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Increased age and reduced physical activity level worsen thermoregulatory pacing behaviour in men during walking exercise in the heat.

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Abstract

Older adults are vulnerable to heat-related morbidity and mortality due to reduced thermoregulatory function associated with aging. The aim of this study was to examine the relationship between age and thermoregulatory behaviour during walking exercise in Control (22°C; 40% relative humidity [RH]) and Hot (35°C, 40% RH) conditions. Thirty-six healthy males (age 46 ± 20 (range 19 to 86) years; stature 177 ± 7 cm; body mass 75.7 ± 11.3 kg; BMI 24.2 ± 2.9 $kg.m^{-2}$; Σskinfolds 33.3 ± 10.5 mm; mean ± SD) each completed two experimental trials, one in Control and one in Hot conditions. Each trial consisted of three bouts of 10 minutes walking at a rating of perceived exertion (RPE) of 13, interspersed with 5 minutes of seated rest. Thermoregulatory behaviour was assessed as the ratio between distance walked in the Control and Hot trials. Participants walked 3.8% less in the Hot (2.63 ± 0.46 km) than in the Control (2.73 ± 0.4 km) condition ($t(36) = -2.38$, $p=0.023$, $d=0.26$). Regression analysis demonstrated that age was the primary predictor of thermoregulatory pacing behaviour, explaining 23% of the variance (Std $\beta = -0.475$, $p=0.003$). Including physical activity levels (PASE) increased the variance accounted to 32% (age Std $\beta = -0.396$, $p=0.011$; PASE Std $\beta= 0.319$, $p=0.038$). In conclusion, thermoregulatory pacing behaviour was impaired with increased age and reduced physical activity when undertaking walking exercise at a perceived exertion of 'somewhat hard' in hot ambient conditions.

Key words:
Exercise; Pacing behaviour; Aging; Thermoregulation; Physical activity

1. Introduction

Heatwaves are a public health concern due to their impact on health and mortality (Ebi et al., 2021). Global warming has resulted in an ~1.1°C increase in the Earth's average temperature since 1900 and this is predicted to rise by a further 1.4 - 4.4°C by 2100 due to human activity (IPCC, 2021). As such, heatwaves are becoming increasingly frequent and severe, and this trend is likely to continue in the context of climate change (American Meteorological Society, 2012; Met Office, 2018). Heatwaves are of particular concern to older adults, who can be considered most susceptible to heat-related mortality and morbidity given decreased thermoregulatory function associated with aging (Inoue et al., 1998; Kenney, 1988; Kenney et al., 1997; Larose et al., 2013). Thermoregulatory behaviours (e.g., removing layers of clothing, seeking shade or air conditioning, taking cooling showers, reducing metabolic heat load [Morano et al., 2016]) offer a near limitless ability to reduce heat strain (Benzinger, 1969). As life expectancy increases across many developed nations (Office of National Statistics, 2018), there is increasing need to understand interactions between ambient temperature and behavioural thermoregulation to reduce the risk heat-related illnesses and deaths in older adults.

Under uncompensable heat stress (when environmental conditions limit the evaporative cooling capacity of an individual to less than is required to maintain heat balance [Sawka et al., 2011]), behavioural alterations are required to regulate body temperature because autonomic thermoregulation (i.e., sweating and skin blood flow) has limited capacity and is insufficient to maintain heat balance. Telemetric pills have confirmed that young adults can maintain a stable core temperature (~37.0°C) despite fluctuating skin (~32°C to ~34°C) and ambient (~17°C to ~40°C) temperatures (Schlader et al., 2016). Physical activity increases metabolic heat production, which lowers the ambient temperature required for the adverse effects of excessive heat stress to transpire. During physical activity, thermoregulatory behaviour usually manifests as a voluntary reduction in exercise intensity, which lowers heat strain by decreasing metabolic heat production. Young men (23 ± 3 years) completed ~28% less work during a self-paced 30 minutes cycling time trial in uncompensable conditions (~40°C, ~19% relative humidity (RH)) than in compensable conditions (~20°C, ~22% RH; Schlader et al., 2011). To date, research is yet to clarify the impact of different environmental conditions and aging on behavioural alterations in physical activity pacing.

Older adults appear to be less sensitive than young adults in correctly perceiving their thermal environment when at rest. For example, when provided with a dual position switch to warm or cool a room, older men (>60 years) reported feeling more thermally comfortable throughout the 2–2.5 h trial despite allowing ambient temperature to fluctuate much more than younger (<40 years) men (Collins et al., 1981; Taylor et al., 1995). Likewise, when older participants (72 ± 5 years) engaged in 30 minutes of fixed intensity recumbent cycling in 25°C and 35°C environments, there was little difference in the peak rectal temperature between the two conditions despite large fluctuations in peak skin temperature (Waldock et al. 2018). However, despite the difference in skin temperature, participants reported similar levels of thermal comfort on a five-point scale for both trials. Therefore, it appears older adults may exhibit reduced sensitivity to the thermal environment, while at rest and during exercise.

Older adults who are able to maintain physical activity appear to reduce their risk of heat-related morbidity and mortality. Increased levels of physical fitness are known to provide some level of heat acclimation (Armstrong & Maresh, 1991). Older adults who are unable to leave their home are at increased risk of mortality during heat wave events, being unable to leave their bed increases that risk further (Bouchama et al., 2007). Those who are able to participate in physical activity into older age may be ameliorating the decline in thermoregulatory capacity through maintaining their ability to implement thermoregulatory behaviour during physical activity.

As people age, their autonomic thermoregulatory capacity declines, leading to increased heat storage during exercise in hot conditions (Balmain et al., 2018). Appropriate thermoregulatory behaviour is the single most effective solution for reducing heat strain, for example, reducing exercise intensity during heat exposure would reduce metabolic heat production and, in turn, heat strain (Flouris & Schlader, 2015). Young adults can implement these behaviours by responding to changes in thermal comfort and skin temperature, but thermal comfort is less sensitive to ambient conditions in older adults (Waldock et al., 2018, 2021). It remains unclear whether this insensitivity results in a reduced ability for older adults to exhibit appropriate thermoregulatory behaviour in reducing exercise intensity during heat exposure. The aim of this study was to examine the relationship between age and physical activity level, and thermoregulatory behaviour during walking exercise in temperate and hot conditions using a fixed rating of perceived exertion (RPE) protocol. We hypothesised that age and thermoregulatory behaviour are negatively related. Increased levels of physical activity are predicted to be positively related with thermoregulatory behaviour. As such, increased age will lead to reduced ability to implement thermoregulatory behaviour, while increased physical activity levels will result in an improved ability to implement thermoregulatory behaviour.

2. Material and methods

2.1 Participants

Thirty-six healthy males (age 46 ± 20 (range 19 to 86) years; stature 177 ± 7 cm; body mass 75.7 ± 11.3 kg; BMI 24.2 ± 2.9 kg.m^{-2}; Σskinfolds 33.3 ± 10.5 mm; mean ± SD) volunteered to participate in the study. Participants were non-smokers, free from any known respiratory, cardiovascular, or metabolic disease and were considered healthy after completing a pre-participation questionnaire. Participants were not taking any medications known to affect thermoregulation. Training status was not included as an inclusion/exclusion criteria. Participants were asked to abstain from alcohol, caffeine, non-steroidal anti-inflammatory drugs, and strenuous exercise in the 24 h before trials, and consume 500 mL of water the evening before and 2 h before arriving at the laboratory. Clothing consisted of a t-shirt, shorts, socks and walking/running shoes. Participants were fully informed of the experimental procedures and possible risks before giving their informed, written consent. The study was approved by the University Ethics Committee and performed according to the Declaration of Helsinki.

2.2 Design and Protocol

This study utilised a within-group, repeated measures design to compare physiological, perceptual, and behavioural responses to exercise in 22^{o}C (Control) and 35^{o}C (Hot) conditions. Participants completed two experimental trials, with each trial comprising three bouts of 10 minutes of self-paced walking at a constant rating of perceived exertion (fixed-RPE), with walking bouts interspersed by 5 minutes of seated rest (Figure 1). The order of the trials was randomised and counterbalanced so that half of the participants first completed the Hot trial, and the other half completed the Control trial first. Participants completed both trials at the same time of day to minimise the effects of circadian fluctuations in core temperature. A schematic of the protocol is shown in Figure 1.

FIGURE 1 ABOUT HERE

2.3 Familiarisation

A week before the first experimental trial, participants completed a familiarisation session to ensure they were comfortable with the RPE scale and motorised treadmill controls. This session was conducted in the laboratory under ambient conditions (20.9 ± 2.2°C). On arrival at the laboratory, anthropometric (stature, body mass, skinfolds) and physical fitness measures (physical activity scale for the elderly [PASE] questionnaire) were taken before participants were familiarised with the RPE scale. Participants self-selected a treadmill speed that felt ‘somewhat hard’ (RPE of 13) while blinded to their actual speed. Participants then walked for 3 minutes while free to adjust the treadmill speed to maintain a RPE of 13. Treadmill speed was recorded but not revealed to the participant. Participants then rested in a seated position for 5 minutes before repeating this procedure until they were able to replicate the speed that elicited an RPE of 13. During familiarisation, participants were able to replicate their self-selected speed in 4 ± 1 attempts.

2.4 Experimental Procedures

Participants initially completed the Control (22.1 ± 0.5°C, 41 ± 4 % RH), or Hot (34.9 ± 0.6°C, 39 ± 4 % RH) trial. Experimental trials were identical apart from the ambient conditions. Prior to commencing the exercise protocol, participants entered the environmental chamber in the Control or Hot condition and sat at rest for 45 minutes. Participants then completed three bouts of 10 minutes walking at a RPE of 13 on a motorised treadmill (95TI Silverline CLST Treadmill, Life Fitness, UK) separated by 5 minutes of seated rest in the environmental chamber. Participants were reminded at the onset and after 5 minutes of walking that their self-selected speed should elicit an RPE of 13. Ambient temperature water was available for *ad libitum* consumption throughout the trials. Rectal, skin, ambient temperature and heart rate were measured continuously and recorded every 5 minutes for analysis. Thermal comfort was assessed every 5 minutes throughout the trials and RPE recorded every 5 minutes during the walking exercise.

2.5 Anthropometry

Stature was assessed to the nearest mm using a stadiometer (217, Seca, Hamburg, Germany). Participants removed shoes and socks and stood with their back to the stadiometer, feet together, heels, buttocks, and upper back touching the stadiometer. The head was then placed in the Frankfort plane, and the stadiometer arm lowered until it rested on the most superior aspect of the head. Body mass was assessed using a digital scale (MC-180MA, Tanita, Tokyo, Japan) and recorded to the nearest 0.05 kg. Body mass index (BMI) was calculated by dividing the participant’s body weight (kg) by stature squared (m^2) and expressed as kilogrammes per square meter ($kg.m^{-2}$). Skinfold measurements were taken in accordance with ISAK guidelines, at four-sites (triceps, biceps, subscapular, and supra-iliac) on the right-hand side of each participant. Participants stood relaxed in the anatomical position. Measures were taken using skinfold callipers (Harpenden, West Sussex, UK) and recorded to the nearest 0.1 mm. Measures were taken in duplicate; a third measure was taken if the first two were not within 5% of each other. A mean was used if two measures were taken, and the median if three were taken.

2.6 Body Temperatures

Rectal temperature was measured to evaluate core body temperature. A single-use rectal thermistor (Philips, Amsterdam, The Netherlands) was self-inserted by participants ~12 cm past the anal sphincter and remained in place throughout the trials. Skin temperature was measured using surface temperature thermistors (EU-U-VL5-0, Grant Instruments, Cambridge, UK) at four sites (chest, biceps, thigh, and calf) on the left side of the body. The thermistors were taped to the skin using a single layer of porous kinesiology tape (Rock Tape, Essex, UK). Mean skin temperature was calculated using a weighting equation for computing the mean skin temperature from observations on the four sites (Ramanathan, 1964).

2.7 Perceptual Measures

The Bedford scale of thermal comfort (Bedford, 1936) was used to measure the comfort of participants every 5 minutes during the experimental conditions. The 7-point scale spans from -3 to +3, with the following qualitative descriptors: "much too cool" (-3), "too cool" (-2), "comfortably cool" (-1), "comfortable" (0), "comfortably warm" (1), "too warm" (2), "much too warm" (3).

A laminated paper copy of the Borg scale, ranging from 6 to 20 was used to determine RPE. The scale had a written descriptor for each level of exertion; "very, very light" (6), "very light" (9), "fairly light" (11), "somewhat hard" (13), "hard" (15), "very hard" (17), and "very, very hard" (19) (Borg, 1982).

2.8 Heart Rate

Participants wore a chest strap throughout the trials and heart rate was measured continuously by short-range telemetry (FT1, Polar Electro, Kempele, Finland).

2.9 Physical activity

The Physical Activity Scale for the Elderly (PASE) was used to determine physical activity levels. This is a brief (5 minutes) questionnaire comprising ten questions related to leisure time activity, household activity and work-related activity. Participants were asked to consider their activity levels for the previous seven days when responding to the questionnaire. The PASE was chosen as it was specifically developed for older adults (≥65 years) to capture daily living activities of this population (Washburn et al., 1993). Items of the PASE were weighted. Half the items were calculated as a mean number of hours participated in per day multiplied by the PASE weight; the other half were scored according to engagement in the activity (Table 1).

TABLE 1 ABOUT HERE

2.10 Thermoregulatory Behaviour

The distance walked in each of the three exercise bouts was recorded, and then summed to give total distance walked in each trial. A marker of thermoregulatory behaviour was calculated as the ratio of distance walked in the Control trial compared with the Hot trial (Equation 1):

$$Thermoregulatory\ Behaviour = \frac{Total\ distance\ walked_{Control}}{Total\ distance\ walked_{Hot}}$$

A thermoregulatory behaviour score of >1 indicated that the participant walked further in the Control trial, <1 they walked further in the Hot trial, and 1 they walked the same distance in both trials.

2.11 Statistical Analysis

Data were assessed for normality using Shapiro-Wilk tests between Control and Hot trial conditions were assessed using a paired-samples t-test. Differences between Control and Hot conditions were assessed using two-way repeated measures ANOVA with main effects of time (pre and post trials) and condition (Control and Hot). Differences between distance walked for young and older men (young <35 years, older >35 years) were assessed using a three-way mixed ANOVA with main effects of age category, time, and condition. The assumptions of normality, sphericity, homogeneity of variance, and independence of observations were evaluated. Mauchly's test of sphericity was conducted, and where the assumption of sphericity was violated, the Greenhouse-Geisser correction was applied. Significant interaction effects were explored with post hoc analyses using Bonferroni corrections to identify the specific locations of differences.

A stepwise multiple regression was used to examine the extent that selected independent variables were associated with the thermoregulatory behaviour ratio in the Hot condition. Predictors were selected based on their strength of association with thermoregulatory behaviour, and only the statistically significant predictors - age and physical activity level (PASE) -were entered into the regression model. Linear regressions were used to determine whether age influenced changes in core temperature or thermal comfort during walking exercise.

All descriptive data are presented as mean ± standard deviation (SD). The level of significance for all analyses was set at $p \leq 0.05$. Effect sizes for t-tests were calculated as Cohen's d from the SD of the difference between the paired observations, and effect sizes for ANOVAs were calculated as partial eta squared (η_p^2). These were interpreted as small (d = 0.20; η_p^2 = 0.01); medium (d = 0.50; η_p^2 = 0.06); or large (d = 0.80; η_p^2 = 0.14) (Cohen 1969; Cohen, 1988). All statistical analyses were conducted using Statistics Package for the Social Sciences (SPSS v28, IBM Corp, Armonk, NY).

3. Results

At the end of the 45-minute resting period, thermal comfort was significantly higher in the Hot condition (1.28 ± 0.68) compared to the Control condition (0.75 ± 0.88: t(31) = -10.82, p<0.001). Participants walked 100 m or 3.8% less in the Hot (2.63 ± 0.46 km) condition than in the Control (2.73 ± 0.40 km) condition (t(36) = -2.38, p=.023, d=0.26) (Figure 2). Thermoregulatory behaviour ratio was 1.05 ± 0.11. Twenty-five participants had a thermoregulatory behaviour ratio above 1.0 and 12 participants had a ratio of 1.0 or lower (Figure 3). The increase in heart rate from pre to post trials was similar between conditions (Control, 66 ± 19 bpm; Hot, 69 ± 20 bpm) ($F(1,35) = 0.91$, p=0.347, η_p^2=0.03). Overall, heart rate was significantly higher in the Hot condition than the Control condition ($F(1,35) = 23.56$, p<0.001, η_p^2=0.40) and at the end of the trials compared to the beginning of the trials ($F(1,35)$ = 515.77, p<0.001, η_p^2=0.94) (Figure 4a).

FIGURES 2 and 3 ABOUT HERE

Rectal temperate was similar at the beginning of the Hot and Control conditions ($F(1,33)$ = 1.10, p=0.302, η_p^2=0.03).) The rise in rectal temperature during the Hot condition (0.92 ± 0.45°C) was greater ($F(1,33) = 13.70$, p<0.001, η_p^2=0.29) than the Control condition (0.64 ± 0.35°C). Rectal temperature was higher (0.35 ± 0.07 °C) in the Hot compared to Control condition at the end of the trials ($F(1,33) = 28.68$, p<0.001, η_p^2=0.47) (Figure 4b). Skin temperature was substantially higher at the end of the trials compared to the beginning of the trials ($F(1,34) = 46.10$, p<0.001, η_p^2=0.58) and in the Hot condition than the Control condition ($F(1,34) = 545.61$, p<0.001, η_p^2=0.94). The increase in skin temperature from pre to post trials was similar between conditions (Control, 0.94 ± 1.03°C; Hot, 0.94 ± 1.08°C; $F(1,34) = 0.10$, $p=0.597$, $\eta_p^2=0.08$; Figure 4c).

There was no correlation between age and PASE score (r=-0.246, p=0.148).

Age did not significantly affect increases in rectal temperature (p=0.529) or thermal comfort (p=0.346) during exercise in the Hot condition. However, age was significantly negatively associated with increases in rectal temperature (β=-0.007, p=0.025) and thermal comfort (β=-.009, p=0.026) in the Control condition.

FIGURE 4 ABOUT HERE

Only age and PASE were significantly associated with thermoregulatory behaviour and entered into the stepwise regression model. There was no evidence of collinearity, as assessed by tolerance values greater than 0.1. Age was the primary predictor of thermoregulatory behaviour and explained 23% of the variance (model 1: Std β = -0.475, p=0.003). The ability of males to reduce exercise intensity in the Hot condition declined with increasing age. Including physical activity levels (PASE) increased the variance explained to 32% (model 2: age Std β = -0.396, p=0.011; PASE Std β=0.319, p=0.038) whereby increased habitual physical activity level reduced the impact of increasing age on thermoregulatory pacing behaviour. Details of both models are presented in Table 2.

TABLE 2 ABOUT HERE

4. Discussion

The aim of this study was to quantify the relationship between age and thermoregulatory pacing behaviour during walking exercise in temperate and hot conditions using a self-determined fixed rating of perceived exertion protocol. We identified a significant relationship between age, physical activity levels and thermoregulatory behaviour during heat stress. Increasing age reduced the likelihood of participants implementing thermoregulatory behaviour while walking in the heat. However, participants with higher levels of habitual physical activity were more likely to implement thermoregulatory behaviour when exposed to heat stress. As increased levels of physical fitness are known to provide some acclimation effects (Armstrong & Maresh, 1991), this may have contributed to this outcome. This is the first study to evaluate a wide range of ages when examining thermoregulatory behaviour during exercise in hot conditions.

The novel use of a fixed RPE approach with older participants aged >60 years permitted a detailed examination of the relationship between age and thermoregulatory behaviour while exercising in the heat. The older men did not self-regulate behaviour sufficiently to reduce exercise intensity when undertaking walking exercise in the heat. Rectal temperature increased during the Control trial by 0.64°C and by 0.91°C in the Hot trial (Figure 4b). This increase in rectal temperature from baseline to the end of the trials showed that participants experienced heat strain, and despite the greater rise in rectal temperature during the Hot trials, older men were less likely than younger men to reduce their walking speed in the heat. The lack of implementation of thermoregulatory behaviour in older adults does not appear to be a response to changes in rectal temperature, which were observed to be similar across ages during the hot trial.

The influence of skin temperature on thermoregulatory behaviour has been demonstrated both at rest (Schlader et al., 2009) and during exercise (Schlader et al., 2011). When resting for 60 minutes, young (~22 years) adults pushed a button that initiated neck cooling ~100 times in 32°C conditions, and this increased to ~1,000 times in 42°C conditions when mean skin temperature was ~1.8°C warmer (Vargas et al., 2018b). A skin temperature increase of ~5.8°C resulted in 2.4% decrease in cycling power output in young healthy men (Schlader et al., 2011). Otani et al. (2019) reported an ~8% decline in power output with a skin temperature increase of ~0.5°C during fixed intensity cycling. The ~5°C warmer skin temperature at the onset of exercise in the Hot compared to the Control trial in the present study (Figure 4c) should have been sufficient to elicit a thermoregulatory response from the participants. However, increased age was associated with a reduction in thermoregulatory behaviour despite similar thermal comfort across ages during the hot trial.

The sensitivity to thermal stimulus applied to the skin appears to decline with age, particularly with hot stimuli (Guergova & Dufour, 2011). When a thermode applied to the skin is heated, adults aged >60 years detect the increase later than adults aged ≤50 years (Dufour & Candas, 2007). This reduced sensitivity to thermal stimuli in the skin suggests older adults may require a greater increase in skin temperature than younger adults before they implement thermoregulatory behaviours during exercise in the heat. Our data indicates that the reduced sensitivity to thermal stimulus reduces the ability to implement thermoregulatory behaviours during heat exposure. Delaying thermoregulatory behaviours when an individual is experiencing heat strain increases the risk of heat-related illness and death. If older adults delay using cooling behaviours during heat exposure events, it poses a risk to their health and the resources of the healthcare system. The relationship between skin temperature and thermoregulatory behaviours during exercise in older adults warrants further investigation.

It is well established that a low level of physical fitness increases the risk of exertional heat illness (Westwood et al., 2020), and sustaining a high level of aerobic fitness attenuates the age-related decline in thermoregulatory ability (Notley et al., 2020). Lack of mobility also increases the risk of death during a heat wave (Vandentorren et al., 2006). Thus, physical activity markers were assessed to investigate if they could explain any differences in thermoregulatory behaviours. Our findings demonstrate that participating in higher levels of physical activity improves the ability to implement thermoregulatory pacing behaviour in hot conditions. Generally, self-reported and objectively measured sedentary behaviour increases with age, with older adults spending 5.3 to 9.4 hours per waking day sedentary (Harvey et al., 2015). Encouraging people to maintain or increase their physical activity levels as they get older is not an easy task, despite the well-established and wide-ranging health benefits of physical activity and exercise (Warburton & Bredin, 2017). Reduced impairments in thermoregulatory behaviour is another health benefit of regular physical activity for older adults, and increasingly important with the increasing frequency and severity of heatwaves.

4.1 Limitations

This study has several limitations. Participants were all healthy, and had to fulfil inclusion criteria, including being free from cardiovascular disease and diabetes, as these are known heat illness risk factors (Åström et al., 2011; Semenza et al., 1996). Omitting participants with cardiovascular disease and diabetes will reduce the transferability of the results to cohorts and individuals with these conditions.

Participants adjusted their behaviour via the controls on a motorised treadmill, and for many participants using a treadmill was a novel or unusual experience. However, the preliminary visit was used to familiarise participants with the equipment and remove this novelty. Unlike previous work (Larose et al., 2014; Waldock et al., 2018), we used walking exercise instead of cycling, to increase the external validity of the study. Cycling exercise is novel to many, only 11% of adults in the UK make at least one cycling journey a week, however, 60% make at least one walking journey a week (Department for Transport, 2019). This research is applicable to active individuals who can walk unaided. Future research should consider more vulnerable elderly populations such as those in care homes, and individuals unable to complete activities of daily living unaided.

The PASE questionnaire was developed for use in older adults (>60 years) and has been validated in this population (Washburn et al., 1999). The questionnaire has not been validated in younger adults (<60 years), however, to ensure consistent data collection techniques across all participants it was used in younger adults in this study. Further information on participant physical activity and training history was not taken. Thus, it is unknown how long-term physical activity status impacted the findings.

Hydration status impacts thermoregulatory capacity but was not measured in this study. Participants were asked to consume 500 mL of water the evening before and 2 h prior to testing to attempt to control for hydration status, but it is possible that this differed among participants and influenced the results of this study.

5. Conclusion

Pacing behaviour for thermoregulation was impaired with increased age and reduced physical activity when undertaking walking exercise at a perceived exertion of ‘somewhat hard’ in hot ambient conditions (35°C, 40% RH). These data provide laboratory evidence that age and thermoregulatory behaviours are negatively correlated. Older adults are less likely to initiate behaviours that reduce heat and physiological stress, such as reducing exercise intensity, during heat exposure. This scenario poses a public health risk during heatwave events as older adults are less able to reduce their heat exposure than younger adults.

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Tables

Table 1 - Physical Activity Scale for the Elderly (PASE) item weights.

PASE Activity	PASE Weight	Example	
		Mean h·d^{-1}	**Item Score**
Muscle strength/endurance	30	0.3	9.0
Strenuous sport	23	0.2	4.6
Moderate sport	23	0.6	13.8
Light sport	21	0.0	0.0
Job involving standing or walking	21	5.0	105.0
Walking	20	0.5	10.0
Lawn work or yard care*	36	0.0	0.0
Caring for another person*	35	0.0	0.0
Home repairs*	30	0.0	0.0
Heavy housework*	25	1.0	25.0
Light housework*	25	1.0	25.0
Outdoor gardening*	20	0.0	0.0
	Total PASE score		**192.4**

Example data taken from (Washburn et al., 1993).
* denotes activities that are scored as engaged in (1) or not engaged in (0).

Table 2 – Stepwise multiple regression predicting thermoregulatory behaviour from age and physical activity levels.

	Model 1				**Model 2**			
	β	**(*SE*)**	**Std β**	***P***	***β***	**(*SE*)**	**Std β**	***P***
Constant	1.159	0.040		<0.001	1.069			<.001
Age	-0.002	0.001	-.475	.003	-.002	0.001	-0.396	.011
Physical Activity Level (PASE)					0.00	0.00	0.319	.038
R^2	0.225				0.321			
F	9.892*				7.801*			

* denotes p<.05. Std β = Standardised β

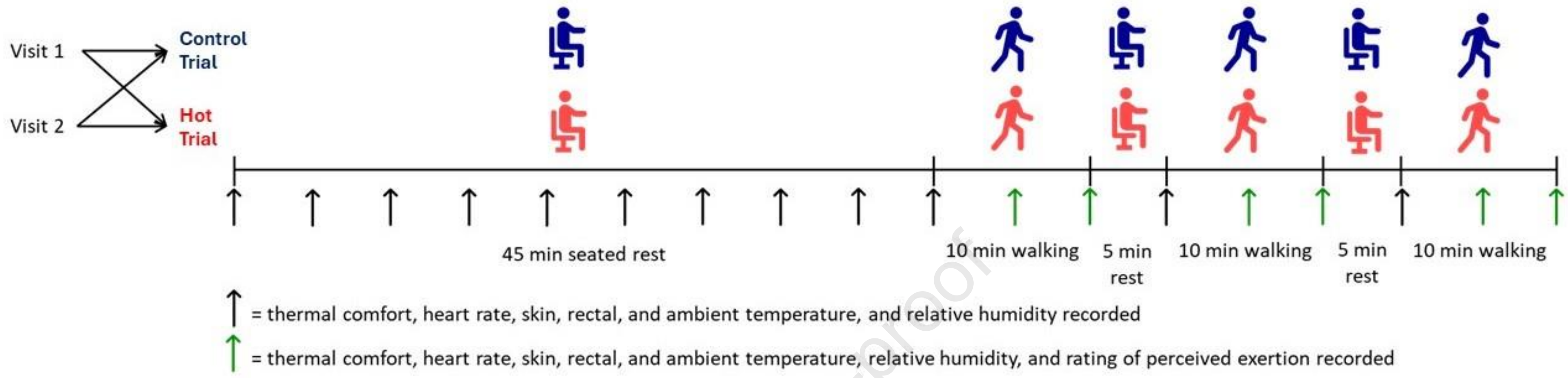

Figure 1 - Schematic of protocol for the experimental trials.

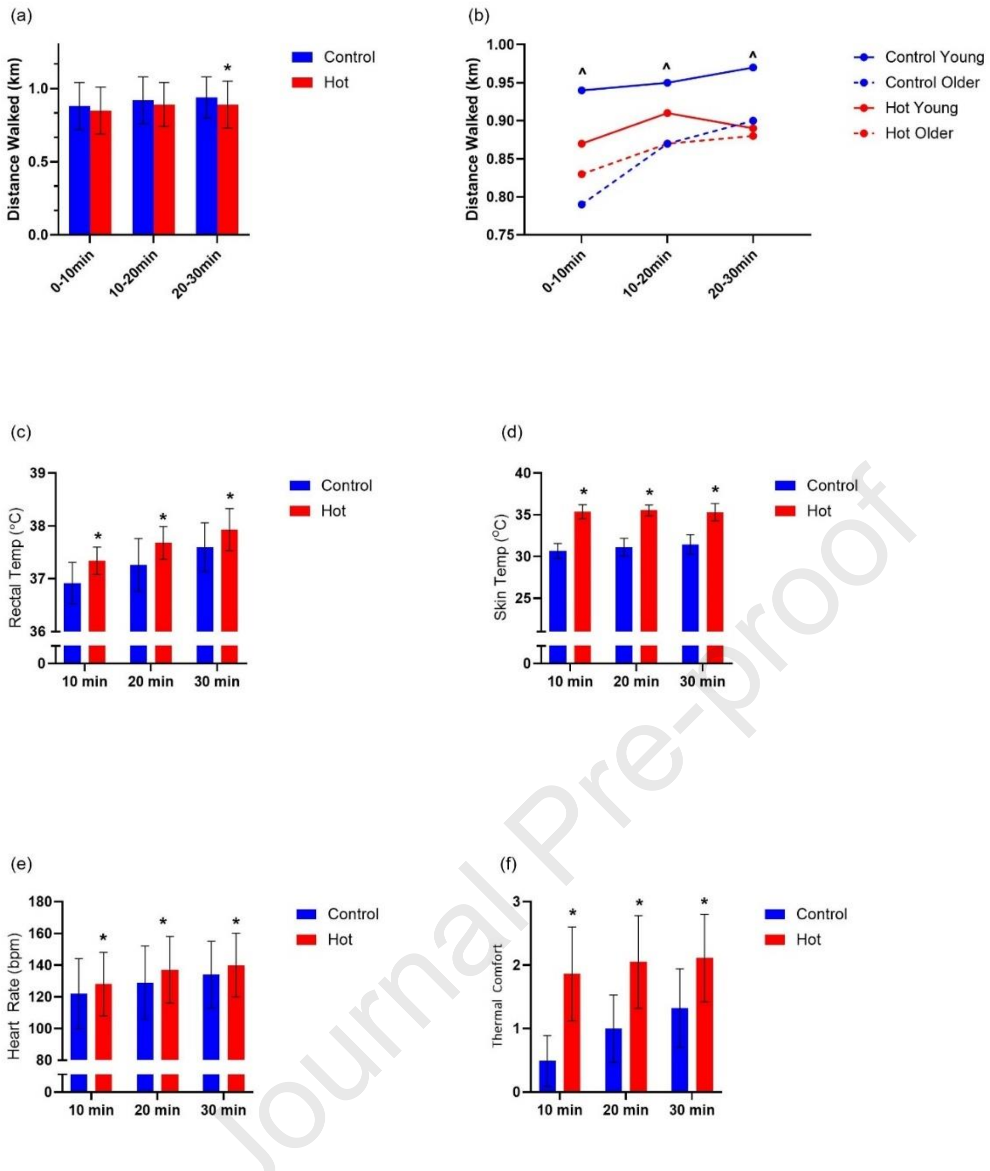

Figure 2 – (a) Distance walked, (b) distance walked by age-group, (c) rectal temperature, (d) skin temperature, (e) heart rate, and (f) thermal comfort in each of the ten-minute exercise bouts (mean ± SD)

* denotes significant difference between conditions
^ denotes significant difference between conditions in Young group only

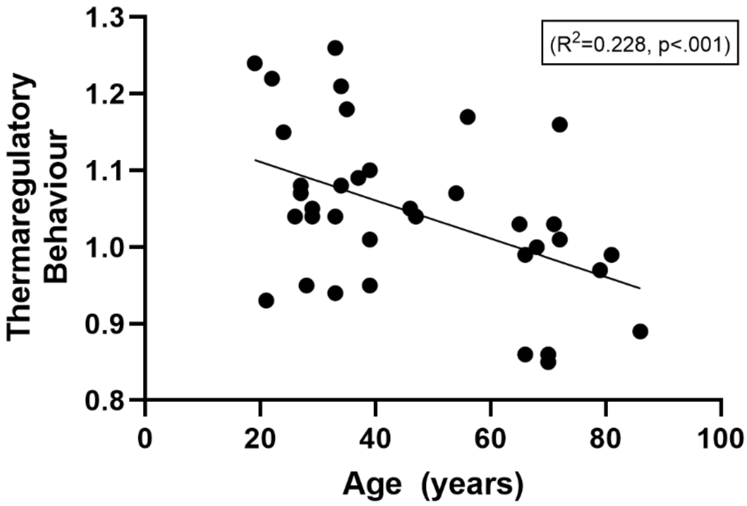

Figure 3 – Scatterplot of thermoregulatory behaviour ratio and age for all participants

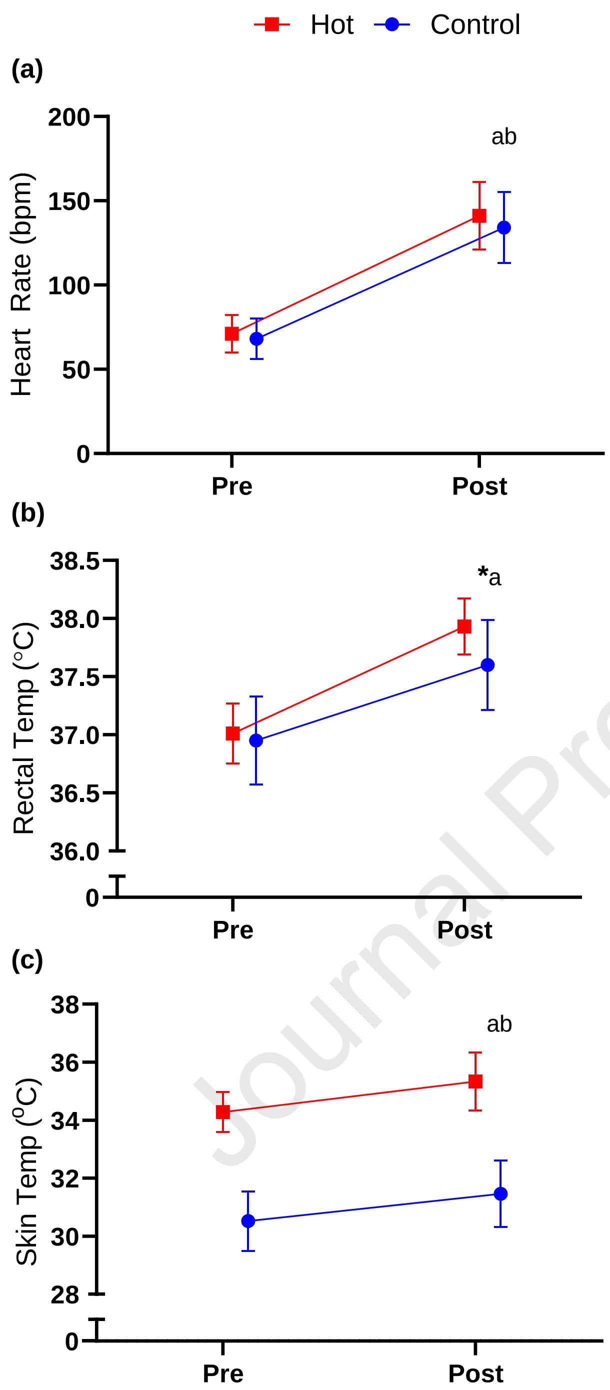

Figure 4 – Changes in (a) heart rate (b) rectal temperature, (c) skin temperature in the control and hot conditions.

* denotes significant interaction effect
a denotes significant effect of time (pre-post)
b denotes significant effect of condition (control-hot)

Highlights

- Thermoregulatory pacing behaviour is impaired with increasing age
- Thermoregulatory pacing behaviour is impaired with decreased physical activity levels
- Increasing age increases vulnerability to heat illness during heat wave events
- Age does not impact rectal temperature rise during self-paced exercise in the heat
- Age does not impact thermal comfort rise during self-paced exercise in the heat

Data Accessibility Statement

The raw/processed data required to reproduce the above findings cannot be shared at this time as the data also forms part of an ongoing study.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: