UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

①

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

AD-A209 753

ECTE
122 1989
D

1b RESTRICTIVE MARKINGS
FILE COPY

3 DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release; distribution is unlimited.

4 PERFORMING ORGANIZATION REPORT NUMBER(S)
M48-89

5 MONITORING ORGANIZATION REPORT NUMBER(S)

6a NAME OF PERFORMING ORGANIZATION
U.S. Army Rsch Inst of Env Med

6b OFFICE SYMBOL (If applicable)
SGRD-UE-MEB

7a NAME OF MONITORING ORGANIZATION
U.S. Army Rsch Inst of Env Med

6c ADDRESS (City, State, and ZIP Code)
Natick, MA 01760-5007

7b ADDRESS (City, State, and ZIP Code)
Natick, MA 01760-5007

8a NAME OF FUNDING/SPONSORING ORGANIZATION
Same as 6a.

8b OFFICE SYMBOL (If applicable)

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c ADDRESS (City, State, and ZIP Code)
Same as 6c.

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO
	3E1627 87A878	878/AE	084

11 TITLE (Include Security Classification) (U)Thermoregulatory Competence During Exercise Transients In A Group of Heat-Acclimated Young and Middle-Aged Men Is Influenced More Distinctly By Maximal Aerobic Power Than Age

12 PERSONAL AUTHOR(S) Richard R. Gonzalez and Kent B. Pandolf

13a TYPE OF REPORT
Presentation

13b TIME COVERED
FROM ________ TO ______

14 DATE OF REPORT (Year, Month, Day)
May 1989

15 PAGE COUNT
6

16 SUPPLEMENTARY NOTATION

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
heat acclimation; maximal aerobic power, middle-aged; thermoregulatory responses

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Pandolf et.al. [J. Appl. Physiol. 65:65-71, 1988] studied a group of 9 young men (21.2 ±2.4 SD, years) and 9 middle-aged men (46.4 ±4.6 SD, years) having parallel body weights, skin surface areas, % body fat, and maximal aerobic power. The men displayed almost equivalent thermoregulatory responses to analogous exercise and heat stress conditions following 10-days heat acclimation. This paper focuses on exercise transients (50 min bouts of exercise at 45% $\dot{V}O_2$max at T_a=49°C; 20%rh) from that study in 9 men whose data were partitioned into two different $\dot{V}O_2$max groups independent of age: a lower fit group (LFG, n=4, age=35.0 ±16.3 y SD, range 19-55 y, $\dot{V}O_2$max=48.6 ±0.98 ml•kg^{-1}• min^{-1}) and a higher fit ($P<0.05$) group (HFG, n=5, age=35.4 ±13.6, range 19-49 y, $\dot{V}O_2$max=55.7 ±4.5 ml•kg^{-1}•min^{-1}). Transient analysis comparing the LFG and the HFG, either pre-acclimated or post acclimated, showed that sweating onset times were longer (+2.6 min, $P\leq0.05$), esophageal temperature thresholds for sweating onset (°C) were higher

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a NAME OF RESPONSIBLE INDIVIDUAL
Richard R. Gonzalez, Ph.D.

22b TELEPHONE (Include Area Code)
508/651-4848

22c OFFICE SYMBOL
SGRD-UE-ME

DD Form 1473, JUN 86 Previous editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

89 6 20 226

THERMOREGULATORY COMPETENCE DURING EXERCISE TRANSIENTS IN A GROUP OF HEAT-ACCLIMATED YOUNG AND MIDDLE-AGED MEN IS INFLUENCED MORE DISTINCTLY BY MAXIMAL AEROBIC POWER THAN AGE

RICHARD R. GONZALEZ and KENT B. PANDOLF

U.S. Army Research Institute of Environmental Medicine. Natick, MA, USA 01760-5007

INTRODUCTION

A fundamental change that occurs with advancing age is a diminishing maximal aerobic power ($\dot{V}o_2$ max) [1,4,7]. In sedentary individuals the rate of decline in $\dot{V}o_2$ max as a function of age is estimated at 10% per ten years after age 20 but becomes more gradual in endurance-trained individuals regardless of gender, approaching about 5% with each ten year span[1,3]. Buskirk and Hodgson[1] proposed a curvilinear decline instead of the conventional linear drop for a given population. In very sedentary individuals, the rapid decline in $\dot{V}o_2$ max between the ages of 20-40 years is suggested to result from the combination of an increase in body weight, loss of lean body mass and reduction in aerobic activity. The eccrine sweating responses to thermal stress and specific neurochemical stimulation are generally found to be attenuated in elderly persons (>70 y) compared to younger individuals, and a higher internal body temperature threshold for the initiation of sweating and vasodilation is observed[2,4]. It is thought that reduced sweating and vasomotor responses to heat stress indicate deterioration in thermoregulatory function[2,7]. A scrutiny of thermoregulatory mechanisms in the aging process is necessary because other quantitative studies of actual efferent thermoregulatory drive point to a maintenance of thermoregulatory competence well into the sixth decade of life provided a level of aerobic fitness is sustained[6]. Pandolf et.al.[6] studied a group of nine young and nine middle-aged men having parallel body weights, skin surface areas, percent body fat and maximal aerobic power. These groups displayed almost equivalent thermoregulatory responses to comparable exercise and heat stress conditions following 10-days of heat acclimation. Interestingly, during the initial three to four days of this 10-day heat acclimation period, the younger men lagged behind these middle-aged individuals in certain physiological responses which was associated with the older group having maintained their aerobic fitness possibly through long term, regular daily exercise. The present paper is an examination of the above study's thermoregulatory responses during exercise transients. Transient analysis to specific exercise/ heat stress provocation provides a clearer understanding of the influence of age and aerobic fitness on thermoregulatory control of sweating than steady-state analysis.

METHODS AND PROCEDURES

Subjects. Many of the procedures and evaluations have been covered previously[6] for the steady-state responses during exercise-heat acclimation. We examined the exercise transient responses of nine subjects who displayed no difficulty inserting and keeping the esophageal temperature probe in place during repeated exercise bouts. They were age-matched according to maximal aerobic power in respect to total body weight and ranked based on magnitude of aerobic capacity (Table I) and divided into two groups: a high-fit group (HFG) and a fit group (FG). Otherwise, the groups had similar specific anthropomorphic characteristics (Table I).

TABLE I. PHYSICAL CHARACTERISTICS OF THE SUBJECTS DESIGNATED AS FIT GROUP (FG-A1) AND HIGHER-FIT GROUP (HFG-B1).

Group	Age (years)	Weight (kg)	Fat (%)	Surface Area (m^{-2})	$\dot{V}o_2$ max ($ml\cdot min^{-1}\cdot kg^{-1}$)
FG-A1 (n=4)	$35\pm16.3^{*}$ (range, 19-55)	$70.2\pm4.2^{\ddagger}$	$16.9\pm2.7^{\ddagger}$	$1.87\pm0.07^{*}$	$48.6\pm1.0^{\ddagger}$
HFG-B1 (n=5)	$35\pm13.6^{*}$ (19-49)	$81\ 0\pm6.0^{\ddagger}$	$11.8\pm3.1^{\ddagger}$	$2.03\pm0.09^{*}$	$55.7\pm4.5^{\ddagger}$

* = no significant difference ($p>0.05$); ‡ = significant difference ($p \leq 0.05$), between groups.

The subjects participated in the study after first giving their informed consent and did the experiments in early Spring and therefore were considered not naturally heat-acclimatized.

Protocol. Prior to the experimental runs in the heat, the subjects' percent body fat (%Fat) was determined by the hydrostatic weighing method[6]. Maximal aerobic power ($\dot{V}o_2$ max) was established using a treadmill protocol on separate days[1,6]. The subjects, unclothed except for gym shoes and shorts, were heat-acclimated over a ten day period at the same time of the day (0800 - 1200 h) by treadmill walking (1.56 $m\cdot s^{-1}$ at 5% grade: 50 min work, 10 min rest, 50 min work each day) in an environmental chamber set at T_a = 50 °C and dew point temperature of 18 °C. All subjects were given water ad libitum in the heat acclimation experiments except for the first and last day (Pre- and Post Heat-Acclimation, HA) in which the measurements of esophageal temperature (T_{es}) were recorded continuously and dictated that the subjects expectorate into a cup for the first bout. Subjects were initially well-hydrated by drinking spring-water previous to the first treadmill bout. Only thermoregulatory data from the first 50-min exercise transient were used in this analysis.

Physiological variables. Continuous recordings were made of T_{es} by a thermistor/polyethylene probe positioned at heart level. We calculated mean skin temperature using weighted averages of upper arm, calf, and chest skin temperatures recorded with thermocouples. We continuously recorded arm sweating rate ($\dot{m}_s$) using a dew point

A-1

sensor assembled into a 13.85 cm^2 individually-ventilated plastic unit placed on the upper arm adjacent to the arm thermocouple[4,6]. All the temperatures were recorded on a data acquisition/computer system for later analysis. Heart rate was monitored from an interval scan of continuous electrocardiographic records (CM5 chest electrode placement) registered on a telemetric system. $\dot{V}o_2$ was analyzed by open-circuit spirometry and heat production ($M, W \cdot m^{-2}$) was calculated from the respirometry parameters obtained and the Dubois surface area equation[6]. Evaporative heat loss ($W \cdot m^{-2}$) was estimated by total nude body weight loss less metabolic and respiratory heat losses. Rate of heat storage (S, $W \cdot m^{-2}$) was calculated by partitional calorimetric analysis using estimates of a mean body temperature weighting of $0.89 \cdot T_{es} + 0.11 \cdot T_{sk}$ [6].

Statistical and data analysis. Individual sweating onset times (min) were determined by on-line observation of the rapid inflection of skin dew point temperature following an initial 10-min baseline recording. The relationships between $\dot{m}_s$ and T_{es} were compared minute to minute during the transients of exercise for the first 50-min treadmill walk of each Pre-HA and Post-HA experiment. A specific T_{es} inflection point for $\dot{m}_s > 0.05$ $mg \cdot min^{-1} \cdot cm^{-2}$ was identified as the threshold locus for initiation of thermoregulatory sweating. The slope of the linear part of the regression ($\geq r^2$ of 0.90) of $\dot{m}_s$ and T_{es} was characterized as a thermoregulatory "gain" coefficient for the thermoregulatory system ($\delta\dot{m}_s / \delta T_{es}$, [$mg \cdot min^{-1} \cdot cm^{-2} \cdot K^{-1}$]) of each subject's specific CNS efferent drive for sweating[6]. Standard analysis of variance (repeated, pairwise, etc.) was performed on all the data and post hoc tests (Tukey) were performed whenever a significant F-ratio occurred ($p < 0.05$).

RESULTS

Table II is a summary of the results. In the FG, sweating onset times were longer, T_{es} thresholds for sweating onset were higher, the rate of heat storage (S) was elevated, and the gain of thermoregulatory sweating response was less in comparison to the HFG, either Pre-HA or Post-HA. A comparison of the $\delta\dot{m}_s / \delta T_{es}$, [$mg \cdot min^{-1} \cdot cm^{-2} \cdot K^{-1}$] determined for each subject within the two groups and their age is shown in Figure 1. The data in Figure 1 indicate a decline in the $\delta\dot{m}_s / \delta T_{es}$, when plotted as a function of age in the FG. This response has been observed in other studies[2,4]. However, when the data are plotted in terms of the subjects' lean body mass (e.g. $\dot{V}o_2$ max-FF, fat-free calculated from hydrostatic weighing and %body fat), a marked response in $\delta\dot{m}_s / \delta T_{es}$ is apparent in the HFG (Figure 2). Typically, the individuals who displayed fitness levels (in terms of $\dot{V}o_2$ max-FF) less than about 60 $ml \cdot min^{-1} \cdot kg^{-1}$, also had the lowest gains ($p < 0.001$) in the thermoregulatory sweating: T_{es} relationship. Alternatively, individuals primarily in the HFG with $\dot{V}o_2$ max-FF > 64 $ml \cdot min^{-1} \cdot kg^{-1}$ also improved their respective $\delta\dot{m}_s / \delta T_{es}$ significantly after the 10-day heat acclimation period notwithstanding their age.

JCS
871

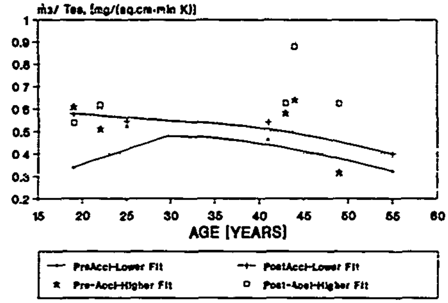

Figure 1. Change in rate of sweating to Tes as a function of age in the subjects.

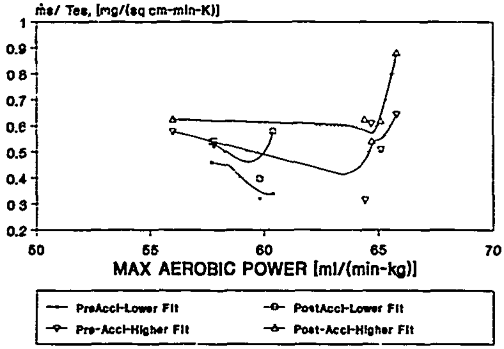

Figure 2. Slope of sweating rate:T_{es}, as a function of $\dot{V}o_2$ max-FF.

DISCUSSION

The separation of the nine subjects into two fitness groups allowed the evaluation of thermoregulatory function owing to both the aging process and level of aerobic fitness of each subject. We examined the thermoregulatory data as a function of the lean body mass of the subjects because the change in muscle mass per se is often considered an important reason for the age-related drop in $\dot{V}o_2$ max[3]. How this variable affects thermoregulatory competence is a interesting issue. It was determined previously that middle-aged men acclimated to heat as easily as younger men with a similar $\dot{V}o_2$ max and body morphology[6].

The exercise transient data show that the increase in $\delta\dot{m}_s/\delta T_{es}$ caused by heat acclimation was less in the fit group compared to the highly fit group, regardless of age (Fig. 1). Subjects in the highly fit group also displayed a further augmentation in $\delta\dot{m}_s/\delta T_{es}$ between the 1st and last days during the heat acclimation process (Fig. 2).

TABLE II. PHYSIOLOGICAL AND THERMOREGULATORY RESPONSES OF SUBJECTS. MEANS (±SD).

Variable	FIT GROUP		HIGHER FIT GROUP		
	PRE-ACCL	POST-ACCL	PRE-ACCL	POST-ACCL	
	A1	A2	B1	B2	Sig dif. $p \leq 0.001$
$\dot{V}o_2$ max ($l \cdot min^{-1}$)	3.42±0.14	----	4.50±0.15	----	A1 < B1
$\dot{m}_s$ onset (min)	8.3±1.7	3.3±1.3	5.2±2.2	1.2±0.4	A1>A2, B1>B2;A1>B1;A2>B2
$\delta\dot{m}_s/\delta T_{es}$ [$mg \cdot min^{-1} \cdot cm^{-2} \cdot K^{-1}$]	0.41±0.10	0.52±0.08	0.53±0.13	0.66±0.13	A1 < B2
T_{es}-intercept	36.97±0.18	36.75±0.11	36.85±0.24	36.66±0.15	All Pre Accl> Post-Accl
Rate of Heat Storage ($W \cdot m^{-2}$)	71.3±26 2	49.2±15.3	52.3±16.7	32.3±14.3	A1>A2>B1 A2>B2; A1>B2 B1>B2

Generally, muscle mass decreases with age in sedentary persons even though body weight stays within normal surface area:body weight boundaries[1,3,7]. With loss of muscle mass during the aging process, given a constant muscle $\dot{V}o_2$ utilization, $\dot{V}o_2$ max would have to decrease. In a population of subjects ages 22 to 87 years, Fleg and Lakatta[3] measured 24-h urinary creatinine excretion rates, (a proportional measurement of total body muscle mass) and found about a 6% $\dot{V}o_2$ max decline per decade. They concluded that almost 50% of the age-drop in $\dot{V}o_2$ max was associated with the decreased muscle mass based on this measurement. Our results confirm that maintenance of a competent thermoregulatory sweating process, in respect to an internal body temperature drive, is associated with augmentation of maximal aerobic power (MAP). A high MAP in the middle-age individuals of our study suggests that adequate improvements might also occur in efficiency of the working muscle groups ($\dot{V}o_2$ per muscle fiber mass). One study supports the idea of a constant metabolic efficiency being maintained in fit individuals and little abatement of critical enzymes involved in energy transport pathways found in individuals between the ages of 16 to 78 years[5]. We are aware that MAP expressed in terms of lean body mass (FF) encompasses ancillary tissues (bone and other organs). As such, %Fat determined from body density measurements does not wholly take into account changes in total body water flux[7] so loss of muscle mass associated with age drop of $\dot{V}o_2$ max may not be wholly valid. Such effects on the thermoregulatory system· especially density, potentiation, and interstitial fluid delivery to the sweat glands deserve further investigation. The maintenance of long term training (LTT), evident by the improvement in the $\delta\dot{m}_s/\delta T_{es}$ in the middle-age persons in this study, clearly assists in the acquiring of heat acclimation. This would potentiate the thermoregulatory system to guard against hyperthermia and therefore lessen its risks (by the fact that unfit persons have a higher heat storage). Also undoubtedly, LTT improves the distribution of blood flow to the active muscle groups. Finally, mechanisms which adjust thermoregulatory effector drive in middle-aged persons are strongly weighted by maintenance of a high maximal aerobic power and this is a critical property in this age group.

REFERENCES

1. Buskirk ER, Hodgson JL (1987) Fed Proc 46:1824-1829.

2. Collins KJ, Exton-Smith AN (1983) J Am Ger Soc 31:519-524.

3 Fleg JL, Lakatta EG (1988) J Appl Physiol 65:1147-1151.

4. Gonzalez RR, Berglund LG, Stolwijk JAJ (1980) In: Szelenyi Z, Szekely M (eds) Contributions to Thermal Physiology Pergamon Press, NY, pp 357-361.

5. Örlander J Kiesling K-H, Larsson L, Karlsson J, Aniansson A (1978) Acta Physiol Scand 104:249-261.

6. Pandolf KB, Cadarette BS, Sawka MN, Young AJ, Francesconi RP, Gonzalez RR (1988) J Appl Physiol 65:65-71.

7. Timiras PS (1988) Physiological Basis of Geriatrics MacMillan, NY pp 331.
