

Age-Related Thermal Strain in Men While Wearing Radiation Protective Clothing During Short-Term Exercise in the Heat

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The aim of the study was to compare heat strain among different age groups of men in protective clothing during short-term physical work. Eight young (20–29 years), 6 middle-aged (41–55 years), and 6 older (58–65 years) men exercised for 30 min on a cycle ergometer (40% $V_{O_2 \max}$) in 2 hot environments with a similar WBGT (ca. 26 °C): once with minimal clothing without infrared radiation (E1), and once with aluminized protective clothing under infrared radiation (E2). All subjects had sedentary jobs, but only the older subjects were physically active in their leisure-time. Body temperatures, heart rate, sweat rate, and subjective feelings were determined during the tests. Higher thermal strain was observed in E2 than in E1. No age-related differences in thermal strain were observed in either experiment indicating that active older men can tolerate short work periods with protective clothing in the heat as well as younger sedentary men.

age heat protective clothing

1. INTRODUCTION

In the presence of radiant heat in hot environments it is often necessary to use reflective protective clothing [1]. In some job settings heavy physical work is performed in such clothing, for example, in sand-mould pouring or hand moulding in the steel industry. Despite protection, such aluminized clothing makes sweat evaporation considerably more difficult limiting heat dissipation from the body. Although external heat stress is reduced by the clothing, the dissipation of internally produced metabolic heat may be hampered significantly, especially during heavy physical work.

In general physical fitness [2] and heat tolerance decrease with age [3, 4]. Some studies

indicate, however, that if middle-aged or older men are physically active or aerobically fit [5] their work heat tolerance may be similar to those of younger individuals. In most studies on age and heat stress, however, the subjects have been clad in minimal clothing. For practical occupational purposes, it would be useful to have data on the effect of clothing on age-related thermal strain. In this respect a rare study by Smolander et al. [6] had their subjects wear a normal working overall with underwear while working in the heat. They found time-related differences in thermal strain between young and older men in the warm humid climate, but not in the temperate and hot dry environment. So the humid microclimate inside clothing may have an effect on age-related thermal strain.

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In our previous study [7] thermal strain imposed by aluminized protective clothing was investigated during passive heating in men of different age. No significant differences in heat strain were observed between age groups but subjective ratings indicated an attenuated feeling of thirst in older men, which could increase the potential risk for dehydration in a hot environment.

The aim of the study was to assess thermal strain in young, middle-aged, and older men exercising at the same relative work load in two hot environments with a similar WBGT value: once with minimal clothing and without infrared radiation (control) and once with infrared radiation and with protective clothing.

2. MATERIAL AND METHODS

2.1. Subjects

Twenty healthy men participated in the study. They were divided into three age groups: group Y consisting of 8 young men (21–29 years), group M-A including 6 middle-aged men (41–55 years), and group O consisting of 6 older men (58–65 years). The subjects from groups Y and M-A were of average fitness but the O had a good fitness level for their age, according to Shvartz and Reibold [2] (Table 1). All subjects had sedentary jobs but only the older subjects were active in their leisure time (cycling, skiing, walking). Body surface area (A_{Du}) was estimated

from body mass and height, using the equation of Du Bois and Du Bois [8]. Body fat was estimated from skinfold thicknesses (GPM-Skinfold Caliper, Switzerland) at four sites (biceps, triceps, subscapular, and suprailiac) and calculated using the equation by Durnin and Womersley [9]. Before the study all subjects had a medical check-up, after which they signed an informed consent. The study procedures were carried out according to the Helsinki Declaration.

2.2. Experimental Sessions

The subjects took part in two experimental sessions E1 and E2 in a climatic chamber (ACS Angelantoni Centro-Sud, Italy) at WBGT of approximately 26 °C. The WBGT index was calculated according to ISO 7243:1989 [10]. In experiment E1 there was no thermal radiation and no protective clothing was used (t_{nwb} 22.3 ± 1.0 °C, t_g 36.5 ± 0.6 °C, relative humidity 30.5 ± 2.6%, and air velocity 0.2–0.3 m·s⁻¹). The subjects wore only shorts, socks, and tennis shoes. In experiment E2 infrared radiation came from two sources and there was a mean radiation of 600 Wm⁻² in the area where the subjects exercised while wearing radiation protective clothing (t_{nwb} 19.4 ± 0.7 °C, t_g 40.5 ± 0.9 °C, relative humidity 30.6 ± 2.1%, and air velocity 0.2–0.3 m·s⁻¹). Garments included shorts, socks, a long-sleeve shirt, trousers, aluminized jacket, aluminized trousers, aluminized gloves, a face cover, and leather shoes. Thermal insulation of

TABLE 1. Characteristics of Subjects ($M \pm SD$)

Characteristics	Group		
	Y (n = 8)	M-A (n = 6)	O (n = 6)
Age (years)	24.2 ± 2.7***	47.5 ± 4.8*	60.5 ± 2.4
Body mass (kg)	74.7 ± 7.5	76.3 ± 8.4	79.0 ± 7.1
Height (m)	1.82 ± 0.04**	1.74 ± 0.04	1.74 ± 0.02
A_{Du} (m ²)	1.94 ± 0.10	1.91 ± 0.11	1.93 ± 0.08
Body fat (%)	15.0 ± 3.4	21.8 ± 2.3	24.9 ± 2.3
$VO_{2\max}$ (ml·kg ⁻¹ ·min ⁻¹)	43.5 ± 5.1**	34.7 ± 4.5	34.2 ± 2.8

Notes. Y—young, M-A—middle-aged, O—older; A_{Du} —body surface area; *** $p < .001$ compared to M-A and O, * $p < .01$ compared to O, ** $p < .01$ compared to M-A and O.

the ensemble was 1.17 clo, as estimated from tables according to ISO 9920:1995 [11]. Clothing was comprised of two layers: one of mineral wool, and one of thin aluminium.

2.3. Study Protocol

Each subject came to the laboratory at the same time in the morning for both experiments. After entering the laboratory, the subjects drank 200 ml of water. Before exposure they rested in a sitting position for 15 min, after which resting heart rate and blood pressure were measured. The subject was weighed in the semi-nude. After that, a thermocouple sensor for rectal temperature was inserted by the subjects. Then thermocouples for skin temperatures and electrodes for ECG were attached. Each piece of clothing was weighed before the tests. After a stabilization period the subjects entered the thermal chamber and exercised for 30 min on a bicycle ergometer. Pedal frequency was kept at 60 rpm. After the experiment the subjects left the chamber, and took off their clothes for weighing. Body weight was also measured.

In both sessions subjects exercised at the level of 40% of the individually determined maximal oxygen consumption ($V_{O_{2max}}$) on a bicycle ergometer (Monark, Sweden). On another day, $V_{O_{2max}}$ was estimated indirectly by a submaximal bicycle ergometer test [12].

During exercise in the climatic chamber the following stop criteria for safety were used:

1. rectal temperature 38.5°C ,
2. heart rate above 90% of individually estimated maximal heart rate (calculated according to the formula: $220 - \text{age}$),
3. objective or subjective signs of severe discomfort or fatigue.

2.4. Measurements and Calculations

Rectal temperature (t_{re}) measured 10 cm past the anal sphincter and eight local skin temperatures were registered by thermocouples, every 5 min, with an electrical thermometer PD 85-U (Ellab

A/S, Denmark). Mean weighted skin temperature (\bar{t}_{sk}) was calculated according to ISO 9886:1992 [13]. Heart rate (HR) was monitored continuously with a Sport Tester System PE 3000 (PolarElectro, Finland) and was registered every 5 min. Heat storage (S) was calculated according to Burton [14]. During the experiments subjective ratings of thirst [7], thermal sensation, perceived skin wetness, and perceived sweating [15] were collected before the heating session and just after exercise had stopped. Total body sweat rate ($TBSR$) was calculated as a difference between body and clothing masses before and after exposure to heat and expressed for 1 hr per square meter of body surface area.

2.5. Statistics

The results were expressed as means \pm SD . For statistical analysis a 2-way ANOVA was used, where the first factor consisted of the three age groups, and experimental conditions E1 and E2 were the other factor as a repeated measure. In the case of significant main effects Duncan's test was used in the post-hoc analysis. The results were considered statistically significant, when $p < .05$.

3. RESULTS

The resting t_{re} values before the experiments were different between the groups and equalled $37.1 \pm 0.4^{\circ}\text{C}$, $37.1 \pm 0.1^{\circ}\text{C}$ and $37.3 \pm 0.3^{\circ}\text{C}$ in E1 and $37.1 \pm 0.1^{\circ}\text{C}$, $37.3 \pm 0.1^{\circ}\text{C}$ and $37.2 \pm 0.2^{\circ}\text{C}$ in E2. Thus, changes from resting values in t_{re} were used in the analysis. The increase in t_{re} during exercise was not significantly different between the Y, M-A, and O groups in E1 ($0.49 \pm 0.26^{\circ}\text{C}$, $0.45 \pm 0.08^{\circ}\text{C}$ and $0.37 \pm 0.23^{\circ}\text{C}$, respectively) and in E2 ($0.49 \pm 0.22^{\circ}\text{C}$, $0.53 \pm 0.10^{\circ}\text{C}$ and $0.42 \pm 0.19^{\circ}\text{C}$, respectively).

During the tests in E1 \bar{t}_{sk} reached $35.10 \pm 0.25^{\circ}\text{C}$, $35.32 \pm 0.19^{\circ}\text{C}$ and $35.07 \pm 0.43^{\circ}\text{C}$ in the Y, M-A and O groups, respectively. The corresponding values for E2 were $35.64 \pm 0.29^{\circ}\text{C}$, $35.94 \pm 0.45^{\circ}\text{C}$ and $35.46 \pm 0.51^{\circ}\text{C}$, respectively. \bar{t}_{sk} was

significantly higher in E2 than in E1 ($p < .001$) in each age group (Figure 1).

Heat storage (S) was 75.7 ± 22.3 , 85.8 ± 11.5 , and $58.5 \pm 31.2 \text{ W}\cdot\text{m}^{-2}$ in E1 and 86.0 ± 31.5 , 110.7 ± 20.2 , and $61.8 \pm 32.7 \text{ W}\cdot\text{m}^{-2}$ in E2 in the Y, M-A, and O groups, respectively. S was statistically significantly higher in E2 than in E1 in the M-A group ($p < .001$). In E2, S in the M-A group was also statistically significantly higher than in the O group ($p < .05$).

In E1, $TBSR$ was equal to 352.0 ± 108.0 , 368.2 ± 79.8 and $365.5 \pm 94.6 \text{ g}\cdot\text{hr}^{-1}\cdot\text{m}^{-2}$ in groups Y, M-A and O, respectively. In E2, $TBSR$ was 448.2 ± 91.8 , $430.2 \pm 110.4 \text{ g}\cdot\text{hr}^{-1}\cdot\text{m}^{-2}$ and $385.3 \pm 170.9 \text{ g}\cdot\text{hr}^{-1}\cdot\text{m}^{-2}$ in groups Y, M-A and O, respectively. The differences in $TBSR$ were not significant between age groups or between experiments.

At the end of experiment E1, HR reached 137.6 ± 11.1 bpm, 129.2 ± 9.7 bpm and 122.83 ± 8.2 bpm in E1 and 151.1 ± 16.1 bpm, 142.7 ± 10.9 bpm and 130.5 ± 14.5 bpm in E2 in the Y, M-A and O groups, respectively. HR was significantly higher in E2 than in E1 ($p < .05$) in each age group (Figure 2).

HR expressed as a percentage of the maximal heart rate ($\%HR_{\text{max}}$) was also statistically significantly higher in E2 than in E1 in the Y ($p < .001$), M-A ($p < .01$) and O groups ($p < .05$), respectively, and was equal on average to $70.3 \pm 5.8\% HR_{\text{max}}$, $74.9 \pm 5.3\% HR_{\text{max}}$ and $77.0 \pm 5.3\% HR_{\text{max}}$ in E1 and $77.2 \pm 8.4\% HR_{\text{max}}$, $82.7 \pm 5.3\% HR_{\text{max}}$ and $81.8 \pm 8.7\% HR_{\text{max}}$ in E2, respectively.

Subjective ratings of thirst, thermal sensations, perceived skin wetness, and perceived sweating were not significantly different between the age groups or between the experiments (Table 2).

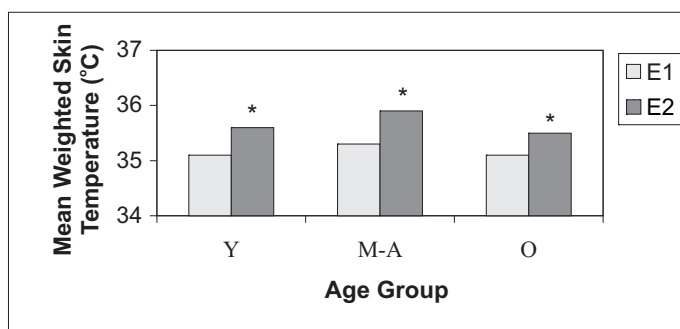


Figure 1. Mean weighted skin temperatures in experiments E1 (without radiation heat sources) and E2 (with radiation sources/protective clothing) in young (Y), middle-aged (M-A) and older (O) groups. Notes. $*p < .001$ between E2 and E1.

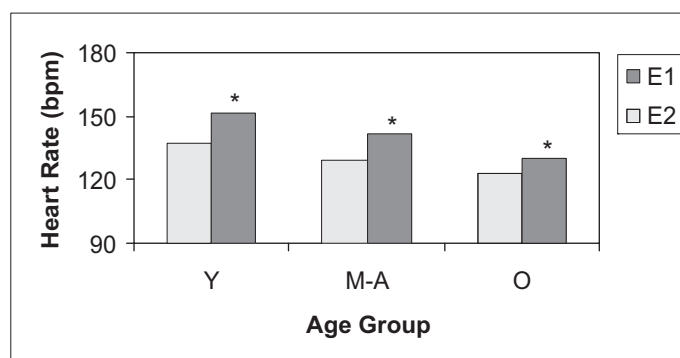


Figure 2. Heart rate in experiments E1 (without radiation heat sources) and E2 (with radiation sources/protective clothing) in young (Y), middle-aged (M-A) and older (O) groups. Notes. $*p < .05$ between E2 and E1.

TABLE 2. Subjective Ratings at the End of Experiments E1 (Without Radiation Heat Sources) and E2 (With Radiation Sources/Protective Clothing) in Young (Y), Middle-Aged (M-A), and Older (O) Groups ($M \pm SD$)

Variable	Experiment	Group		
		Y	M-A	O
Thirst	E1	2.5 ± 0.5	2.3 ± 0.8	1.7 ± 0.7
	E2	2.7 ± 0.8	2.7 ± 0.7	1.8 ± 0.7
Perceived skin wetness	E1	7.2 ± 0.9	6.2 ± 1.3	5.8 ± 1.5
	E2	7.4 ± 0.5	6.3 ± 0.9	6.3 ± 1.2
Perceived sweating	E1	6.7 ± 0.5	6.2 ± 0.7	6.3 ± 0.8
	E2	6.7 ± 0.5	5.8 ± 0.7	6.5 ± 0.8
Thermal sensation	E1	2.5 ± 0.5	2.2 ± 0.4	2.2 ± 0.7
	E2	2.7 ± 0.5	2.5 ± 0.5	2.4 ± 0.5

4. DISCUSSION

In general, the results indicated that physiological and subjective responses of older men did not differ from those of the younger subjects during short-term exercise at 40% V_{O2max} in a hot environment both without and with infrared radiation. Only S was statistically significantly higher in the M-A than in the O group in E2. The O group had a slightly smaller average increase in t_{re} and heat storage during exercise than the subjects from the other groups. This finding may be related to the lifestyle, especially physical activity during leisure time and physical fitness of the participants. All the subjects were engaged in sedentary jobs but only those from the older group were physically active during their leisure time and their V_{O2max} was relatively high for their age. Results obtained by other authors indicated that physical training can improve heat tolerance [16, 17, 18] even in older men [5, 6]. Some authors indicate that if older men have their V_{O2max} higher than 40 ml·kg⁻¹·min⁻¹ they could tolerate heat and work in the heat equally or even better than young sedentary subjects [19, 20, 21].

Results obtained in other studies showed that heat strain (t_{re} , \bar{t}_{sk} , HR) did not differ between young sedentary men with V_{O2max} of approximately 40 ml·kg⁻¹·min⁻¹ and older moderately active men with V_{O2max} of

approximately 35 ml·kg⁻¹·min⁻¹ [6, 22] during 75-min exercise at 40% V_{O2max} , but during more prolonged exercise up to 3.5 hrs [6] older subjects experienced greater strain. Armstrong, and Kenney [23] reported that older men sweated less and their sweating started later than in younger individuals. Our study demonstrated that total sweat loss was similar in all groups. A tendency was observed that the older men's ratings of thirst were slightly lower compared to the other groups. Results of other authors indicated that thirst sensation was attenuated in elderly individuals [24, 25, 26]. In our study, the slightly lower thirst ratings among the O group may also be related to the slightly lower increases in t_{re} and S , rather than to age per se.

In the present study, \bar{t}_{sk} and HR were significantly higher in E2 compared to E1. Also, a tendency for higher subjective ratings of thirst and thermal sensation in E2 than in E1 was observed in all groups. It is well known that clothing disturbs heat exchange between man and environment in the heat, especially while wearing protective clothing [16]. The most important constraint is the limited vapour permeability of the protective clothing. The delayed diffusion of water vapour hampers sweat evaporation, creating a very humid microclimate under the clothing. The resultant accumulation of sweat within the garment leads to discomfort, especially when exercising in a hot environment.

5. CONCLUSIONS

Healthy, physically active older men can tolerate short-term physical work of moderate intensity in a hot environment without and with radiation protective clothing at least as well as young and middle-aged sedentary men. Higher thermal strain was observed in all age groups with aluminized protective clothing than without it despite similar WBGT values.

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