Abstract

Objectives: The elderly population are at an increasingly significant health risk to heat-related illnesses and mortality when compared with younger people in the same conditions. This is due to an increased frequency and severity of heatwaves, attributed to climate change, and reduced ability of elderly individuals to dissipate excess heat. Consequently, the majority of excess deaths and emergency visits during heatwaves occur in people aged over 65 years. The aim of this investigation was to assess the physiological and perceptual responses of elderly people during exercise sessions equating to activities of daily living in UK summer climatic conditions.

Study design: Mixed methods, randomised research design.

Methods: Twenty-eight participants (17 males; 10 females; 1 transgender female) were randomly assigned into three experimental groups; 15°C, 25°C or 35°C, 50% relative humidity. Participants completed one preliminary and three experimental trials within their assigned environment. The data from the preliminary incremental recumbent cycling test was used to calculate individual exercise intensities equating to 2, 4 and 6 metabolic equivalents (METs) for the subsequent trials. During experimental trials participants completed 30-min of seated rest and 30-min of cycling.

Results: No change was observed in thermal comfort ([TC] just uncomfortable in both trials) and only modest changes in RPE (14 ± 2 *vs* 15 ± 2) at 6 METs in 25°C compared to 35°C. In contrast, thermal strain markers did significantly increase ($P < 0.05$) across the same conditions, including change in rectal temperature (ΔT_{re}) during exercise (0.27 ± 0.17°C *vs* 0.64 ± 0.18°C) and peak skin temperature ([T_{skin}] 32.94 ± 1.15°C *vs* 36.11 ± 0.44°C).

Conclusion: When completing exercise that equates to activities of daily living, elderly people could have a decreased perceptual awareness of the environment, even though physiological markers of thermal strain are elevated. Consequently, the elderly could be less likely to implement behavioural thermoregulation interventions (i.e. seek shade and/or remove excess layers) due to a decreased awareness of an increasingly thermally challenging environment.

Key Words: Elderly; activities of daily living; heat illness; exercise; health; MET

1. Introduction

It has been predicted that climate change will increase the risk of heat-related morbidity and mortality of elderly people (>65 yrs) in the UK [1]. There are ~2000 heat-related deaths per year in the UK with a predicted 5-fold increase by 2080, equating to ~12,700 preventable deaths[1]. Furthermore, extreme heatwaves such as the 2003 European heatwave resulted in ~70,000 deaths[2,3], the majority being elderly[4]. Elderly people also comprise the majority of the emergency and general practitioner (G.P) visits during heatwaves for heat-related illnesses[5,6]. In response to the extreme weather events, advice and governmental policy have been issued to the general public and health services, with the aim to decrease heat illness risk[7,8]. The information provided encourages people to; increase fluid intake, seek shade, take cool showers and reduce physical activity[7,8]. Metabolic heat production ($\dot{H}_{prod}$) is decreased with decreased physical activity, consequently less excess heat dissipation is required to maintain a thermal equilibrium[9]. However, advising less physical activity is a conflicting health message that can have serious health consequences. The UK Government recognises the benefits of exercise and have several health campaigns to encourage greater exercise participation including; One You[10], Change4Life[11] and Couch to 5K[12]. These campaigns highlight the benefits of regular exercise which include; reducing the risk of diseases such as type 2 diabetes, heart disease, several types of cancer and stroke, reducing the incidence of obesity and improving mental health. A more cohesive message of safe and effective exercise during periods of hot weather for the elderly will improve health messages across environmental and physical health services.

Current research into heat, exercise and elderly health has focused on comparing physiological responses to younger adults[13-18]. It is well established that elderly people have an attenuated ability to dissipate heat through their reduced; cutaneous blood flow, physical fitness and sweat gland output, resulting in a decrease in sweat rate[5]. More recent research has advanced our understanding of when elderly people store greater amounts of heat compared to younger adults, therefore placing them at a greater risk of heat illness. Stapleton and colleagues found that when exercising at a fixed rate $\dot{H}_{prod}$ in a 40°C environment, older people began to store greater amounts of heat compared to younger individuals, from 400W $\dot{H}_{prod}$ (~ 47% $\dot{V}O_{2peak}$) in older men and from 325W $\dot{H}_{prod}$ (~ 50% $\dot{V}O_{2peak}$) in older women[17-18]. However, the exercise intensities employed in these previous studies are at a set $\dot{H}_{prod}$[16-18] and do not replicate activities of daily living for the elderly. Furthermore, the extreme environments > 35°C and < 20 % relative humidity (RH) used in the aforementioned research do not simulate current UK summer environments. The average summer temperature for the UK is ~15°C and the average hottest temperature experienced across the UK was 34.4°C, with 38.5°C being the hottest ever recorded temperature[19]. The RH in the UK is variable, during average summers RH ranges from ~60-80%[20] however, during periods of hot weather RH is between 20-60%[21-22]. Consequently, the physiological and perceptual responses to activities of daily living of elderly people in UK summer environments remains unclear.

Metabolic equivalents (METs) are an easy way to quantify energy expenditure of activities of daily living[23] and is commonly used as an estimate of energy expenditure in elderly participants[24]. One MET, commonly referred to as resting metabolic rate (RMR), is the utilisation of 3.5ml O_2 $kg^{-1}min^{-1}$ for a 70 kg individual and consequently 2 METs require 7.0ml O_2 $kg^{-1}min^{-1}$ to complete. Activities equivalent to 2 METs include; washing the dishes and cooking, 4 MET activities include; gardening and painting and 6 MET activities include walking and dancing[23].

The elderly population could benefit from advice on how to maintain healthy and active lifestyles during periods of hot weather, in order to gain the health benefits of exercise whilst avoiding the risks of heat illness. Therefore, the aim of this study was to investigate the physiological and perceptual response of elderly people during exercise that equated to various activities of daily living in environmental temperatures associated with UK summer conditions. It was hypothesised that physiological and perceptual responses would increase with exercise intensity and environmental temperature.

2. Methods

2.1. Ethical approval

The experimental protocol was approved by the University of Brighton's ethics committee and conducted in accordance with the revised Declaration of Helsinki[25]. Prior to testing, participants provided their written consent and a medical questionnaire in which participants were excluded if they had a prior or were currently being treated for; cardiovascular or respiratory illnesses, or they were taking medication that affected thermoregulation. Additionally, the participants' G.P's were informed of their patient's participation and gave their written consent for their patient to participate.

2.2. Participants

28 (17 males; 10 females; 1 transgender female) habitually active participants volunteered for the study and were divided into three experimental groups. Participants were matched, between groups for; stature, body mass, body fat percentage and age (Table 1).

2.3. Preliminary testing

During the preliminary testing, anthropometric and baseline data were collected, followed by a graded exercise test (GXT). Stature (Detecto, USA) and body mass (0.01kg) (Adam GFK 150, Adam Equipment Inc., USA) were recorded. The percent body fat was determined from 4 skin folds[26] and the equations of Siri[27]. On completion, a 10-min supine 12 lead ECG analysis was completed by a qualified technician to detect abnormalities in heart activity. Resting blood pressure was measured post ECG to ensure participants were not hypertensive. If a heart abnormality was detected or the participant was hypertensive then they could not complete exercise testing and were referred to their physician. No participants were excluded from the study based on these criterion.

The GXT were performed on a recumbent cycle ergometer (Cardiostrong, BC50, Germany) within the main trial environment (15°C, 25°C or 35°C, 50% RH [TISS, Hampshire, UK]). The purpose of the GXT was to determine the participants' power output at 2, 4 and 6 METs. GXT consisted of seven continuous, 3-min, incremental (15W) stages, from an initial power of 25W. Expired air was collected using open-circuit spirometry for ~ 45s at the end of the 20-min habituation period to assess individual resting oxygen consumption and during the last minute of each exercise stage. Indirect calorimetry from resting gaseous analysis provided the participant's individual RMR to calculate their 1 MET resting value and to subsequently calculate the power outputs required to achieve 2, 4 and 6 METs. Individual 1 MET values were calculated due to the standardised 1 MET value of 3.5ml O_2 $kg^{-1}min^{-1}$ over-estimating energy expenditure at rest for the elderly[28]. The 2, 4 and 6 MET equivalent activities remain the same, because the activity still requires 2, 4 or 6 times as much oxygen consumption from rest, to complete. Rectal temperature (T_{re}) was assessed throughout the test using a disposable rectal probe (Henley Reading, UK) inserted 10 cm past the anal sphincter.

2.4. Experimental testing

Main trials consisted of 30-min seated rest followed by 30-min of cycling exercise at randomly selected intensity of; 2, 4 or 6 METs within the participant's assigned environmental condition. Participants' trials were conducted at the same time of day and outside of the summer months (October-May); to control for circadian rhythm[29] and additional natural heat load[30], respectively. Participants avoided strenuous activity and alcohol for 24 hours, caffeine for 12 hours and eating food for 2 hours prior to testing[17]. To ensure euhydration, participants were asked to consume 500ml of water 2 hours prior to testing, euhydration was achieved with a urine specific gravity value ≤ 1.020 and osmolality value ≤ 700 $mOsm.kg^{-1}$ [31].

Participants were fitted with a heart rate monitor (HR) (Polar Electro, Kempele, Finland), T_{re} and skin temperature thermistors (Eltek Ltd, Cambridge, UK). Four skin thermistors were attached in accordance with Ramanathan[32] for the assessment of mean skin temperature (T_{skin}).Core-to-skin gradient was calculated post exercise[33]. Whole body sweat rate (WBSR) was determined from a nude body mass (NBM) measurement pre-post exercise.

Throughout testing, HR, T_{re} and T_{skin} were recorded every 5-min. Thermal sensation (TS)[34], thermal comfort (TC) (modified Gagge et al.[35]; 1 = comfortable, 5 = very uncomfortable) and ratings of perceived exertion (RPE)[36] were recorded at 10-min intervals. Gaseous analysis via Douglas bags was taken at minute 19 during rest and minutes 4, 14 and 24 during exercise, with a collection time of ~ 45s, to monitor and to calculate MET's and $\dot{H}_{prod}$[37] (Servomex 4100 Xentra gas analyser, Crowborough, UK). Exercise was terminated if T_{re} ≥ 39.0°C, or the participant withdrew due to volitional exhaustion. Participants completed the experimental trial at a different MET intensity 7-9 days later.

2.5. Statistical analyses

All data are presented as mean ± standard deviation (SD) and were assessed for normality and sphericity prior to further statistical analyses. When the assumption of sphericity was violated the Greenhouse-Geisser adjustment was used. One-way Analysis of Variance (ANOVA) were used to ensure no statistical difference among groups for physical characteristics. Two way mixed methods ANOVAs (environment*exercise intensity) were performed on rest and end exercise data with a between subjects' factor of environment (3 levels; 15°C, 25°C and 35°C) and a within subject factor of exercise intensity (3 levels: 2, 4 and 6 METs), with follow up Bonferroni-corrected post-hoc comparisons. Effect sizes were estimated using η_p^2 within statistical ANOVA analysis, to analyse the magnitude and trends of the intervention[38]. Effect sizes were categorised as; small (0.01), moderate (0.06), and large (0.14) for η_p^2 [39]. Data were analysed using SPSS (Version 22, SPSS Inc., Chicago, Illinois, USA) with significance set at $P < 0.05$. An a priori power analysis indicated that the minimum total sample size required to detect a change in core temperature with a large effect size (η_p^2 0.14) and with at least 95% statistical power, was 15 participants.

3. Results

3.1. Baseline measures and exercise intensity

There were no observed differences between the environmental groups for participant characteristics (Table 1). Similarly, no within or between–participant differences were observed for baseline; T_{re} ($P = 0.127$, $\eta_p^2 = 0.14$), HR ($P = 0.239$, $\eta_p^2 = 0.10$) and T_{skin} ($P = 0.294$, $\eta_p^2 = 0.09$).

By research design there were no observed differences for exercise condition between environmental conditions for METs ($P = 0.860$, $\eta^2 = 0.004$), or for $\dot{H}_{prod}$ ($P = 0.240$, $\eta^2 = 0.04$) (Table 2). Furthermore, there was no observed differences for peak RPE ($P = 0.905$, $\eta_p^2 = 0.01$) and peak HR ($P = 0.165$, $\eta_p^2 = 0.07$) for environmental condition. However, as expected, there were observed differences for peak RPE ($P < 0.001$, $\eta_p^2 = 0.72$) and peak HR ($P < 0.001$, $\eta_p^2 = 0.81$) for exercise condition. Post-hoc analyses identified a difference ($P < 0.001$) between all exercise conditions for peak RPE (Table 2) and peak HR (Table 3).

Table 1: Mean ± SD participant characteristics.

Group	Age (yrs)	Stature (m)	NBM (kg)	BSA (m^2)	Body fat (%)
15°C	70 ± 3	1.66 ± 0.11	74.89 ± 14.68	1.83 ± 0.23	24 ± 4
25°C	70 ± 2	1.72 ± 0.09	79.43 ± 17.46	1.91 ± 0.25	22 ± 3
35°C	72 ± 5	1.70 ± 0.09	76.48 ± 12.34	1.88 ± 0.19	23 ± 4

Abbreviations: NBM = nude body mass; BSA = body surface area.

3.2. Perceptual response

This section reports the statistical analyses of the perceptual responses to the exercise and environmental conditions. Table 2 presents the mean ± SD of the peak perceptual data. It also displays the absolute difference across exercise conditions within environmental conditions.

There were observed difference for peak TS ($P < 0.001$, $\eta_p^2 = 0.64$) and peak TC ($P < 0.001$, $\eta_p^2=0.35$) for exercise condition (Figure 1). Furthermore, there were observed difference for peak TS ($P < 0.001$, $\eta_p^2 = 0.69$) for environmental condition (Figure 1). Interestingly, there was no observed differences for peak TC ($P = 0.095$, $\eta_p^2 = 0.17$) for environmental conditions. Furthermore, TC at 6 METs, 25°C compared to 35°C remained exactly the same, TC = 3 (just uncomfortable). Post-hoc analyses identified differences between all exercise intensities for peak TS and peak TC (Figure 1 and Table 2). Additionally, peak TS demonstrated a difference between environmental conditions (Figure 1). There was no observed interaction between environmental and exercise conditions for peak TS ($P = 0.150$, $\eta_p^2 = 0.13$).

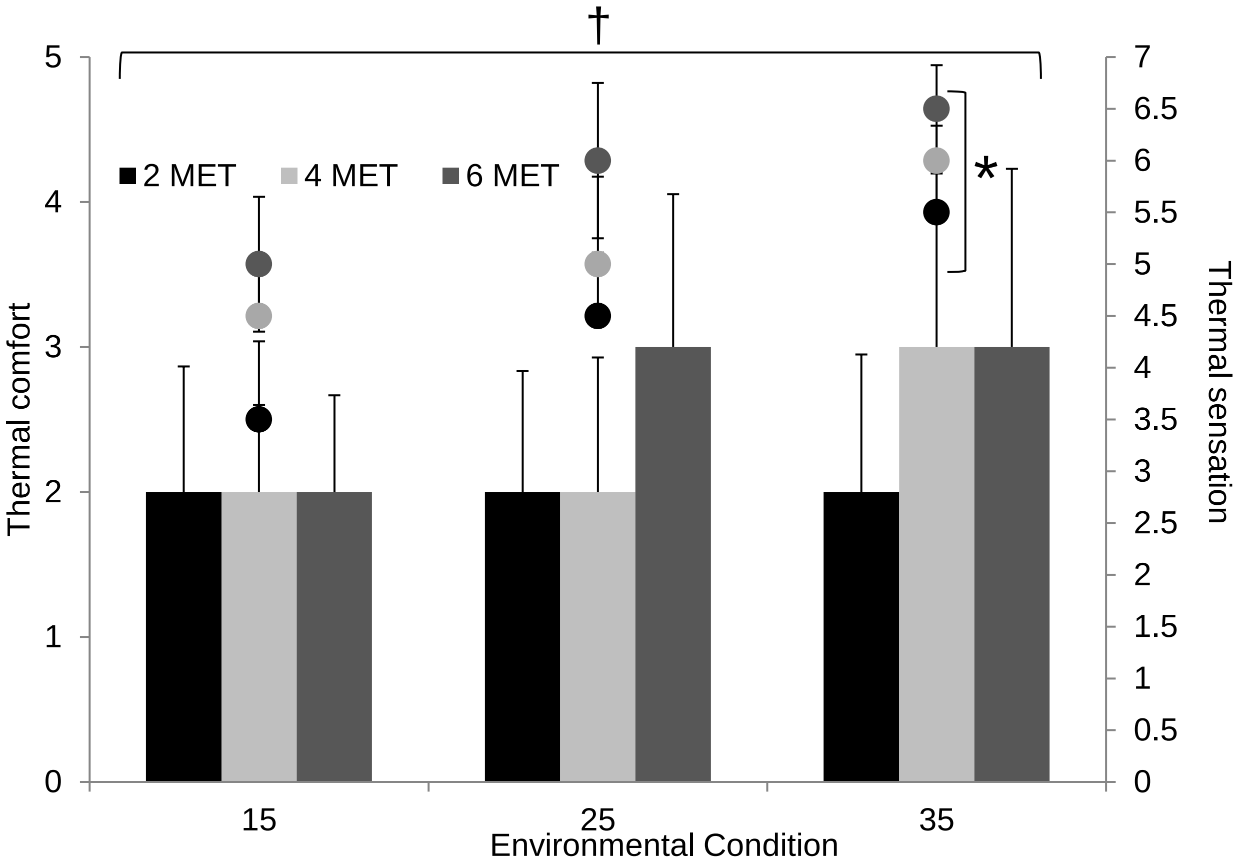

Figure 1: Mean ± SD for TC (bar chart) and TS (circles) across environmental conditions and exercise intensity. *denotes a significant difference (*P* < 0.05) in TS and TC across exercise intensities. † denotes a significant difference (*P* < 0.05) in TS across environmental conditions.

Table 2: Mean ± SD of the exercise intensity and peak perceptual data. It also displays the absolute difference across exercise conditions within environmental conditions. *denotes a significant difference ($P < 0.05$) between the exercise conditions.

		2 MET	4 MET	6 MET	Δ2-4 MET	Δ4-6 MET	Δ2-6MET
METs	15°C	2.56 ± 0.46	4.42 ± 0.37	5.52 ± 0.68			
	25°C	2.52 ± 0.29	4.28 ± 0.61	5.92 ± 0.86			
	35°C	2.21 ± 0.43	4.15 ± 0.50	5.73 ± 0.53			
$\dot{H}_{prod}$ (W)	15°C	162 ± 63	245 ± 65	280 ± 75			
	25°C	138 ± 44	203 ± 51	261 ± 52			
	35°C	129 ± 46	200 ± 35	263 ± 61			
Peak RPE	15°C	10 ± 2	13 ± 1	14 ± 2	2 ± 1 *	2 ± 2 *	4 ± 2 *
	25°C	10 ± 2	12 ± 2	14 ± 2	1 ± 2 *	3 ± 1 *	4 ± 2 *
	35°C	10 ± 3	12 ± 2	15 ± 2	2 ± 3 *	2 ± 2 *	5 ± 3 *
Peak TS	15°C	3.5 ± 1.0	4.5 ± 0.5	5.0 ± 0.5	0.5 ± 1.0 *	0.5 ± 0.5 *	1.0 ± 1.0 *
	25°C	4.5 ± 0.5	5.0 ± 1.0	6.0 ± 1.0	0.5 ± 1.0 *	1.0 ± 0.5 *	1.5 ± 1.0 *
	35°C	5.5 ± 0.5	6.0 ± 0.5	6.5 ± 0.5	1.0 ± 0.5 *	0.0 ± 0.5 *	1.0 ± 0.5 *
Peak TC	15°C	2 ± 1	2 ± 1	2 ± 1	0 ± 1 *	0 ± 1 *	1 ± 1 *
	25°C	2 ± 1	2 ± 1	3 ± 1	0 ± 1 *	1 ± 1 *	1 ± 1 *
	35°C	2 ± 1	3 ± 1	3 ± 1	1 ± 1 *	0 ± 1 *	1 ± 1 *

Abbreviations: METs = metabolic equivalents; $\dot{H}_{prod}$ = metabolic heat production; HR = heart rate; RPE = rating of perceived exertion; TS = thermal sensation; TC = thermal comfort

3.3. Physiological responses

This section reports the statistical analyses of the physiological responses to the exercise and environmental conditions. Table 3 presents the mean ± SD of the physiological data; peak and change from post rest to end of exercise. It also displays the absolute difference across exercise conditions within environmental conditions.

There were observed differences for change in exercise T_{re} (ΔT_{re}) ($P < 0.001$, $\eta_p^2 = 0.70$) and peak T_{re} ($P < 0.001$, $\eta_p^2 = 0.65$) for exercise condition (Table 3). Likewise, there were observed differences for ΔT_{re} ($P < 0.001$, $\eta_p^2 = 0.83$), however, no differences for peak T_{re} ($P = 0.201$, $\eta_p^2 = 0.13$) for environmental condition. Post-hoc analyses identified a difference ($P < 0.001$) between all exercise conditions for ΔT_{re} and peak T_{re} (Table 3). Additionally, between 15-35°C and 25-35°C for ΔT_{re} (Figure 1). There were no observed interactions for ΔT_{re} ($P = 0.141$, $\eta_p^2 = 0.14$) between exercise and environmental conditions.

There were observed differences for ΔT_{skin} ($P = 0.006$, $\eta_p^2 = 0.19$) and peak T_{skin} ($P < 0.001$, $\eta_p^2 = 0.33$) for exercise condition (Table 3). Likewise, observed differences for ΔT_{skin} ($P = 0.01$, $\eta_p^2 = 0.45$) and peak T_{skin} ($P < 0.001$, $\eta_p^2 = 0.94$) for environmental condition. Post-hoc analyses identified a difference between 2-6 METs for ΔT_{skin} and a difference, between 2-4 METs and 2-6 METs for peak T_{skin} (Table 3). Furthermore, there were differences present between environmental conditions for peak T_{skin} and ΔT_{skin} between 15-35°C and 25-35°C (Figure 2). There were no observed interactions for ΔT_{skin} ($P = 0.244$, $\eta_p^2 = 0.02$), nor peak T_{skin} ($P = 0.244$, $\eta_p^2 = 0.10$) between exercise and environmental condition.

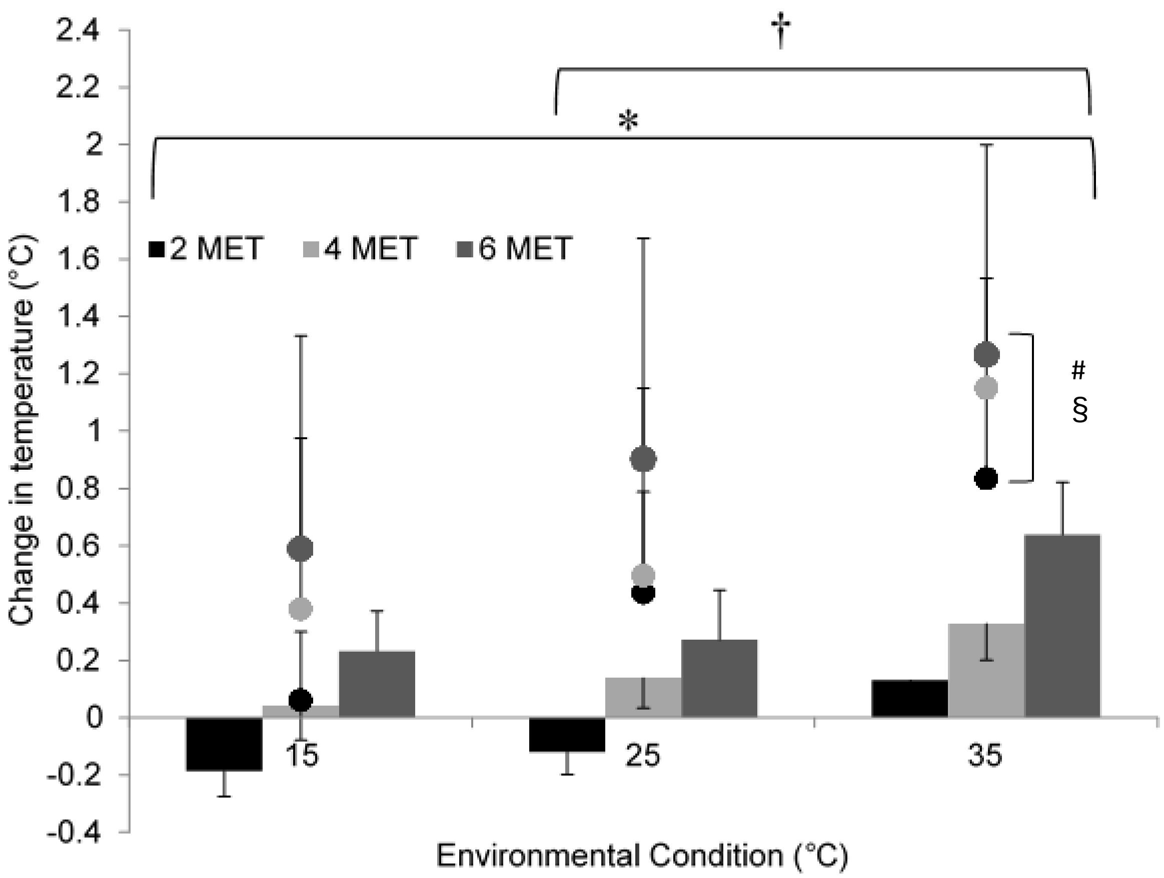

Figure 2: Mean ± SD for ΔT_{re} (bar chart) and ΔT_{skin} (circles), across environmental and exercise conditions. *denotes a significant difference ($P < 0.05$) in ΔT_{re} and ΔT_{skin} between 15-35°C. † denotes a significant difference ($P < 0.05$) ΔT_{re} and ΔT_{skin} between 25-35°C. # denotes a significant difference ($P < 0.01$) in ΔT_{re} across all conditions. § denotes a significant difference ($P < 0.05$) in ΔT_{skin} between 2-6 METs.

Likewise, core-to-skin gradient demonstrated a difference ($P < 0.001$, $\eta_p^2 = 0.96$) for environmental condition (Table 3). There was no difference observed ($P = 0.165$, $\eta_p^2 = 0.07$) between exercise conditions (Table 3). Post-hoc analyses identified a difference ($P < 0.001$) between all environmental conditions (Figure 3).

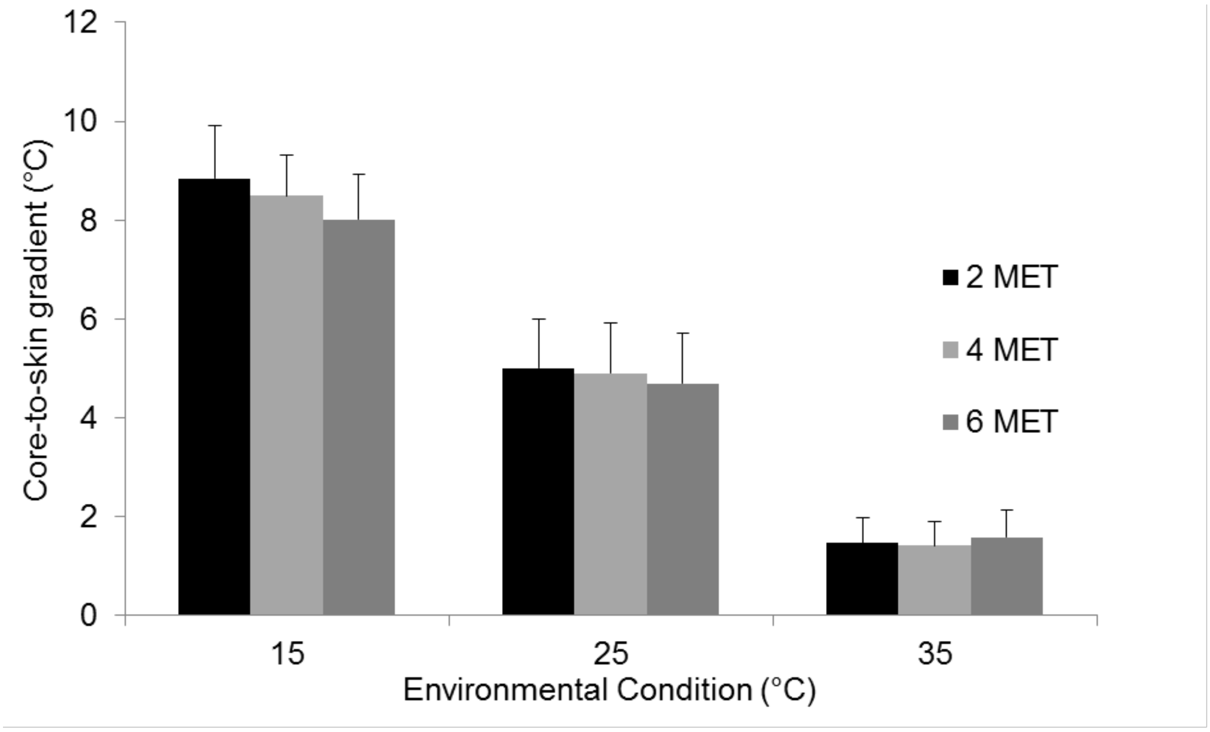

Figure 3: Mean ± SD of end exercise core-to-skin gradient, across environmental conditions and exercise intensity. * denotes a significant difference ($P < 0.001$) for environmental condition.

There were observed differences in WBSR for exercise ($P = 0.001$, $\eta_p^2 = 0.29$) and environmental conditions ($P = 0.02$, $\eta_p^2 = 0.40$). Post-hoc analyses identified a difference between 2-6 METs and 4-6 METs (Table 3). Furthermore, there was a difference between 15-35°C. There was no interaction observed ($P = 0.143$, $\eta_p^2 = 0.13$) for WBSR between environmental and exercise conditions.

Table 3: Mean ± SD of the physiological data; peak and change from post rest to end of exercise. It also displays the absolute difference across exercise conditions within environmental conditions. *denotes a significant difference ($P < 0.05$) between the exercise conditions.

		2 MET	4 MET	6 MET	Δ2-4 MET	Δ4-6 MET	Δ2-6 MET
Peak T_{re} (°C)	15°C	36.98 ± 0.29	37.28 ± 0.26	37.43 ± 0.29	0.30 ± 0.18 *	0.15 ± 0.27 *	0.45 ± 0.36 *
	25°C	37.02 ± 0.24	37.30 ± 0.40	37.63 ± 0.20	0.28 ± 0.31 *	0.33 ± 0.33 *	0.61 ± 0.28 *
	35°C	37.28 ± 0.30	37.41 ± 0.36	37.70 ± 0.41	0.12 ± 0.25 *	0.30 ± 0.21 *	0.42 ± 0.22 *
Δ T_{re} post rest to end exercise (°C)	15°C	-0.19 ± 0.09	0.04 ± 0.12	0.23 ± 0.14	0.23 ± 0.09 *	0.19 ± 0.15 *	0.42 ± 0.18 *
	25°C	-0.12 ± 0.08	0.14 ± 0.11	0.27 ± 0.17	0.26 ± 0.10 *	0.13 ± 0.15 *	0.39 ± 0.16 *
	35°C	0.13 ± 0.13	0.33 ± 0.13	0.64 ± 0.18	0.20 ± 0.13 *	0.31 ± 0.12 *	0.51 ± 0.21 *
Peak T_{skin} (°C)	15°C	27.86 ± 1.21	28.44 ± 1.23	29.06 ± 1.37	0.58 ± 0.66 *	0.61 ± 1.19 *	1.20 ± 1.23 *
	25°C	32.03 ± 1.06	32.39 ± 1.01	32.94 ± 1.15	0.37 ± 0.81 *	0.55 ± 1.04 *	0.91 ± 0.85 *
	35°C	35.81 ± 0.45	35.99 ± 0.38	36.11 ± 0.44	0.17 ± 0.55 *	0.13 ± 0.44 *	0.30 ± 0.63 *
ΔT_{skin} post rest to end exercise (°C)	15°C	0.06 ± 0.24	0.38 ± 0.60	0.59 ± 0.74	0.32 ± 0.64	0.21 ± 1.00	0.53 ± 0.75 *
	25°C	0.44 ± 0.35	0.50 ± 0.65	0.90 ± 0.77	0.06 ± 0.76	0.40 ± 0.80	0.47 ± 0.77 *
	35°C	0.83 ± 0.28	1.15 ± 0.38	1.27 ± 0.73	0.32 ± 0.41	0.12 ± 0.71	0.43 ± 0.76 *
Skin to core gradient (°C)	15°C	8.83 ± 1.08	8.50 ± 0.82	8.02 ± 0.90	-0.34 ± 0.73	-0.48 ± 1.22	-0.82 ± 1.33
	25°C	5.00 ± 1.01	4.91 ± 1.00	4.69 ± 1.01	-0.09 ± 0.98	-0.22 ± 1.06	-0.31 ± 0.81
	35°C	1.47 ± 0.50	1.42 ± 0.47	1.59 ± 0.55	-0.05 ± 0.53	0.17 ± 0.53	0.12 ± 0.63
WBSR (L.h^{-1})	15°C	0.21 ± 0.14	0.20 ± 0.14	0.34 ± 0.22	-0.01 ± 0.15	0.14 ± 0.25*	0.13 ± 0.23*
	25°C	0.41 ± 0.36	0.30 ± 0.16	0.71 ± 0.55	-0.12 ± 0.35	0.41 ± 0.56*	0.30 ± 0.64*
	35°C	0.41 ± 0.37	0.64 ± 0.26	0.85 ± 0.31	0.23 ± 0.30	0.21 ± 0.21*	0.44 ± 0.36*
Peak HR beats min^{-1}	15°C	84 ± 12	104 ± 14	116 ± 22	20 ± 12 *	12 ±10 *	32 ± 16 *
	25°C	77 ± 12	93 ± 14	110 ± 18	15 ± 8 *	17 ± 9 *	32 ± 14 *
	35°C	80 ± 9	104 ± 19	118 ± 23	23 ± 13 *	15 ± 6 *	38 ± 18 *

Abbreviations: T_{re} = rectal temperature; Δ =change; T_{skin} = skin temperature; WBSR = whole body sweat rate; HR = heart rate

4. Discussion

This study is the first to investigate the physiological and perceptual response of elderly people during exercise equating to various activities of daily living in simulated UK summer environments. The main findings within the physiological and perceptual data was an increase in T_{re}, $T_{skin,}$ WBSR and TS with exercise intensity and environmental condition, whilst HR, TC and RPE increased with only exercise intensity. The novel finding within this data is that a driver of thermoregulatory behaviour, TC, did not become more uncomfortable when exercising at 6 MET's (i.e walking/dancing) in 35°C compared to 25°C.

The present study found that there was no statistical difference between environmental conditions for TC despite there being a significant difference for core-to-skin gradient, ΔT_{skin} and ΔT_{re}. Interestingly, T_{skin} is a modulator of TC which is a driver of thermoregulatory behaviour[40-41] and T_{re} is a marker of heat illness[42-43]. In our study, thermal strain markers are increasing, but peak TC remains at just uncomfortable (3) between 6 METs, 35°C and 6 METs, 25°C. It is well known that an individual will only implement behavioural, heat alleviating strategies when they feel uncomfortable within the environment[40]. The potential implications of an attenuated response to environmental discomfort is an increased risk of heat illness due to a continued increase in thermal strain markers (i.e T_{re} and T_{skin}). Heat illnesses occurs along a continuum, therefore minor heat illnesses (i.e heat rash) can develop into a severe heat illness (i.e heat stroke), if left untreated[43]. Consequently, if an elderly person does not feel uncomfortable enough to minimise heat illness risk, there is the potential for them to develop heat stroke without knowing, which is partly diagnosed from a core temperature > 40°C[44]. In addition to no changes in TC, RPE, which is a modulator of thermoregulatory behaviour during exercise[41], had a minimal increase from 25°C, 6 METs (14 ± 2) to (15 ± 2) at 35°C, 6 METs.

Previously, Larose and colleagues demonstrated that older (55 – 70 yrs), compared to younger adults (20 – 30yrs) report identical perceptions of heat for a similar RPE despite having greater body heat storage (292 ± 28 kJ *vs* 158 ± 21 kJ, respectively)[45]. This suggests the elderly may display a decreased perception of heat and consequently delayed or modified behavioural thermoregulatory responses compared to younger counterparts increasing the risk of heat illness. The current work supports this contention by observing a potential behavioural thermoregulatory attenuation via a decrease in perceptual awareness. The elderly participants remained just uncomfortable (TC = 3) and only slightly warmer (6 *vs.* 6.5) at the same exercise intensity despite environmental temperature being increased by 10°C.

It is noteworthy that scales that measure subjective variables (i.e TC, RPE and TS) have limitations that were controlled during testing. Firstly, the points on the scale can be interpreted differently between participants. To minimise inter-individual differences a set of standardised instructions was given to the participants to anchor the points on the scales for example; RPE '*6 means no exertion at all and 20 means the most maximal exertion*'[46]. Furthermore, it is also standard practice to familiarise participants with perceptual scales prior to testing[47-49]. In this study, all the perceptual scales were presented to the participants during a pre-experimental visit, to ensure scale understanding.

An aim of the study was to contribute evidence in order to advise elderly people on how to maintain healthy and active lifestyles during periods of hot weather. The present study demonstrated a ΔT_{re} of 0.64°C during exercise equating to walking and or dancing intensity (6 MET) in a 35°C 50% RH environment. This equated to an end exercise T_{re} of 37.70 ± 0.41°C, which is not considered hyperthermic. Furthermore, all other exercise and environmental conditions demonstrated lower end T_{re} and ΔT_{re} compared to 6 MET 35°C trial (Table 3). Therefore, it can be concluded that it is safe for habitually active elderly to complete one 30-min bout of activity that equates to activities of daily living within UK summer environments. However, the caveat to this advice, is that the present research only assessed completing exercise over 30-min with a total environmental exposure time of 60-min. During a period of hot weather, exposure time would be considerably longer resulting in an accumulation of heat strain throughout the exposure time that would raise resting T_{re} and T_{skin} and increase an individual's risk of developing a heat illness. This is demonstrated by Stapleton and colleagues, where intermittent exercise and recovery stages provoked a change in oesophageal temperature (ΔT_{es}) of 0.68°C from the penultimate recovery stage (37.65 ± 0.29°C) to the end of the last exercise bout (38.33 ± 0.22°C), the change in ΔT_{es} (0.68°C) is similar to the present study (ΔT_{re} of 0.64°C)[18]. However, the overall ΔT_{es} was 1.15°C with a total heat exposure time of 165-min[18]. Stapleton and colleagues highlights the accumulation of heat strain during repeated bouts of exercise that would likely to be experienced during periods of hot weather[18].

One limitation to the research is that the elderly participants were healthy and habitually active individuals. Frail elderly people and those transitioning from healthy to frail, are at an even greater risk of heat illness during periods of hot weather[50]. Consequently, the physiological and perceptual response could be exacerbated in an elderly population who could be classed as in transition or frail. Therefore, further research into the physiological and perceptual responses of elderly subpopulations to summer environments is warranted, for example people with cardiovascular diseases, type 2 diabetes, sedentary populations and people in care homes. Additionally, due to experimental design the participants clothing was controlled to athletic shorts and T-shirt. Therefore, it remains unclear of the extent to which behavioural thermoregulation effects thermal physiology through elderly individuals' conscious decision to remove or add layers of clothing when exercising within UK summer environments.

5. Conclusion

The current study demonstrates increasing thermal strain in the elderly when exercising at a somewhat-hard to hard intensity (i.e. RPE of 14-15 and exercise intensity equivalent to walking/dancing) in high ambient temperatures (35°C) without a concurrent perceptual recognition and therefore possible attenuated ability to detect thermal discomfort within the environment. Consequently, the elderly may be less likely to implement lifesaving behavioural thermoregulation interventions such as; seeking shade, decreasing metabolic rate and removing excess layers, as thermal comfort is the drive for thermoregulatory behaviour and therefore should use caution when exercising in hot ambient temperatures.

6. Acknowledgement

The authors wish to thank the study participants, researchers and staff for their contribution to the research.

6.1. Ethical approval

University of Brighton's research ethics committee.

6.2. Funding

The study was supported by the Eastbourne Leisure Trust. Their support was solely financial, consequently they were not involved in the research design, data collection or statistical analysis.

6.3. Competing interests

There were no competing interests.

References

1. S. Hajat, S. Vardoulakis, C. Heaviside, B. Eggen, Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s., *J. Epidemiol. Community Health* 2014; **68**: 1–8.

2. J.M. Robine, S.L.K. Cheung, S. Le Roy, H. Van Oyen, C. Griffiths, J.P. Michel, F.R. Herrmann, Death toll exceeded 70,000 in Europe during the summer of 2003, *Comptes Rendus - Biol*. 2008; **331**: 171–178.

3. D. Oudin Åström, F. Bertil, R. Joacim, Heat wave impact on morbidity and mortality in the elderly population: A review of recent studies, *Maturitas* 2011; **69**: 99–105.

4. S. Conti, P. Meli, G. Minelli, R. Solimini, V. Toccaceli, M. Vichi, C. Beltrano, L. Perini, Epidemiologic study of mortality during the Summer 2003 heat wave in Italy, *Environ. Res*. 2005; **98**: 390–399.

5. W.L. Kenney, D.H. Craighead, L.M. Alexander, Heat waves, aging and human cardiovascular health, *Med. Sci. Sports Exerc.* 2014; **46**: 1891–1899.

6. S. Smith, A.J. Elliot, S. Hajat, A. Bone, G.E. Smith, S. Kovats, Estimating the burden of heat illness in England during the 2013 summer heatwave using syndromic surveillance., *J. Epidemiol. Community Health.* 2016; **70**: 459–465.

7. World Health Organisation, Public health advice on preventing health effects of heat. New and updated information for different audiences., WHO 2011: 1–37.

8. Public Health England, Heatwave Plan for England, https://www.gov.uk/government/publications/heatwave-plan-for-england; 2015 [assessed 29 September 2017].

9. M.N. Sawka, A.J. Young, Physical exercise in hot and cold climates, in: *Exerc. Sport Sci.,* 2000: 385–400.

10. Public Health England, One You, https://www.gov.uk/government/publications/heatwave-plan-for-england; 2017. [assessed 29 September 2017].

11. Department of Health, Change4Life,

https://www.gov.uk/government/publications/change4life-three-year-social-marketing-strategy; 2011 [assessed 29 September 2017].

12. National Health Service, Couch to 5K, http://www.nhs.uk/Livewell/c25k/Pages/couch-to-5k.aspx; 2017. [assessed 29 September 2017].

13. R.K. Anderson, W.L. Kenney, Effect of age on heat-activated sweat gland density and flow during exercise in dry heat, *J Appl Physiol.* 1987; **63**: 1089–1094.

14. Y. Inoue, G. Havenith, W.L. Kenney, J. Lommis, E. Buskirk, Exercise- and methylcholine-induced sweating responses in older and younger men: effect of heat acclimation and aerobic fitness, *Int. J. Biometeorol.* 1999: 210–216.

15. Y. Inoue, M. Shibasaki, H. Ueda, H. Ishizashi, Mechanisms underlying the age-related decrement in the human sweating response, *Eur. J. Appl. Physiol. Occup. Physiol.* 1999; **79**: 121–126.

16. J. Larose, H.E. Wright, J. Stapleton, R.J. Sigal, P. Boulay, S. Hardcastle, G.P. Kenny, Whole body heat loss is reduced in older males during short bouts of intermittent exercise., *Am. J. Physiol. Regul. Integr. Comp. Physiol.* 2013; **305**: R619-29.

17. J.M. Stapleton, M.P. Poirier, A.D. Flouris, P. Boulay, R.J. Sigal, J. Malcolm, G.P. Kenny, Aging impairs heat loss, but when does it matter?, J. Appl. Physiol. 2014; **118**: 299–309.

18. J.M. Stapleton, M.P. Poirier, A.D. Flouris, P. Boulay, R.J. Sigal, J. Malcolm, G.P. Kenny, At what level of heat load are age-related impairments in the ability to dissipate heat evident in females?, *PLoS One* 2015; **10**: 1–17.

19. Met Office, UK Climate Extremes, https://www.metoffice.gov.uk/public/weather/climateextremes/#?tab=climateExtremes;2018 [accessed 7 March 2018]

20. Met Office,UK Climate,

https://www.metoffice.gov.uk/public/weather/climate; 2018 [accessed 7 March 2018]

21. S. Burt, The August 2003 heatwave in the United Kingdom: Part 1- Maximum temperatures and historical precedents, *Weather*. 2004;**59**: 199-208.

22. J. Shanklin, S. Colwell, The UK's hottest day on record, *Weather.* 2005; **60**: 25.

23. M. Jetté, K. Sidney, G. Blümchen, Metabolic equivalents (METS) in exercise testing, exercise prescription, and evaluation of functional capacity., Clin. Cardiol. 1990; **13**: 555–565.

25. World Health Organisation, Declaration of Helsinki World Medical Association Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects, *J. Am. Med. Assoc*. 2013; **310**: 2191–2194.

26. J. V Durnin, J. Womersley, Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years, *Br J Nutr.* 1974; **32**: 77–97.

27. W.E. Siri, The gross composition of the body., *Adv. Biol. Med. Phys.* 1956.

28. M. Kwan, J. Woo, T. Kwok, The standard oxygen consumption value eqivalent to one metabolic equivalent (3.5 ml/min/kg) is not appropriate for elderly people, *Int. J. Food Sci. Nutr.* 2004; **55**: 179–182.

29. K. Kräuchi, A. Wirz-Justice, Circadian rhythm of heat production, heart rate, and skin and core temperature under unmasking conditions in men., *Am. J. Physiol.* 1994; **267**: R819–R829.

30. Y. Shapiro, R.W. Hubbard, C.M. Kimbrough, K.B. Pandolf, Physiological and hematologic responses to summer and winter dry-heat acclimation., *J. Appl. Physiol.* 1981.

31. M.N. Sawka, L.M. Burke, E.R. Eichner, R.J. Maughan, S.J. Montain, N.S. Stachenfeld, Exercise and fluid replacement, Med. Sci. Sports Exerc. 2007; **39:** 377–390.

32. N.L. Ramanathan, A new weighting system for mean surface temperature of the human body, *J. Appl. Physiol.* 1964.

33. J.S. Cuddy, W.S. Hailes, B.C. Ruby, A reduced core to skin temperature gradient, not a critical core temperature, affects aerobic capacity in the heat, J.

Therm. Biol. 2014; **43**: 7–12.

34. A.J. Young, M.N. Sawka, Y. Epstein, B. Decristofano, K.B. Pandolf, Cooling different body surfaces during upper and lower body exercise, *J. Appl. Physiol.* 1987.

35. A.P. Gagge, J.A.J. Stolwijk, J.D. Hardy, Comfort and thermal sensations and associated physiological responses at various ambient temperatures, *Environ. Res.* 1967; **1**: 1–20.

36. G.A. V Borg, Psychophysical bases of percieved exertion, Med. Sci. Sport. Exerc. 1982.

37. M.N. Cramer, O. Jay, Selecting the correct exercise intensity for unbiased comparisons of thermoregulatory responses between groups of different mass and surface area, *J. Appl. Physiol.* 2014; **116**: 1123–1132.

38. S. Nakagawa, I.C. Cuthill, Effect size, confidence interval and statistical significance: A practical guide for biologists, Biol. Rev. 2007; **82**: 591–605.

39. J.D. Cohen, Statistical power analysis for the behavioral sciences, *Stat. Power Anal. Behav. Sci.* 1988.

40. Z.J. Schlader, S.R. Stannard, T. Mündel, Human thermoregulatory behavior during rest and exercise - A prospective review, *Physiol. Behav.* 2010; **99**: 269–275.

41. A.D. Flouris, Z.J. Schlader, Human behavioral thermoregulation during exercise in the heat, *Scand. J. Med. Sci. Sport*. 2015; **25**: 52–64.

42. A. Bouchama, J. Knochel, Heat Stroke, *N. Engl. J. Med*. 1978; **346**; 1978–1988.

43. E.E. Coris, A.M. Ramirez, D.J. Van Durme, Heat Illness in Athletes: The Dangerous Combination of Heat, Humidity and Exercise, *Sport. Med*. 2004; **34**: 9–16.

44. M.N. Nadir, B. Kachela, N. Nadir, Z. Khan, A detailed account of heat stroke, 2016; **20** 1–4.

45. J. Larose, P. Boulay, H.E. Wright-Beatty, R.J. Sigal, S. Hardcastle, G.P.

Kenny, Age-related differences in heat loss capacity occur under both dry and humid heat stress conditions., *J. Appl. Physiol.* 2014; **117**: 69–79.

46. G.A. V Borg, An introduction to Borg's RPE-Scale, in: Mouv. Publ., 1985.

47. J.M. Johnson, Exercise in a hot environment: the skin circulation, Scand. J. *Med. Sci. Sport.* 2010; **20**: 29–39.

48. A. D. Flouris, S.S. Cheung, Human conscious response to thermal input is adjusted to changes in mean body temperature., *Br. J. Sports Med*. 2009; **43**: 199–203.

49. Z.J. Schlader, H.D. Prange, T.D. Mickleborough, J.M. Stager, Characteristics of the control of human thermoregulatory behavior., *Physiol. Behav*. 2009; **98**: 557–62.

50. S. Hajat, R.S. Kovats, K. Lachowycz, Heat-related and cold-related deaths in England and Wales: who is at risk?, *Occup. Environ. Med.* 2007; **64**: 93–100.