THE EFFECTS OF EXERCISE AND GENDER ON HEAT TOLERANCE TIME DURING PROLONGED HEAT EXPOSURE

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INTRODUCTION

The U.S. Navy has recently begun to increase the number of female sailors stationed aboard ship and personnel staffing ratios on the majority of suface ships are to be 50% male and 50% female by the year 2000. There is concern the Navy's current heat exposure policy may not provide the appropriate guidance for female personnel because these heat exposure standards, commonly referred to as the Physiological Heat Exposure Limits or PHEL curves, were developed using males. It has been established that most gender differences in thermoregulation are negligible when males and females are evenly matched for factors such as age, acclimation, body size, maximal aerobic capacity, and relative versus absolute workload (1,2,3). However, female sailors within the U.S. Navy population differ in size, fitness, and body composition from male 'sailors. Additionally, though body size was incorporated in the development of the PHEL curves, application of the PHEL curves is based on personnel performing shipboard tasks at an absolute work rate. We hypothesized that gender differences in thermoregulation would not appear at low activity levels (PHEL 1, PHEL 2) and/or low thermal environments, but may begin to appear at a moderate work rate and moderate to high thermal environments. We have previously reported the thermoregulatory responses of males to a PHEL 3 work rate (4,5). The purpose of this study was to compare thermoregulatory responses between males and females to the PHEL 3 work rate which has time-weighted-mean metabolic rate of 111.7 $W \cdot m^2$.

MATERIALS and METHODS

Upon the completion of an 8-day heat acclimation protocol, 26 males and 17 females (Table 1) volunteered to perform three heat tolerance tests in an environmental chamber. The three thermal conditions were as follows: low environment (LOW = 43.3°C T_{db}, 46°C T_g, **51%** rli; medium environment (MED = 50.6°C T_{db}, 53°C T_g, 32% rh; and hot environment (HOT = 57.2°C T_{db}, 60°C T_g, 25% rh. Each heat exposure was designed to last a maximum of 6 hours with the subjects attempting to complete a 20 min treadmill walk (80.5m/min, 3%grade) followed by 40 min of seated rest each hour. End of test termination criteria were established as a core temperature ≥ 39.5°C, heart rate ≥ 180 bpm for 5 min, or volitional withdrawal. Rectal temperature (T_{re}), mean skin temperature (T_{msk}) calculated from four sites - shoulder, chest, thigh, calf, and heart rate (HR) were measured each minute throughout the heat exposure. Whole body sweat rate (WBSR) was determined from nude pre- to post-exposure weight changes, corrected for intake and output of fluids, and adjusted for both body surface area (BSA, from height and weight), and the heat exposure duration or stay time (STYTM). Metabolic rates ($\dot{V}O_2$) were determined from 1.5 min Douglas Bag collections and sampled midway through each treadmill walk. A repeated measures MANOVA was used for statistical analysis of the data with the significance set at the .05 level.

RESULTS

Table 1 provides subject characteristics (means and standard deviations). Males and females differed significantly on all measures except age as the mean age for all subjects was 23 to 24 yr. Except for weight, the mean values for these subjects are similar to mean values for the U.S. Navy male and female personnel. Navy males are typically taller in stature and heavier in body mass thereby resulting in a significantly higher BSA. Additionally, Navy males have a significantly lower percentage of body fat (BFAT) and a significantly higher aerobic capacity. The females in this study were approximately 7 kg heavier than the average Navy female. While a lower body weight would most likely reduce the BFAT content, it would also result in a decreased BSA producing an even greater BSA difference between males and females.

Table 1. Subject Characteristics

	HEIGHT (cm)	WEIGHT (kg)	BSA (m^2)	BFAT (%)	PEAK $\dot{V}O_2$ (ml/kg/min)
MALE	178.0 (7.6)	77.5 (7.3)	1.95 (0.11)	16.7 (4.7)	50.8 (5.0)
FEMALE	162.2 (5.4)	67.0 (7.5)	1.71 (0.10)	31.1 (5.0)	43.9 (6.5)

Mean (SD) responses to the heat exposures are provided in Table 2. T_{re}, T_{msk}, and HR data are the last min values of each heat exposure prior to exiting the chamber. There were significant STYTM effects for both gender and environment. Post hoc analysis revealed that STYTM was different between each environment, but male STYTM was significantly higher than female STYTM only at the MED environment. HR was not different between environments, however, male HR responses were significantly lower than female

Table 2. End of Test Physiological Results

LOW	STYTM (min)	HR (bpm)	T_{re} (°C)	T_{msk} (°C)	WBSR ($gm/m^2/min$)
MALE	206 (78)	132 (24)	38.5 (0.5)	37.9 (0.6)	10.1 (3.8)
FEMALE	184 (38)	150 (23)	38.9 (0.4)	38.1 (0.5)	7.4 (3.5)

MED	STYTM (min)	HR (bpm)	T_{re} (°C)	T_{msk} (°C)	WBSR ($gm/m^2/min$)
MALE	129 (42)	139 (19)	38.9 (0.5)	38.5 (0.6)	12.6 (2.8)
FEMALE	94 (26)	155 (20)	38.9 (0.4)	38.4 (0.5)	10.0 (3.8)

HOT	STYTM (min)	HR (bpm)	T_{re} (°C)	T_{msk} (°C)	WBSR ($gm/m^2/min$)
MALE	77 (21)	139 (28)	38.8 (0.4)	38.9 (0.4)	16.9 (3.5)
FEMALE	71 (6)	157 (20)	38.9 (0.4)	38.4 (0.5)	10.7 (3.6)

HR responses within each environment. Upon the completion of the three heat exposures, end of test HR values for males were approximately 70% of their maximal HR compared to 79% for female HR values. There were no significant gender or environment effects for T_{re} and the average increase in T_{re} for males and females was similar, 2.0°C and 2.2°C, respectively. T_{msk} was significantly different between environments but not between males and females. WBSR response for males was significantly higher than females within each environment and WBSR was significantly different between environments. Lastly, although exercising $\dot{V}O_2$ was not different between environments, male values were statistically lower than female values, 14.4 ml/kg/min and 16.2 ml/kg/min, respectively. During the exercise intervals, males worked at 28% of their maximal aerobic capacity while females worked at 37% of their maximal aerobic capacity. There was no significant $\dot{V}O_2$ drift within the heat exposures or between the environments for either males or females.

CONCLUSIONS

Results from this study compare favorably with the physiological responses of males and females working at an absolute workload (36% and 29%, respectively) reported by Avellini et al. (6). T„ HR and WBSR responses between males and females were similar in both studies. In contrast to the previous study, we did not observe a gender difference in T_{msk}, and there was a gender difference in **STYTM** at the **MED** environment. **It** was concluded that the females in this study experienced a greater degree of cardiovascular strain as evidenced by a lower **STYTM, WBSR,** and a higher HR response. While matching for anthropometry, aerobic capacity and relative work rates in a controlled research environment can eliminate many of these differences, males and females within the operational setting of the military and industrial work environments are usually very different in body size and aerobic capacity. More importantly, the ability to structure a work environment that utilizes a relative work rate design is difficult to employ. These findings suggest that application of the U.S. Navy's existing heat exposure guidelines may need to be modified in order to provide the appropriate heat exposure guidance for all Navy personnel. The database generated from these investigations could be used **to** develop gender-neutral heat exposure standards for **U.S.** Navy personnel.

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