a hot environment while wearing a liquid cooling garment underneath firefighters' protective clothing

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Abstract

Firefighters' protective clothing (FPC) can limit human thermoregulation due to limited water vapor permeability and insulation. This study investigated the effect of cooling on the physiological responses and probability of hyperthermia in subjects wearing FPC during exercise in a hot environment. Twelve males participated in this study. A maximal graded treadmill exercise test was performed to measure maximal oxygen uptake ($\dot{V}O_{2max}$) and to assess subjects' capacity to perform the assigned exercise. Exercise included treadmill walking at 40% $\dot{V}O_{2max}$ in warm ($30\,^{\circ}C$) and humid (70% RH) conditions for 40 min while wearing FPC. Subjects participated in two randomly counterbalanced assigned experimental protocols: control (no cooling) and intervention (cooling). The experimental intervention consisted of a cooling garment infused with cooled water ($18\,^{\circ}C$) through silastic tubing sewn into the fabric and worn underneath FPC. Each subject served as their own control and, therefore, completed both the control and intervention of the protocol. A logistic regression model was used to analyze the interaction effect of cooling on the probability of progression to hyperthermia ($T_c \geq 38\,^{\circ}C$). Subjects' physiological responses increased during exercise in a warm and humid environment. Active cooling decreased ($p < 0.05$) the thermal stress thereby reducing the probability of hyperthermia while exercising in hot and humid conditions. The results indicate that when cooling was used each subject, on average, was 91% less likely to reach the lower threshold limit of hyperthermia. Exercise in hot environments while wearing FPC results in significant physiological strain, which may lead to hyperthermia. Utilization of a cooling garment reduced physiological strain and the probability of hyperthermia.

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Keywords

Continuous cooling; firefighters; heat stress; PPE; work physiology

Introduction

Firefighters often work while exposed to high-temperature conditions, which range from 100 °C to 30 °C (Krasny et al. 1988; Rossi 2003). Under extremely hot conditions, uncompensated heat loading among firefighters may occur due to the production of metabolic heat combined with wearing encapsulating firefighters' protective clothing (FPC) which limits heat transfer from the body. The Threshold Limit Values (TLVs®) guidelines provided by the American Conference of Governmental and Industrial Hygienists (ACGIH®) were established to assure that heat balance and body core temperature (T_c) do not exceed a lower threshold limit of 38 °C for extended periods of work while wearing encapsulating protective clothing (ACGIH 2017). In addition, the guidelines provided by the National Fire Protection Association (NFPA) Standard 1584 recommend that firefighters' T_c be maintained between 36 °C and 38 °C (NFPA 2008). The effect of heat stress on physiological functions, such as heart rate (HR) and other cardiovascular variables, poses a serious safety issue. Indeed, since 1977 between 45% and 60% of active duty firefighters fatalities that occur are related to cardiovascular events (Kales et al. 2007; Banes 2014). HR remains elevated for more than 1 hr after strenuous exercise in the heat (Mani et al. 2013). If effective intervention strategies are not put in place to manage a significantly elevated HR, extended exposure to heat stress may lead to cardiovascular strain or acute cardiovascular events (CDC/NIOSH 2007; Elsner and Kolkhorst 2008).

A live burn firefighting study (Mani et al. 2013) showed that over 12% of firefighters had sustained T_c above the lower threshold limit of hyperthermia (> 38 °C) for 2–3 hr after completing 50 min of live burn training. The study also showed that firefighters exceed the recommended upper limit for HR elevation (≥ [180 - age]) (ACGIH 2017) associated with physical exertion during live burn training exercises (Mani et al. 2013).

From a physiological standpoint, the natural thermoregulatory mechanisms of the human body are ineffective while wearing personal protective clothing (Barr et al. 2010). The encapsulating nature of the FPC inhibits the normal heat transfer mechanisms of the body, especially sweat vaporization. Thus, an additional cooling method may be needed to reduce heat stress (Barr et al. 2010).

Several studies have investigated the effects of different active cooling methods on physiological responses while working in diverse hot environments. These methods include the use of ice vests, air-cooled vests, and liquid-circulated garments suggesting that active cooling may help reduce heat stress and recovery time and increase work productivity in hot environments (Bennett et al. 1995; Selkirk et al. 2004; Barr et al. 2011; Katica et al. 2011; Kim et al. 2011). A study (Kim et al. 2011) determined that a cooling method consisting of a wearable liquid cooling garment (LCG) that circulates cold water (18 °C) while worn underneath encapsulating FPC is an effective method to reduce thermal strain, enhance recovery, and extend exercise performance time in subsequent bouts of exercise. However, further exploration of the effect of this cooling method on hyperthermia is warranted.

The objective of this study was to investigate the interaction effect of continuous cooling on the physiological responses and to determine the probability of achieving the lower threshold limit of hyperthermia while wearing a liquid cooling garment underneath FPC during exercise in a warm humid environment. We hypothesized that the proposed cooling method would mitigate heat stress and physiological strain imposed by external environmental heat during exercise, thus reducing the probability of hyperthermia, mitigating fatigue, and increasing work productivity.

Materials and methods

Study design

The data analyzed in this study represent a subset of larger data set portion of which has been published previously (Aljaroudi et al. 2020). The methods used in this larger study have also been described in detail elsewhere (Aljaroudi et al. 2020). Briefly, this study consisted of a randomized cross-over design with two experimental conditions/sessions: cooling and no cooling. These two conditions allowed the investigation into the mitigating effect of cooling on the physiological responses to each and on the probability of achieving the lower threshold limit of hyperthermia following exercise in a warm and humid environment while wearing FPC. The study was approved by the National Institute for Occupational Safety and Health (NIOSH) Institutional Review Board (IRB) # 15 NPPTL-01.

Study population

Twelve healthy, nonsmoking, physically fit ($\dot{V}\mathrm{O}_{2\max} \geq 45\,\mathrm{mL.kg}^{-1} \cdot \mathrm{min}^{-1}$) men aged 21–40 were recruited from the general population to participate in this study. Inclusion criteria for this study have been described in detail elsewhere (Aljaroudi et al. 2020).

Medical evaluation

On the first visit, both oral and written informed consent was obtained from all subjects after an orientation about the study procedures and the nature of the study, including potential risks associated with participation. Subjects then completed a medical history questionnaire prior to participation and before each experimental sessions of the study.

Upon completion of the formal consent process and medical screening, eligible subjects completed a maximal graded exercise test (GXT). During the GXT, electrocardiographic (ECG) and pulmonary metabolic measurements were obtained. The subjects' maximal aerobic capacity ($\dot{V}O_{2max}$) was used to calculate individual subjects' relative exercise intensity (workload) during the experimental sessions. In addition, relative workload (40% $\dot{V}O_{2max}$) was calculated after adding the weight of the FPC (20.45 kg) to each subject's measured body weight to account for additional external stress of wearing the FPC.

Physical fitness evaluation

As mentioned in the previous section, all subjects medically cleared for participation in the study performed a GXT during which electrocardiographic rhythm (ECG), peak ("maximal") heart rate (HR_{max}), pulmonary ventilation ($\dot{V}E$), metabolic [oxygen consumption per minute ($\dot{V}O_2$), and carbon dioxide production per minute (($\dot{V}CO_2$)] measurements were obtained to assess $\dot{V}O_{2max}$ as well as to reveal potential undiagnosed cardiovascular disease (e.g., ischemia or dysrhythmias). The presence of potential cardiopulmonary disease would exclude the subject from continued participation in the study.

Subjects performed the maximal GXT to volitional fatigue using a modified Bruce protocol (Bruce 1971). Participants completed the GXT wearing sport clothes (shorts, t-shirt, athletic socks and shoes). This consisted of a ramping treadmill protocol with stages starting at a 0% rather than a 10% grade. The grade was started at 0% to ensure that the calculated sub-maximal grade was low enough for comfortable walking while wearing FPC. Treadmill speed stages remained unchanged from the standard Bruce protocol. The results from the GXT were used to determine the treadmill speed and incline that would impose a workload of ~ 40% of the subject's measured $\dot{V}O_{2max}$ after accounting for the additional weight of the FPC.

Experimental procedures

The following techniques and procedures have been described in detail elsewhere (Aljaroudi et al. 2020). Briefly, the experimental protocol was conducted inside an environmental chamber [air temperature (T_A): $30\,^{\circ}C$, relative humidity (RH): 70%] with subjects wearing FPC, including a self-contained breathing apparatus (SCBA). The SCBA was not used as a respirator but solely to provide similar weight and weight distribution on the subject as would be experienced by a firefighter. The subject wore the SCBA facemask, however the facemask was not connected to the SCBA tank. The subject instead breathed ambient air through the airline port in the facemask.

The experimental protocol consisted of four stages (Figure 1, reprinted with permission; Aljaroudi et al. 2020): (1) 15-min stabilization; (2) 5-min transition; (3) 40-min treadmill exercise; and (4) a 10-min recovery stage. During the 15-min stabilization stage (1), subjects were seated on a chair inside the environmental chamber under the experimental conditions ($30\,^{\circ}C$, 70% RH) during which baseline physiological and subjective (thermal, exertion) measures were obtained. Next (Stage 2), the treadmill belt was started, and the subject was instructed to step onto the moving treadmill belt and begin the 40-min exercise (Stage 3). Upon completion of the 40-min treadmill exercise, subjects dismounted the treadmill, exited the environmental chamber, and were seated on a chair at room temperature ($20\,^{\circ}C$, 50% RH) to begin the recovery (Stage 4). The subjects were instructed to remove the FPC and change into clean clothes (shorts, t-shirt, athletic socks and shoes) that were provided to them. At the beginning of the recovery stage, the subject's T_c (as measured with a rectal thermistor [Aljaroudi et al. 2020] and reported as T_c) and HR continued to be monitored and the subject remained in the recovery (Stage 4) until their T_c decreased to $< 38\,^{\circ}C$ and HR decreased to

$< 100\,\mathrm{b} \cdot \mathrm{min}^{-1}$. Cool liquids (water or sports drink) were provided to the subject during the recovery stage. The volume of fluids consumed by the subject was recorded and used in the calculation of sweat rates (Williams et al. 2011).

Outcome measure variables

The physiological outcome measures of HR ($\mathrm{b} \cdot \mathrm{min}^{-1}$), T_c ($^{\circ}$C), and mean skin temperature, T_{sk} ($^{\circ}$C), were obtained two times, both pre- and post-exercise for each experimental session. The initial pre-exercise measurements were calculated as one-min averages. Pre-exercise physiological variables were calculated as one-min averages at the end of stabilization (Stage 1). Physiological variables measured post-exercise were calculated as one-min averages during the last 1 min of exercise (Stage 3). In addition, for safety reasons, all three physiological variables were continuously monitored for the entire experimental session (Stages 1–4). Seminude body weight (subjects were wearing underwear only) was collected before (Stage 1) and directly after (Stage 3) to determine hydration status. Ratings of Perceived Exertion (RPE) and subjective Thermal Sensation (TS) scores were collected both pre- and post-exercise using the Borg scale (Borg 1982) and the Thermal Comfort Scale (O’Sullivan 1984), respectively. (Note: the “transition” phase seen in the figure involves moving from the seated position to mounting the treadmill in preparation for the exercise phase of the testing.) The following calculations were used to calculate the heat exposure appear below.

Physiological strain index (PhSI)

The following equation, adapted from Moran et al. (1998), was used to calculate the physiological strain index:

$$\begin{aligned}\mathrm{PhSI} = {} & \frac{5 * [(post - exercise\ Tc - pre - exercise\ Tc)}{(39.5 - pre - exercise\ Tc)]} \\ & + \frac{5 * [(post - exercise\ HR - pre - exercise\ HR)}{(180\ - pre - exercise\ HR)]}\end{aligned} \tag{1}$$

where HR = heart rate and T_c = core body temperature.

Perceptual strain index (PeSI)

Perceptual levels of heat strain (PeSI) have been quantified using the following equation developed by Tikuisis et al. (2002):

$$PeSI = \frac{5 * (TS - 0)}{8} + \frac{5 * (RPE)}{20} \tag{2}$$

where TS = thermal sensation and RPE = rating of perceived exertion (Borg scale).

Sweat rate (SR)

The following formula was used for calculating sweat rate from changes in weight and consumption or excretion of fluids (Dunford 2010):

$$\mathrm{SR}\ (\mathrm{L}\cdot \mathrm{h}^{-1}) = \frac{pre-exercise\ W\ (kg\ or\ L) - post-exercise\ W\ (kg\ or\ L) + fluid\ intake\ (L) - urine\ volume\ (L)}{exercise\ time\ in\ hours} \tag{3}$$

where W = body weight.

Heat storage (HS)

The following equation (Van Gelder et al. 2008) was used to calculate heat storage:

$$\begin{aligned} HS\ (\mathrm{watts}\cdot \mathrm{h}^{-1}) = W\ (kg)\ x\ (post-exercise\ Tc \\ - pre-exercise\ Tc)]\ (\overset{\circ}{C}) \\ x\ specific\ heat\ capacity\ of\ body\ tissue \\ (0.97\ watts\cdot h^{-1}\cdot kg^{-1}\cdot {}^{\circ}C^{-1}) \end{aligned} \tag{4}$$

where W = body weight and T_c = core body temperature.

Physiological monitoring equipment

A wearable physiological monitoring system (BioHarness III, Zephyr Technology Corporation, Annapolis, MD) was used to measure HR (Kim et al. 2012). A rectal thermistor/probe (4600 precision rectal thermistor; YSI Temperature, Dayton, OH) consisting of a flexible silastic tube containing the thermistor, was used to measure T_c. Skin thermistors (SQ2020–1F8 skin temperature logger; Grant Instruments Ltd., Cambridgeshire, UK) were used to measure T_{sk}. The thermistors were attached to four skin sites (chest, shoulder, thigh, and calf). Temperature measurements from the skin sites were used to calculate mean T_{sk} using a previously published weighting coefficient as follows (Ramanathan 1964):

$$T_{sk} = [0.3(T_{chest} + T_{shoulder})] + [0.2(T_{thigh} + T_{calf})] \tag{5}$$

Seminude body weight (W, Kg) was obtained to the nearest 2 g by a precision weighing scale (Electronic Scale series 4450; GSE, Farmington Hills, MI).

A standard FPC (Morning Pride Mfg. LLC, Dayton, OH, now Honeywell Corp.) with SCBA (Scott NXG2 AIRPAK with 45-min rated carbon cylinder; Scott Health & Safety, Monroe, NC) was used as part of the experimental FPC. Structural/Proximity Bunker Boots were used in this study (Model 5050B, Honeywell International Inc., Charlotte, NC).

A walk-in, climate-controlled chamber (WM-Series, Russell Technical Products, Inc., Holland, MI) was used to create the environmental exercise conditions specified by the study protocol (T_A: 30 °C, RH: 70%). A treadmill (Desmo S, Woodway Corp., Waukesha, WI) was located inside the chamber upon which the subject exercised per protocol.

A liquid cooling garment (LCG) infused with cooled water (18 °C) supplied by an external water circulator (Koscheyev et al. 2002; Kim et al. 2011) was used to provide the continuous cooling application. Details of the LCG have been described previously (Kim et al. 2011; Aljaroudi et al. 2020).

Statistical analysis

All variables measured were first calculated as mean and standard deviation ($\overline{X} \pm \mathrm{s.d.}$) for each individual subject across all experimental conditions. Data was then summarized for the pre- and post- point of each exercise stage for statistical analysis.

A two-way (conditions and time) repeated measures analysis of variance (ANOVA) was used to examine the effect of continuous cooling on PhSI and PeSI. A significant two-way interaction in this context reveals a difference between the pattern of the physiological indicator between pre- and post-exercise as a function of the group considered. Post-hoc, adjusted pairwise comparisons were used to examine the differences in each of the measures over time for within each session (cooling vs. no cooling), between each session at pre-exercise, and between each session at post-exercise.

In addition, a repeated measures logistic regression (Generalized Estimating Equations) was used to examine the odds of subjects reaching the lower safe limit of hyperthermia (i.e., case: $T_c \geq 38\,^{\circ}\mathrm{C}$, no-case: $T_c < 38\,^{\circ}\mathrm{C}$) as a function of condition (Equation 1). The independent variables within this model were the cooling status and a subset of the demographic variables data (age, BMI, $\dot{V}O_{2\max}$). These covariates were included to account for known variability of the T_c response to heat stress across these variables (Kenney et al. 1990; Havenith 2001; Foster et al. 2020): $\dot{V}O_{2\max}$. Statistical analysis was performed using SAS software version 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Demographic data

The subjects who participated in this study were part of a larger study in which their demographics have been described in detail (Aljaroudi et al. 2020). The subjects' demographics data are briefly summarized in Table 1 ($[\overline{X} \pm \mathrm{s.d.}]$, range, minimum, and maximum).

Descriptive summary statistics

Dependent variables used in both control (no cooling) and intervention (cooling) are summarized in Table 2 as descriptive statistics ($\overline{X} \pm \mathrm{s.d.}$).

Physiological measures

The physiological data and its significance have been published in detail elsewhere (Aljaroudi et al. 2020). Briefly, all subjects completed the entire 40 min of the exercise. As expected, the subjects' physiological responses (T_c, T_{sk}, HR) were significantly increased at the end of exercise under hot and humid climate conditions. This physiological data has been used to calculate PhSI (Eq. 1), PeSI (Eq. 2), and HS (Eq. 4) (see the next section). A significant decrease in body weight occurred in the control group (no cooling) by the end of the exercise (Stage 3). The interaction of the continuous cooling method had a significantly suppressed the increase in all physiological responses during the experimental exposure to heat stress.

PhSI

The PhSI increased ($p < 0.05$) at the end of exercise in control sessions. The interaction of continuous cooling method reduced ($p < 0.05$) the physiological strain in intervention sessions.

PeSI

The subjects’ PeSI significantly increased at the end of exercise in control sessions. The application of the continuous cooling method significantly decreased the PeSI in interventions sessions. Figure 2 shows the two-way interaction plot for each of the physiological variables entered as a dependent variable in the repeated measures ANOVA. Each of the two-way interactions were significant ($p < 0.05$) except for subject weight. Additionally, each of the follow-up, post hoc, adjusted pairwise comparisons measuring the effect of time on the physiological measures for the control and the cooling group were significant except for subject weight. During the pre-exercise phase, the only variable that was significantly different was skin temperature. The interaction of cooling has a significant impact on reducing heat buildup and dehydration level (Table 3).

HS: As it is shown in Figure 3, cooling interaction reduced heat buildup significantly.

Logistic regression model

The results of the logistic regression are shown in Table 4. Within the model, cooling was entered as a categorical independent variable with no cooling (i.e., the control sessions) set as the reference group. The exponentiated regression coefficient is then the probability of reaching the lower threshold limit of hypothermia when the cooling intervention is used compared to the control group (no cooling). The results of the model indicate that when cooling was used, on average, each subject was 91% less likely to reach hyperthermia (i.e., $T_c \geq 38\,^{\circ}C$).

Discussion

Physiological outcome measures

The cooling effect on the physiological and perceptional responses support the study hypothesis and previous studies (Bennett et al. 1995; Selkirk et al. 2004; Barr et al. 2009; 2011; Katica et al. 2011; Kim et al. 2011; Mokhtari Yazdi and Sheikhzadeh 2014; Jang et al. 2015).

As expected, in the present study, significant increases in physiological and perceptional responses while wearing FPC and a liquid cooling garment after continuous exercise (40% $\dot{V}O_{2max}$) in a hot humid environment ($30\,^{\circ}C$ T_A, 70% RH) occurred. As such, metabolic heat produced by exercise (Table 2) resulted in an increase in both fatigue and physiological strain observed at the end of exercise (PhSI: 6.48 ± 1.16) in addition to a strong perceptual sensation of thermal stress (PeSI: 8.36 ± 0.47).

The effect of the cooling intervention on the physiological responses suggests that body cooling is an effective method for reducing thermal physiological strain under hot humid conditions as indicated by a PhSI = 4.3 ± 1.5 and a perceptual sensation of thermal stress indicated by a PeSI= 7.2 ± 1.0). Moreover, significant decreases in dehydration level via sweat loss (0.54 ± 0.18 kg decrease in body weight corresponding to the sweat loss) were found with the cooling application.

Probability model of hyperthermia

The probability model outcomes of the data agreed with the study hypothesis. The model outcomes suggest that, on average, the odds of an individual achieving a T_c indicative of hyperthermia ($T_c \geq 38\,^{\circ}C$) is 91% lower while using the cooling system than without the cooling system. Moreover, results suggest that demographic factors (e.g., age, BMI) did not have a significant influence on the results since all subjects fell within a ten-year age range and had similar BMI classifications. Hence, future research should explore the possible influences of significant demographic factors (age, obesity represented by BMI, gender) on the probability of achieving hyperthermia between different populations in hot and humid environments. Although the probability model in this study suggests that the cooling application may decrease the probability of reaching the lower threshold limit of hyperthermia, there is a need to develop an individualized predictive model of cooling intervention associated with increasing the time to achieve hyperthermia in order to increase work time while limiting the possibility of heat related injuries. To that end, a study described a practical and easy-to-use individualized predictive model for early identification of firefighters who are likely to reach the lower safe limit of hyperthermia during firefighting (Mani et al. 2015). However, the influence of a cooling application was not included. Thus, individualized predictive models of cooling as a prevention method would enhance the value of the predictive model developed by Mani et al. (2015).

Limitations

The main limiting factor affecting study outcomes is the small sample size (n = 12) utilized in this study. However, the experimental conditions imposed a significantly powerful physiological effect that statistical significance was achieved and, thus, the study hypotheses could be addressed. Also, the feasibility of using the cooling garment in the field is quite low because of the use of an electric powered water bath used to control circulating water temperature. However, the purpose was to investigate the efficacy of cooling on PhSI and PeSI in the present study.

Conclusions

The results suggest that exercising in a warm and humid environment combined with the additional burden imposed by wearing encapsulated FPC is physically demanding and can result in a significant physiological and thermal burden including hyperthermia and increased fatigue levels as represented by the PhSI. The utilization of body cooling via a wearable liquid cooling garment worn underneath the FPC significantly decreased the physiological and thermal strain and probability of reaching hyperthermia in hot environments. Physical fitness and age did not have any influence on the probability of reaching hyperthermia in this study.

Recommendations

Many civilian professions including firefighting, emergency first responders, construction workers, and healthcare providers may encounter high occupational thermal loads. Such workplace settings may involve work in physically and/or biologically hazardous environments, which requires wearing some combination of a personal protective equipment (PPE) ensemble. PPE is required in certain settings as a means of providing protection against health and safety risks at work. However, whole body encapsulating PPE ensembles, including FPC, can increase thermal strain and physiological load as shown in the present study. Cooling techniques that are customized to be used underneath encapsulating PPE ensembles may contribute to the prevention of occupational injuries related to heat strain. This study demonstrates that a although cooling the body during hazardous occupational work can extend continuous work time in hot environments before reaching the lower limit of hyperthermia and could be used to improve occupational safety, the customized cooling method (LCG) used in this study will not entirely prevent thermal risk in the absence of administrative hazard controls as part of a comprehensive plan to reduce occupational thermal stress. Therefore, a rational recommendation is to examine both personal cooling and administrative and engineering controls to limit exposure of workers to heat and potential heat injury.

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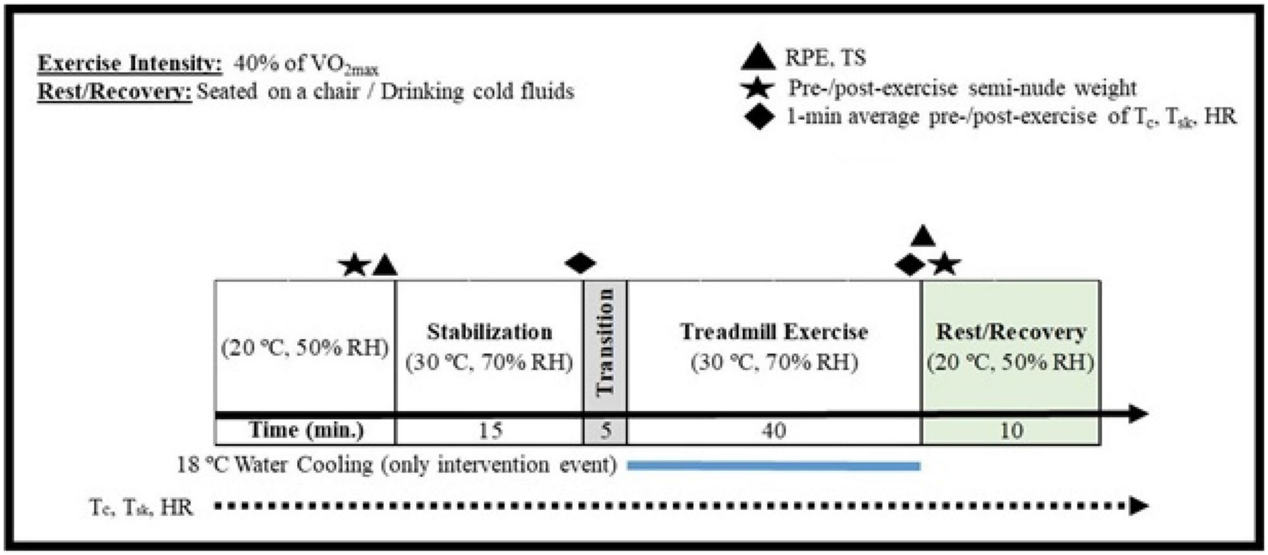

Figure 1.

Schematic of the experimental protocol (reprinted with permission from Taylor and Francis [Aljaroudi et al. 2020]).

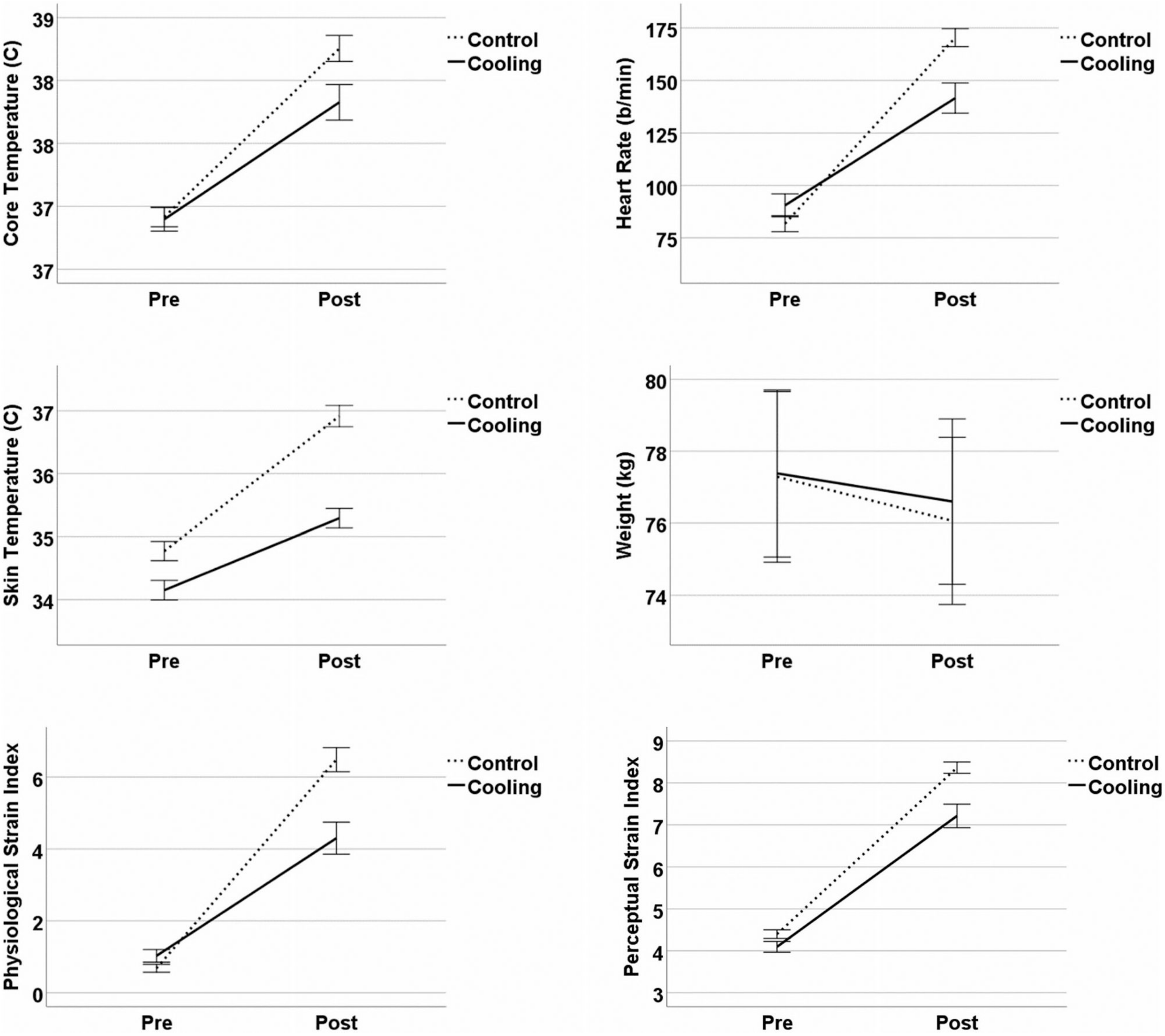

Figure 2.

Two-way interactions for each of the physiological measures. The effect of continuous cooling significantly decreased the SR and HS of the study subjects. Both skin and core body temperature are expressed in °C. The values for PhSI and PeSI are expressed in a universal dimensionless scale of between 1.0 and 10.0.

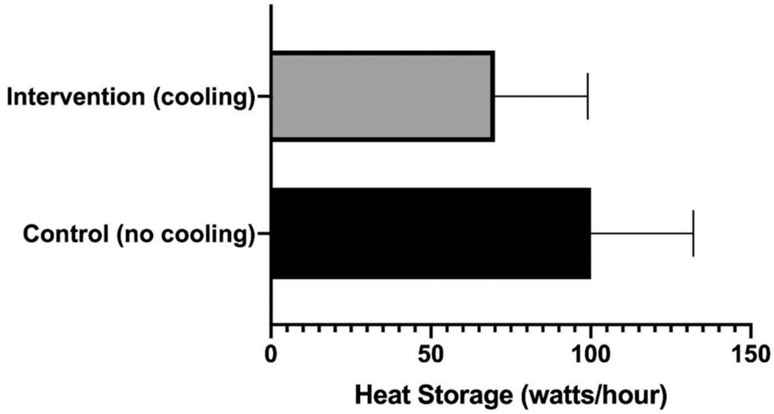

Figure 3.

Heat storage across conditions.

Table 1.

Descriptive summary statistics of the study population.

Variable (s)	$\bar{X} \pm \mathrm{s.d.}$	**Minimum**	**Maximum**
Age (Years)	24 ± 3.2	21	31
Weight (kg)	78.1 ± 8.2	64.6	94.9
BMI ($\mathrm{kg \cdot m^2}$)	24.8 ± 3	21	29.9
$\dot{V}\mathrm{O}_{2\max}$ ($\mathrm{mL \cdot kg^{-1} \cdot min^{-1}}$)	56.3 ± 7.4	45.6	70.1

Table 2.

Descriptive summary statistics of all dependent variables.

	Control (no cooling)		Intervention (Cooling)	
Variable (s)	**Pre-Exercise**	**Post-Exercise**	**Pre-Exercise**	**Post-Exercise**
RPE	6 ± 0.5	16 ± 1.8	6 ± 0.4	14 ± 2.8
TS	4.5 ± 0.6	7.0 ± 0.3	4.1 ± 0.6	6.1 ± 0.9
PhSI	0.68 ± 0.38	6.48 ± 1.16	1.03 ± 0.61	4.29 ± 1.54
PeSI	4.39 ± 0.35	8.36 ± 0.47	4.09 ± 0.44	7.21 ± 0.97
SR ($L \cdot h^{-1}$)	1.22 ± 0.35		0.78 ± 0.35	
HS (watts · h^{-1})	100. ± 32		70 ± 29	

Table 3.

The p-values, t-values, and M_{diff} ± SE of SR and HS derived from pairwise t-test.

Variable (s)	M_{diff} ± SE	t-value	p-value
$SR\ (L \cdot h^{-1})$	0.44 ± 0.39	3.92	<0.01
HS (watts $\cdot\ h^{-1}$)	30.21 ± 20.66	5.07	<0.01

Table 4.

Logistic regression model.

Parameter(s)	**B**	**SE**	**Wald χ^2**	**P-value**	**OR**
Cooling	−2.83	1.1	4.66	0.03	0.09
Age	−0.03	0.14	0.03	0.86	0.97
BMI	−0.1	0.13	0.55	0.46	0.91
$\dot{V}O_{2max}$	−0.22	0.33	0.45	0.5	0.8

Note: B is the regression coefficient, SE is the standard error, and OR is the odds ratio for each of the predictors.