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ORIGINAL RESEARCH

Comparison of Short-Term Aerobic Training and High Aerobic Power on Tolerance to Uncompensable Heat Stress

STEPHEN S. CHEUNG, M.SC., PH.D., AND TOM M. MCLELLAN, M.A., PH.D.

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This study investigated whether, in subjects of moderate aerobic fitness, short-term aerobic training could replicate the improved physiological responses to exercise-heat stress observed in individuals with a high level of aerobic fitness. Males of moderate (MF; <50 ml · kg^{-1} · min^{-1} $\dot{V}o_{2peak}$, n = 8) and high (HF; >55 ml · kg^{-1} · min^{-1} $\dot{V}o_{2peak}$, n = 8) aerobic fitness walked at 3.5 km · h^{-1} in the heat (40°C, 30% relative humidity) wearing nuclear, biological, and chemical protective clothing. Tests were conducted once on HF subjects and on MF subjects before (MF-Pre) and after (MF-Post) a 2-week program 6 d · week^{-1} of daily aerobic training (1 h treadmill exercise at 65% $\dot{V}o_{2peak}$ for 12 d, 22°C, 40% relative humidity). The training significantly increased $\dot{V}o_{2peak}$ by 6.5%, while heart rate (f_c) and rectal temperature (T_{re}) rise decreased during exercise in a thermoneutral environment. HF had lower body mass and body fat content than MF, and $\dot{V}o_{2peak}$ remained lower in MF pre-or post-training. In the heat, MF-Post had a decreased skin temperature ($\bar{T}_{sk}$) and an increased sweat rate compared with MF-Pre, but no changes were observed in f_c, T_{re}, or tolerance time (TT). No significant differences during the first 60 min in T_{re} and f_c were observed between the MF-Post and the HF subjects, though the HF subjects exhibited a lower $\bar{T}_{sk}$. The endpoint T_{re}, ΔT_{re}, and TT remained significantly higher in HF than in either the MF-Pre or MF-Post subjects. It was concluded that, in preparation for exercise in an uncompensable heat stress environment, short-term aerobic training offers little, if any, benefit and is not an adequate substitute for a high level of aerobic fitness resulting from habitual exercise and training.

Keywords: heat exhaustion, temperature regulation, aerobic fitness, aerobic training.

WHERE WORKERS may be required to work in hot environments with minimal preparation time or facilities to perform heat acclimation through a repeated and programmed regimen of heat exposures, the ability of other physiological manipulations to rapidly increase exercise-heat tolerance is of great occupational and medical interest. The wearing of protective clothing–such as the nuclear, biological, and chemical (NBC) protective ensembles worn by military personnel–in the heat produces a situation of uncompensable heat stress, where evaporative heat loss is limited and less than that required to maintain thermal equilibrium, resulting in an inability to maintain a thermal steady state (8). In these settings, the need for heat adaptation may be especially crucial prior to deployment.

One method of heat adaptation is through an increase in aerobic fitness (2,13,17–19). Highly fit subjects had a greater exercise-heat tolerance while exercising in the heat wearing NBC clothing compared with moderately fit subjects (23). In a thermoneutral environment, aerobic training programs of as short as 2 weeks have been successful in bringing about a slight but significant increase in peak oxygen uptake ($\dot{V}o_{2peak}$, 4.5%), increases in plasma volume (11.8%), and a significant decrease in cardiovascular and thermoregulatory strain during prolonged exercise (10). In contrast, 8 weeks of aerobic training did not produce significant improvements in heat tolerance in subjects wearing NBC clothing (1). However, the metabolic rate of 500 W used to evaluate the changes in heat tolerance in that study may have produced a rapid onset of heat exhaustion independent of any physiological adaptations due to the treatment programs. For the military, soldiers may not have the time to undertake or be willing to commit to a long-term endurance training program in order to prepare for exercise in a hot environment. Thus, a 2-wk training program may be an attractive alternative. While it may not replicate all of the physiological and other changes observed with long-term training and habitual exercise spanning months or years, it is possible that a short-term training program in individuals with moderate aerobic fitness will produce improvements in exercise-heat tolerance which allow them to

From the Defence and Civil Institute of Environmental Medicine, Human Protection and Performance Section, Toronto, Ont., Canada; and Graduate Department of Community Health, University of Toronto, Toronto, Ont., Canada.

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Address reprint requests to: Tom M. McLellan, Ph.D., Defence and Civil Institute of Environmental Medicine, Human Protection and Performance Section, P.O. Box 2000, Toronto, Ont. M3M 3B9, Canada. Stephen S. Cheung is currently Assistant Professor, School of Health and Human Performance, Dalhousie University, Halifax, Nova Scotia, Canada.

perform at a level more similar to individuals with a high aerobic fitness.

The present analysis compares, in the uncompensable heat stress environment found while exercising in a hot (40°C, 30% relative humidity) environment and wearing NBC clothing, the responses of moderately fit individuals before and following a short-term aerobic training program with individuals already possessing a high level of aerobic fitness derived from habitual exercise and training. The data, some of which have been previously reported (4,5), are derived from two previous studies in our laboratory on responses to uncompensable heat stress by non-fit and fit individuals. The studies were deliberately designed using identical equipment, laboratory personnel, and protocols for the heat stress test (HST) to allow for cross-comparisons. It was hypothesized that the short-term aerobic training would improve the physiological responses and tolerance to exercise-heat stress of the low fitness group to a level similar to that observed in individuals of high aerobic fitness.

METHODS

Subjects

The experimental protocol and instrumentation used were approved by the Ethics Review Committees of the University of Toronto and the Defence and Civil Institute of Environmental Medicine (DCIEM). A total of 16 healthy males between the ages of 18–40, recruited from the university population or the military community, participated in the heat stress tests included in the present analysis. Subjects underwent a medical examination, were checked for any cardiovascular, respiratory, and renal ailments, and were informed of all details of the experimental procedures and the associated risks and discomforts before they provided their consent. Subjects were grouped into two general categories of either moderately fit (MF) or highly fit (HF), based on an interview of their exercise habits and the results of a treadmill test of peak aerobic power. MF subjects were either inactive at the time of the study or engaged in physical activity only on an irregular basis ($<1\ h \cdot week^{-1}$ aerobic exercise) and had a $\dot{V}O_{2peak}$ between 40 and 50 $ml \cdot kg^{-1} \cdot min^{-1}$. All MF subjects agreed to abstain from regular aerobic activities outside of the laboratory for the duration of the experiment. HF subjects were defined as those engaged in a regular program of physical activity ($>5\ h \cdot wk^{-1}$ aerobic exercise for > 1 yr) and having a $\dot{V}O_{2peak}$ in excess of 55 $ml \cdot kg^{-1} \cdot min^{-1}$.

Determination of Peak Aerobic Power

Peak aerobic power was determined on a motorized treadmill using open-circuit spirometry both before and after (before only for HF) the series of experiments in the climatic chamber. Following 3 min of running at a self-selected pace, the treadmill grade was increased 1% each minute to 10%. Thereafter, increases in treadmill speed and grade of 0.22 $m \cdot s^{-1}$ (0.8 $km \cdot h^{-1}$) or 2%, respectively, alternated each minute until the subject could no longer continue. Subjects were given verbal encouragement throughout the test. $\dot{V}O_{2peak}$ was defined as the highest 30 s oxygen consumption ($\dot{V}O_2$) observed during the incremental test. Heart rate (f_c) was monitored throughout the incremental test from a telemetry unit (Polar Vantage XL). The value recorded at the end of the exercise test was considered to be the individual's maximum heart rate. Body fatness was estimated from skinfold measurements using a gender-specific regression equation developed from hydrostatic measurements of body density (7).

Experimental Design

All heat stress tests were conducted at DCIEM from late September to early May to limit initial heat acclimation through casual exposure to high ambient temperatures. On three (MF) or two (HF) separate occasions, subjects performed a heat stress test (HST), consisting of walking on a motorized treadmill (3.5 $km \cdot h^{-1}$ and 0% grade) in a hot (40°C, 30% relative humidity, wind speed $< 0.1\ m \cdot s^{-1}$) environment while wearing the Canadian Forces NBC protective clothing ensemble. In all subjects, the first session was used as a familiarization trial and the results were discarded. A minimum of 1 week separated each HST to avoid the effects of partial heat acclimation (3). Nutrition was controlled the evening before each trial by providing subjects with a set meal plan consisting of PowerBar® meal replacement bars.

Following the initial experimental HST (MF-Pre), MF subjects underwent a 2-week aerobic training program. For 6 $d \cdot week^{-1}$, subjects dressed in shorts and running shoes and walked on a motorized treadmill at 60–65% $\dot{V}O_{2peak}$ (4.8 $km \cdot h^{-1}$, 8–13% grade) in an exercise laboratory (22°C, 40% relative humidity) for 1 h. Oxygen uptake was measured during the first and last training session to ensure that the training intensity was at the desired range. On the completion of the 2-week training period, MF subjects performed another HST (MF-Post).

NBC Protective Clothing

The Canadian Forces NBC protective clothing ensemble worn in all trials consisted of shorts, T-shirt, socks, combat shirt and trousers, running shoes, semipermeable NBC overgarment, gas mask and cannister, and impermeable rubber gloves and overboots. Total mass of the ensemble was approximately 8.0 kg. In order to allow some sweat evaporation, there is limited mass penetration of charcoal-filtered air through the fabric. Thermal resistance and the Woodcock vapor permeability coefficient of the ensemble determined on a heated and wetted manikin at a wind speed of 1.12 $m \cdot s^{-1}$ were 0.291 $m^2 \cdot °C \cdot W^{-1}$ (1.88 clo) and 0.33, respectively (9).

Dressing and Weighing Procedure

Subject preparation, insertion of the rectal thermistor, and placement of skin thermistors have been detailed previously (14). Both nude and dressed weights were recorded prior to entry into the chamber. On full encapsulation and entering the chamber, the subject's skin and rectal thermistor monitoring cables were connected to a computerized data acquisition system and the ex-

TABLE I. ANTHROPOMETRIC MEASURES OF THE SUBJECTS IN THE MODERATELY FIT (MF) AND HIGH FIT (HF) GROUPS, WITH AGE, HEIGHT, BODY MASS AND FAT CONTENT, SURFACE AREA AND SURFACE AREA-TO-MASS RATIO, AND PEAK AEROBIC POWER ($\dot{V}O_{2PEAK}$) EXPRESSED RELATIVE TO TOTAL ($ML \cdot KG^{-1} \cdot MIN^{-1}$) OR LEAN BODY MASS (LBM).

Group	Age (y)	Height (m)	Body Mass (kg)	Body Fat Content (%)	Surface Area (m^2)	Surface Area-to-Mass ($m^2 \cdot kg^{-1} \cdot 10^2$)	$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) Total body mass/LBM Pre	Post
MF (n = 8)	30.3 (6.7)	1.77 (0.05)	84.7† (12.6)	19.2† (3.9)	2.02 (0.14)	2.41 (0.20)	43.2†/53.6† (2.7)/(4.2)	46.0†/56.9† (2.5)*/(2.4)*
HF (n = 8)	27.9 (6.5)	1.77 (0.03)	76.8 (4.3)	11.5 (2.9)	1.94 (0.14)	2.56 (0.08)	59.8/67.6 (2.8)/(4.3)	—

Values are means (S.D.).
* Significant effect of aerobic training.
† Significantly different from the HF group.

ercise began, such that subjects were fully encapsulated in the NBC ensemble for < 1 min before the start of exercise. During all HSTs, subjects underwent a fluid replacement program consisting of 200 ml of water every 15 min, with the water temperature maintained near 37°C. Mean values over 1-min periods for core temperature (T_{re}), and a 12-point weighted mean skin temperature ($\bar{T}_{sk}$) (22) were calculated, recorded, and printed by the data acquisition system. f_c was recorded every 5 min from the Polar Vantage XL unit. After the completion of each trial, dressed weight was recorded within 1 min after exit from the chamber. Nude weight was recorded within 5 min of undressing and toweling dry.

Differences in nude and dressed weights before and after each trial were corrected for respiratory and metabolic weight losses (see below). The amount of sweat produced was calculated as pre-trial minus post-trial nude weight (corrected) plus water given. Evaporative sweat loss from the clothing was calculated as pre-trial minus post-trial dressed weight (corrected) plus water given.

Gas Exchange Analyses

During each trial, open-circuit spirometry was used to determine expired minute ventilation, $\dot{V}O_2$, and carbon dioxide production from a 2-min average obtained every 15 min. An adaptor was attached to the respirator which allowed expired air to be collected. Respiratory water loss was calculated using the measured $\dot{V}O_2$ and the equation presented by Mitchell et al. (15). Metabolic weight loss was calculated from the $\dot{V}O_2$ and the respiratory exchange ratio using the equation described by Snellen (21).

Tolerance Time

Tolerance Time (TT) for all trials was defined as the time until rectal temperature reached 39.3°C, heart rate remained at or above 95% of maximum for 3 min, dizziness or nausea precluded further exercise, either the subject or the experimenter terminated the experiment, or 4 h had elapsed.

Statistics

Data are presented as means (SD). A 2-way (training status × time) repeated measures analysis of variance (ANOVA) was performed to compare the responses of T_{re}, $\bar{T}_{sk}$, and f_c of the MF-Pre and MF-Post subjects to the HST. When a significant F-ratio (corrected for the repeated measures factor) was obtained, a Newman-Keuls post-hoc analysis was performed to isolate differences among treatment means. The T_{re}, $\bar{T}_{sk}$, and f_c responses of the HF group were compared separately to either the MF-Pre or MF-Post groups using a two-factor (group × time) repeated measures ANOVA, while the responses of tolerance times, sweating and evaporation rate, and metabolic rate were compared using an independent t-test. For all statistical analyses, the 0.05 level of significance was used.

RESULTS

Subjects

Table I presents the physical characteristics of the test populations. The selection process was successful in producing two subject groups with a strong separation in peak aerobic power. Short-term aerobic training was effective in significantly increasing $\dot{V}O_{2peak}$ 6.5% from 43 to 46 $ml \cdot kg^{-1} \cdot min^{-1}$. However, $\dot{V}O_{2peak}$ in MF-post remained significantly lower than the HF subjects. MF subjects had a higher body mass and body fat content than HF subjects.

Physiological Response of MF to the Training Program

The results of the short-term aerobic training program on the MF group are presented in **Table II**. In addition to the increase in $\dot{V}O_{2peak}$, the 2 weeks of training resulted in an attenuation in the cardiovascular and thermal strain induced by the training exercise, as evidenced by a significantly lower f_c and ΔT_{re} at the end of the hour of exercise in the thermoneutral environment on the final day of training. The training program did not result in an increased sweating response or a decrease in respiratory exchange ratio during the exercise.

Physiological Response to the HST

Table III summarizes some of the physiological responses to the HST. The exercise was moderate in intensity, and < 30% $\dot{V}O_{2peak}$ for all subjects. The metabolic rate, and therefore the rate of heat production, was similar for all trials for the MF-Pre, MF-Post, and HF groups. Though no change in sweating rate occurred in

TABLE II. PHYSIOLOGICAL RESPONSES AT THE START AND END OF THE TRAINING PERIOD FOR THE MODERATELY FIT SUBJECTS. TRAINING TOOK PLACE OVER 2 WK (12 DAYS, 1 $H \cdot D^{-1}$) WEARING SHORTS, SOCKS, AND SHOES IN ENVIRONMENTAL CONDITIONS OF 22°C, 40% RELATIVE HUMIDITY.

	Day 1	Day 12
SR ($L \cdot {}^{\circ}h^{-1}$)	0.73 (0.18)	0.78 (0.22)
SR ($L \cdot {}^{\circ}C^{-1}$	0.64 (0.30)	0.74 (0.19)
ΔT_{re} (°C)	1.26 (0.44)	1.09† (0.31)
T_{re} end (°C)	38.38 (0.25)	38.21 (0.26)
f_c end ($b \cdot min^{-1}$)	146.9 (12.9)	137.3† (5.8)
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	28.9 (3.4)	29.1 (2.4)
RER	0.89 (0.02)	0.87 (0.03)

Values are means (S.D.).
* Sweat rate (SR), change in rectal temperature (ΔT_{re}), rectal temperature (T_{re}) and heart rate (f_c) at the end of the training session, oxygen uptake ($\dot{V}O_2$), and respiratory exchange ratio (RER).
† Significantly different from Day 1.

the MF while training in a thermoneutral environment, the more extreme heat environment of the HST was sufficient to expose an increase in sweating rate due to training. However, due to the limited water vapor transfer through the NBC ensemble, these adaptations did not result in significant changes in evaporation rate. Overall, the HF subjects maintained a significantly higher SR than MF subjects either before or after training, though this did not translate into a higher evaporation rate.

High levels of aerobic fitness appear to impart some degree of protection during exercise in an uncompensable heat stress environment, with a significantly lower level of physiological strain at each timepoint in HF compared with MF-Pre subjects. Prior to undergoing the training program, T_{re}, f_c, and $\bar{T}_{sk}$ (**Figs. 1–3**, respectively) were all higher in MF-Pre than in HF individuals. In MF subjects, the primary effect of training was a significantly lower $\bar{T}_{sk}$ (Fig. 3), which may have been brought about by the increased sweating and

TABLE III. PHYSIOLOGICAL RESPONSES TO THE HEAT STRESS TEST FOR MODERATELY FIT SUBJECTS BEFORE (MF-PRE) AND AFTER (MF-POST) 2 WK OF AEROBIC TRAINING, COMPARED WITH HIGHLY FIT (HF) SUBJECTS.

	MF-Pre	MF-Post	HF
Sweat Rate ($L \cdot h^{-1}$)	0.87 (0.27)†	1.00* (0.29)†	1.30 (0.34)
Evaporation Rate ($L \cdot h^{-1}$)	0.31 (0.07)	0.29 (0.05)	0.38 (0.13)
Average Metabolic Rate ($W \cdot m^{-2}$)	173.9 (8.3)	171.4 (12.8)	175.1 (23.8)
Initial T_{re} (°C)	37.08 (0.24)†	36.93 (0.34)	36.85 (0.22)
Endpoint T_{re} (°C)	38.70 (0.37)†	38.61 (0.25)†	39.15 (0.18)
Tolerance Time (min)	93.1 (18.9)†	94.0 (16.2)†	117.6 (26.1)

Values are means (S.D.).
* Significant main effect of training.
† Significantly different from the HF group.

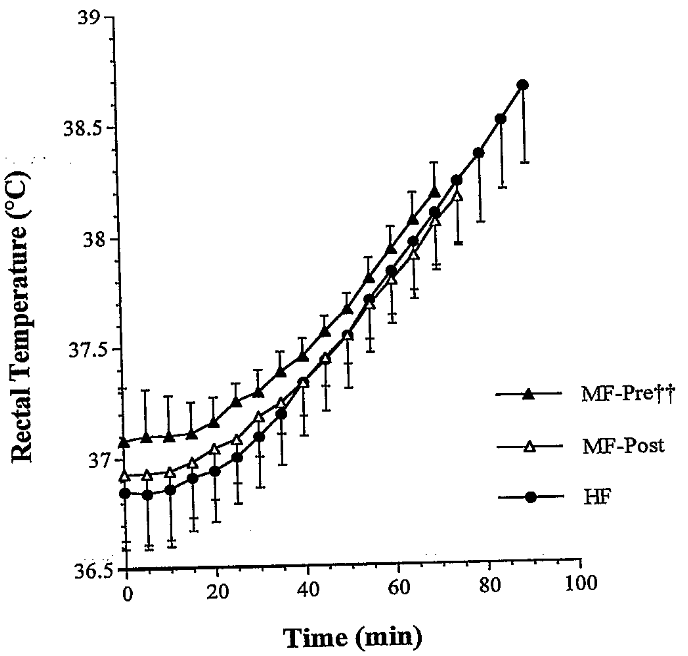

Fig. 1. Rectal temperature response during the heat stress tests of the moderately fit (n = 8) subjects, before (MF-Pre; filled triangles) and following (MF-Post; open triangles) 2 weeks of aerobic training, and the high fit (n = 8) subjects (HF; circles). Values are mean ± SD. ††Significantly different from the HF group.

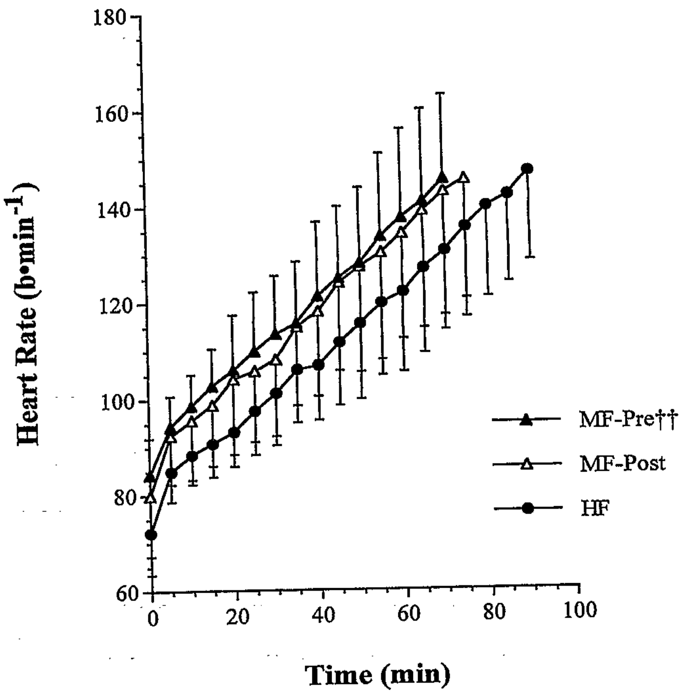

Fig. 2. Heart rate response during the heat stress tests of the moderately fit (n = 8) subjects, before (MF-Pre; filled triangles) and following (MF-Post; open triangles) 2 weeks of aerobic training, and the high fit (n = 8) subjects (HF; circles). Values are mean ± SD. ††Significantly different from the HF group.

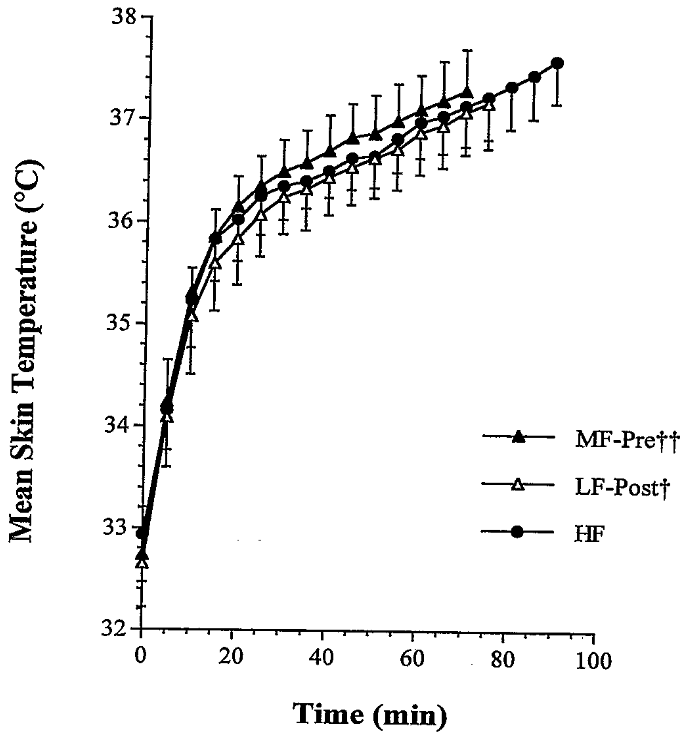

Fig. 3. Mean skin temperature response during the heat stress tests of the moderately fit (n = 8) subjects, before (MF-Pre; filled triangles) and following (MF-Post; open triangles) 2 weeks of aerobic training, and the high fit (n = 8) subjects (HF; circles). Values are mean ± SD. †Significant main effect of training. ††Significantly different from the HF group.

skin wettedness following training. Training resulted in no change in T_{re} response during the HST. Though nonsignificant, the slight changes in physiological responses following training were sufficient to eliminate the significant differences observed between MF-Pre and HF subjects during the HST. T_{re}, f_c, and $\bar{T}_{sk}$ were not significantly different between MF-Post and HF groups.

Tolerance to the HST

Tolerance to the HST was determined by time, ethically imposed physiological endpoints, or subject exhaustion. None of the trials approached the 4-h time limit. In MF individuals, training did not result in an increased tolerance during uncompensable heat stress. In addition, the HF subjects had a significantly higher tolerance time by 20–25 min than the MF subjects. A significant disparity in the reasons for the termination of the HST was evident between the MF and HF groups. In MF subjects, the large majority of the HSTs (14 of 16) were terminated due to voluntary exhaustion before reaching the ethically imposed core temperature limit of 39.3°C. In contrast, most of the HST with HF subjects were terminated due to T_{re} reaching 39.3°C (6 of 8). While voluntary exhaustion was sometimes coincident with this limit, HF subjects often felt that they could have continued further. As a result, the $T_{re\ end}$ was likely underestimated in this group, but was still significantly higher than in MF subjects either pre- or post-training.

DISCUSSION

A general consensus has arisen that increases in aerobic fitness, whether through a short-term period of physical training or through months or years of habitual activity, are linked to an improvement in physiological response to exercise in the heat (2,18). In the uncompensable heat stress environment found when exercising in hot environments and wearing protective clothing with limited water vapor permeability, cross-sectional studies have demonstrated a greater exercise-heat tolerance in highly fit compared with moderately fit subjects (20,23). In an occupational setting, the time or facility for a proper heat acclimation protocol may not exist. Therefore, while recognizing that a short-term training program cannot replicate all of the physiological changes occurring as a result of chronic exercise and fitness, it would be of operational interest to examine whether a short-term period of training in previously untrained subjects can produce heat adaptation sufficient to simulate the improved level of heat tolerance seen in subjects with high aerobic fitness. The results of the present study demonstrate that, despite a significant increase in peak aerobic fitness, a 2-week aerobic training program did not increase exercise-heat tolerance in MF subjects to a level similar to that of HF subjects.

In an occupational setting involving work with protective clothing, a major question of interest is often the length of time that work can be performed before subjects reach the point of voluntary exhaustion. With the light exercise intensity of the present analysis, the HF subjects exhibited a longer tolerance time than the MF-Pre subjects, supporting prior comparisons between fitness groups using protective clothing in the heat with heavy exercise (23), and the general consensus of an improved exercise-heat tolerance with increased fitness (2). Short-term training was unsuccessful in prolonging the tolerance time for the MF subjects. Furthermore, despite the lack of any significant difference between the HF and MF-Post subjects in T_{re}, $\bar{T}_{sk}$, or f_c during exercise, tolerance time remained significantly higher in the HF subjects compared with the MF-Post subjects. On the basis of tolerance time, therefore, short-term training was of no benefit to subjects of moderate aerobic fitness.

The longer tolerance times in the HF subjects, compared with MF subjects pre- or post-training, appear to be primarily due to a higher core temperature which could be tolerated by the HF subjects during the HST. No changes in $T_{re\ end}$ (~38.6°C) or ΔT_{re} (~1.6°C) were observed in MF subjects pre- and post-training, with both lower than that observed in HF subjects ($T_{re\ end}$ ~39.2°C and ΔT_{re} ~2.3°C). The elevated $T_{re\ end}$ in the HF subjects suggests that high aerobic fitness and/or habitual activity trains individuals to tolerate higher levels of core temperature and discomfort, as the lower $\bar{T}_{sk}$ and trend toward a decreased f_c in the MF-Post compared with the MF-Pre argues against either factor being the limiting factor to tolerance. Extrapolating an increase in ΔT_{re} of 0.7°C in MF-Pre subjects, and assuming a rate of T_{re} increase of approximately 1.0°C per 45 min (Fig. 1, estimated from T_{re} values between t =

30–60 min), the MF-Pre tolerance time would increase by 31.5 min, exceeding the actual observed difference in tolerance time of approximately 22 min between the MF-Pre and HF groups. Thus, for the aerobic training program to affect tolerance time, there may be a requirement to train at an intensity and/or duration that increases T_{re} to higher levels on a daily basis. It may also be beneficial to achieve this increase in T_{re} by wearing the NBC clothing during the training sessions.

Indeed, the difference in ΔT_{re}, $T_{re\ end}$, and tolerance times between the HF and MF groups was likely underestimated in the present study due to our definition of tolerance. The test sessions were terminated when subjects either reached the point of voluntary exhaustion and collapse or else a T_{re} of 39.3°C. However, the termination of the HST was primarily due to voluntary exhaustion, at a T_{re} below 39.3°C, in the MF subjects. In contrast, the HF subjects typically terminated the HST due to T_{re} reaching 39.3°C. While voluntary exhaustion was sometimes coincident with T_{re} reaching the ethical limit, the HF subjects subjectively felt that they could continue further in most cases, such that the time required to reach voluntary exhaustion was likely underestimated. The first familiarization trial served to prepare all subjects for the discomfort associated with the HST. Unfortunately, ratings of perceived exertion were not taken to measure differences in tolerance of discomfort between the two groups, and differences may have existed in the motivation levels in the MF and HF groups to tolerating discomfort.

The degree of adaptation is strongly governed by the nature of the training program, and it is recognized that the training protocol may not have been of sufficient intensity to increase peak aerobic power to the levels seen in HF subjects or to maximize physiological adaptations. Henane et al. (13) suggested that a minimum increase of 15% in $\dot{V}O_{2peak}$ was required to significantly improve exercise-heat tolerance. In contrast, the present training program produced a significant increase in $\dot{V}O_{2peak}$ of only 6.5%. However, Henane et al. (13) trained subjects over a much longer time span consisting of several months, while the present study attempted to simulate an operational scenario requiring short-term aerobic training of only 2 wk. In addition, heat adaptations are due to both the exercise stimulus itself and the exercise-induced hyperthermia (6). Therefore, the present protocol was a balance between two requirements: 1) a sufficiently high intensity to stimulate physiological adaptations due to the exercise itself; and 2) an exercise light enough that the untrained and relatively nonfit MF subjects could perform the entire protocol, thereby maximizing the degree and duration of exercise-induced hyperthermia. With the treadmill exercise used in the present study, MF subjects walked at 4.8 km $\cdot$ h^{-1} at a grade of 8–13% to achieve an exercise intensity of approximately 65% $\dot{V}O_{2peak}$ and a final T_{re} of approximately 38.4°C. To achieve a higher exercise intensity or a final T_{re} would have likely required running, an exercise which the MF subjects could not perform for 1 h continuously.

The comparison of fitness levels was made between two subject groups separated based on aerobic fitness and activity levels. However, care should be taken to avoid automatically assuming that fitness was the primary or only factor responsible for the differences observed during exercise-heat stress between the MF and HF groups. In addition to significant differences in $\dot{V}O_{2peak}$, the HF subjects also had a lower body mass and body fat content. Each of these factors, along with other anthropometric measures, could also have contributed to the observed differences, and it is recognized that an inherent difficulty in cross-sectional studies lies in controlling for these additional factors. However, the lower body fat content and body mass were likely an indirect result of increased activity and $\dot{V}O_{2peak}$, and previous studies reported aerobic fitness as being the primary factor correlating with the amount of physiological strain tolerated during exercise-heat stress (11,12). The higher relative work load for the MF subjects may also have contributed to the higher heat strain and lower tolerance time. However, the exercise intensity was $<$ 30% $\dot{V}O_{2peak}$ for all subjects and the average metabolic rates were similar for all subject groups (Table III), such that the exercise intensity itself was unlikely to be a significant factor in determining the limits of tolerance.

Another caveat to the interpretation of the results is to avoid an overemphasis on the dependent measure of tolerance time as the primary determinant of heat strain. While tolerance time is often the measure of most practical or occupational interest, its reliability and repeatability during submaximal exercise in an uncompensable heat stress environment has been criticized (16). In the present study, the claims of an improved physiological response to heat stress and an increased exercise-heat tolerance in the HF compared with either the MF-Pre or MF-Post subjects are supported by an increased ΔT_{re} and $T_{re\ end}$ in addition to the longer tolerance times.

In summary, the present study attempted, in a group of subjects with moderate aerobic fitness, to replicate the increased tolerance typically seen with high $\dot{V}O_{2peak}$ and habitual exercise by using short-term aerobic training at 60–65% $\dot{V}O_{2peak}$ for 1 h, 6 d $\cdot$ week^{-1} for 2 weeks. Prior to the training period, inactive individuals of moderate aerobic fitness had decreased tolerance compared with active individuals with high aerobic activity. Following training, cardiovascular and thermoregulatory strain were similar in individuals of moderate compared with those of high fitness. However, the the final core temperature before the onset of voluntary exhaustion and the overall tolerance time remained significantly lower in MF subjects post-training. It was concluded that, in preparation for exercise in an uncompensable heat stress environment, the short-term aerobic training used in this study was not an adequate substitute for a high level of aerobic fitness resulting from habitual exercise and training.

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