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Effectiveness of an indoor preparation program to increase thermal resilience in elderly for heat waves

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ABSTRACT

Elderly indoors can be subject to considerable heat strain during heat waves. We investigated if a short indoor acclimation (HA) program leads to improved resilience to heat. Although full HA takes about ten days, the main changes occur in the first days, leading to reduced heat strain with similar stress. This study investigates changes after 3 days HA in 8 elderly (>75 y) and 8 young (20–30 y) females. The pre-test (Monday) and post-test (Friday) was a 20-min 50 W cycle exercise test in 35 °C/40% relative humidity (RH); the indoor preparation program or HA consisting of one hour exercise in the same climate aimed at reaching a gastrointestinal temperature (T_{gi}) of 38 °C. HA did not result in any changes in T_{gi}, mean skin temperature, heart rate, weight loss or thermal sensation. The elderly felt more fatigued but evaporated 28% less sweat than the young group during the tests. We conclude that 3-day HA for one hour daily is insufficient to cause physiological benefits in young and elderly females.

1. Introduction

In the framework of the Dutch Climate Proof Cities program, research is initiated to investigate the effect of hot cities on human health [1]. The ambient temperature in cities shows a steady increase in ambient temperature due to global warming and the urban heat island effect. The increased ambient temperatures are reflected in the indoor climate. Indoor temperature and indoor humidity behave as a low-pass filter of ambient temperature and humidity [2]: the amplitude is reduced and a time delay is introduced. The indoor climate, in combination with the worn clothing and daily activity, forms the main thermal stressor for humans in hot periods.

Humans maintain their body core temperature in a narrow range of 36.8–37.7 °C in rest [3]. In warm circumstances, heat loss is compromised and body core temperature may increase to levels above this range, leading to a reduction in performance and a threat to human health. The increase in body core temperature depends on local climate (hot humid situations with sunshine and low wind speeds are the worst), clothing insulation and water vapour permeability, exercise intensity and personal factors like acclimation status.

It is well documented that repeated exposure to heat, in particular in combination with exercise, leads to functional adaptations, which lowers thermal strain. The trigger for heat acclimation is a prolonged increased body core temperature [4]. The best way to achieve this, is to perform physical exercise: heat production often exceeds 1000 W and heat loss mechanisms do not fully compensate the heat production, so that the core temperature remains elevated. This so-called (heat) acclimation is defined as a method to acquire physiological adaptations to heat in an artificial environment [5]. The rate of acclimation induction follows a logarithmic path: the changes in the initial days exceed those in the later days of the acclimation program. The physiological systems adapt at a different rate; the heart rate and plasma volume changes occur first, followed by the reduction in core temperature, and the adjustments in sweat rate and composition adapting last [6]. Full acclimation generally takes about 10 days [7], but most changes are observed during the first days [8,9]. Sunderland et al. [10] showed that four sessions with 30–45 min training in the heat (30 °C, 24% relative humidity (RH)) resulted in a lower core temperature in

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females. Weller et al. [11] showed that 50% of the total drop in heart rate over 10 days of acclimation was observed after three days.

Acclimation is a standard procedure prior to competitive events in the heat, but it may also be useful in preparation for heat waves. During the 2010 heat wave in The Netherlands resting intestinal temperatures exceeding 38 °C were recorded in elderly during the day [2], illustrating the considerable thermal strain that occurs in hot days. In ages under 65 heat tolerance is related to fitness level and not to age [12,13], but climate related mortality is eminent in the elderly over 75 years of age [14] in particular when confined to bed [15]. No studies are known to us that investigated acclimation and thermal strain in elderly over 75 years, the vulnerable part of the population during heat waves [16].

Heat mitigation strategies are based on reduction of the impact of ambient climate on indoor climate, for instance by changing the orientation, ventilation, structure or colour of the buildings that humans live in (e.g. Ref. [17]). In this way vulnerable groups, like the elderly, will experience less heat stress. It is, however, hardly investigated if elderly can adapt to repeated heat stress and thus reduce heat strain. If a heat wave is foreseen by the meteorological offices and if the possibility exists to acclimate elderly to heat, dedicated acclimation programs may be followed by elderly under controlled conditions, such as in elderly homes. The physiological adaptations that this preparation program generates, such as lower heart rate and body core temperature and higher sweat rates, will lower the heat strain during the heat wave and this may be reflected in lower mortality rates.

Therefore, we conducted an experiment to evaluate if three days of acclimation involving exercise in the heat may lower thermal strain in subjects aged over 75 years of age. Only females were included since they constitute the major part of the elderly population. The participants were their own control: heat tolerance changes were investigated with and without an acclimation period. As a reference group, females aged 20–30 years participated. The acclimation period was set at three days and used the controlled hyperthermia model [8]. Previously, four days was shown to be sufficient to induce changes [10] and we wanted the period to be as short as possible to induce high predictive values for the heat wave. Therefore, we selected three acclimation days. Moreover, it cannot be excluded that the pre-test day also helped to generate some acclimation effects in which case the acclimation period may be considered to last 4 days. Exercise was performed during acclimation to maintain core temperatures at sufficient high levels for acclimation [4]. We hypothesize that both young females and females over 75 years will show a reduction in heart rate, but no changes in sweat rate and core temperature due to three days of acclimation. Heart rate is the most sensitive parameter for heat acclimation [11]. If the heart rate in rest and during exercise drops due to acclimation, this is a sign that effective adaptation to heat is possible and that the heat strain during a heat wave may be reduced in this way.

2. Methods

2.1. Subjects

Eight female subjects aged over 75 (mean age 78.3 ± 2.7 years, stature 166 ± 8 cm, body mass 73 ± 14 kg, body mass index 26.5 ± 3.9 kg/m^2, body surface area 1.81 ± 0.20 m^2 [18]) and eight female subjects aged 20–30 (mean age 24.8 ± 2.9 years, stature 172 ± 5 cm, body mass 72 ± 14 kg, body mass index 24.0 ± 3.4 kg/m^2, body surface area 1.84 ± 0.18 m^2) participated voluntarily in this study.

The elderly group had a Morton Mobility Index (DEMMI) ranging from 74 to 100 (86 ± 10), which means that they had a good mobility for their age [19]. The DEMMI is an easy uni-dimensional measure of mobility based on 15 items from bed bound to independent mobility.

The study was approved by the Medical Ethics Committee of Utrecht University Medical Center. The elderly subjects were screened on having no contra-indications to exercise testing as judged by a physician based on assessment of medical history, physical examination and the results of the 12-lead ECG examination. The elderly did not use medicine related to thermal regulation (e.g. beta blockers). The menstrual cycle phase of female subjects aged 20–30 was recorded and the last day of menstruation preceded the first day of test with 19 ± 13 days. One subject had irregular menstruation. The variation was such that order effects are unlikely.

2.2. Protocol

In a balanced cross-over study the elderly and young subjects participated in two 5-day measurement periods with three weeks recovery in between. The subject started at the same time of day. The subjects performed a heat strain test on day 1 and 5 with and without a acclimation protocol at days 2, 3 and 4. All subjects came for their first heat strain test on Monday. Half of the group of subjects started with acclimation at day 2, 3 and 4 and the other half started without acclimation. All subjects participated in a second heat strain test on Friday. The procedure was repeated after 4 weeks (three weeks in between) but then the subjects acclimatized that did not acclimatize before and reverse. The subjects were dressed in underwear, an oversized T-shirt, shorts, socks and shoes.

Each day the participants arrived at the lab at least 30 min before entering the climatic chamber to prepare for the measures. The participants ingested a disposable core temperature capsule (Jonah, Hidalgo, Cambridge, UK) to measure gastrointestinal temperature, however, only if the pill taken the day before was not detected anymore. The subjects were equipped with a Hidalgo Equivital™ Physiological Monitor system (Hidalgo, Cambridge, UK) to record gastrointestinal temperature (T_{gi}) and heart rate (HR) at 15-s intervals. These measurements continued until the end of the trial. To determine mean skin temperature (T_{sk}), four iButtons (DS1922L, Maxim Integrated Products Inc, Sunnyvale, CA, USA) were taped to the skin (neck, right scapula, right shin, left hand) using sweat-proof tape (Fixomull stretch, BSN Medical, Hamburg, Germany). The resolution was set to 0.0625 °C. T_{sk} was calculated using weighing factors or 0.28 for the neck, scapula and shin and 0.16 for the hand [20]. Mean body temperature (T_b) was calculated as a weighed average of T_{gi} (0.8) and T_{sk} (0.2) [21].

The heat strain test and the acclimation protocol started with the following procedure. Just prior to entering the climatic chamber, the subject was weighed using a Sartorius balance (1 g resolution). Subjects would then enter the climatic chamber and sit for 30 min in the chamber set at 35 °C/40% relative humidity to get accustomed to the ambient conditions. Hereafter, they would start exercising for 20 min at a work rate of 50 W using a Lode Excalibur cycle ergometer (Lode, Groningen, The Netherlands) in the pre- and post-test. On the acclimation days the subject started the exercise on the ergometer with an initial load of 50 W for at least 5 min; thereafter, the load was decreased or increased in such a way that a core temperature above 38 °C was reached and maintained within 38–38.5 °C. This method is called the controlled hyperthermia of isothermal strain model and preferred over traditional methods with fixed work load [8]. Sixty minutes after the start of exercise the acclimation period was ended. Every 10 min the subject would rate Thermal Sensation (TS) (9-point scale ranging from −4 very cold to +4 very hot) and Rating of Perceived Exertion (RPE) [22]. Heart rate and temperatures were registered and monitored