Optimising heat illness prevention strategies for the elderly population

Kirsty A. M. Waldock

University of Brighton
School of Sport and Service Management
March 2019

A thesis submitted in partial fulfilment of the requirements of the University of Brighton for the degree of Doctor of Philosophy

University of Brighton

Abstract

The aim of this thesis was to develop practical strategies for the maintenance of safe and effective exercise during periods of hot weather for the elderly population. Strategies were focused on the prevention of heat illness during exercise that simulated activities of daily living for elderly people in UK summer climatic conditions.

The first study investigated the validity and reliability of a new heat illness susceptibility questionnaire (HIS-Q). The HIS-Q demonstrated significant construct validity, via a significant decrease in individual HIS-Q scores post short term heat acclimation (STHA). The reliability of the HIS-Q during a laboratory protocol with mild heat stress could be improved, warranting further HIS-Q investigation within field-based environments with greater heat stress.

The second study assessed elderly peoples' physiological and perceptual responses to exercise at different intensities that simulated activities of daily living, across UK summer climatic conditions. Elderly people had an increase in physiological and thermal strain with an increase in exercise intensity and heat stress. However, there was a decreased perceptual awareness of the environment, due to minimal or no change in perceptual strain with an increase in heat stress.

The third study investigated elderly peoples' physiological and perceptual responses to physical and perceptual cooling during exercise simulating moderate activities of daily living in the hottest UK summer climatic conditions. Findings suggest that when elderly people drink refrigerated water periodically throughout rest and exercise, their physiological strain decreases. It also provided further evidence of a decreased perceptual awareness, as L-menthol had no observed changes in perceptual markers of thermal strain. Performance and physiological strain in a six-minute walk test of functional exercise capacity, were also improved in the refrigerated water trial compared to L-menthol and control trials.

The last study compared the differences in phenotypic adaptations to isothermic STHA, between elderly and young adults. Additionally, it assessed the differences in phenotypic adaptations between a novel STHA protocol and isothermic STHA within the elderly. The outcome of the study was the development of some phenotypic adaptations in the elderly groups from day 1 to day 5 of STHA.

The main outcomes of this thesis were; elderly people have a decreased perceptual awareness of the environment, when UK summer climatic conditions are at their hottest. Additionally, acute and chronic strategies for the prevention of heat illness have the potential to protect the elderly against the harmful effects of heat.

Table of contents

List of abbreviation

~	Approximately
Δ	Change
°C	Degrees Celsius
np^2	Partial eta squared
%	Percentage
6MWT	Six-minute walk test
A & E	Accident and emergency
AMS	Acute Mountain Sickness
ANOVA	Analysis of variance
$b.min^{-1}$	Beats per minute
BHF	British Heart Foundation
BM	Body mass
BSA	Body surface area
CNS	Central nervous system
CI	Confidence internal
CO_2	Carbon dioxide
CON	Control
COSHH	Control of Substances Hazardous to Health
CV	Coefficient of variation
CVC	Cutaneous vascular conductance
d	Cohen’s d effect size
E	Elderly
EHS	Exertional heat stroke
G.P	General practitioner
GXT	Graded exercise test
$\dot{H}_{prod}$	Metabolic heat production
HA	Heat acclimation
Hb	Heamoglobin
Hct	Haematocrit
HHWS	Heat health watch system
HISI	Heat illness symptoms index
HIS-Q	Heat illness susceptibility questionnaire
HPE	Heatwave plan for England
HR	Heart rate
HRI	Heat related-illness
HST	Heat stress test

HWI	Hot water immersion
ICC	Intra-class correlation coefficient
ICE	Ice slurry drink
J	Joule
kg	Kilogram
kJ	Kilojoule
km	Kilometre
$km.h^{-1}$	Kilometers per hour
LLQ	Lake Louise questionnaire
LoA	Limits of agreement
$L.hr^{-1}$	Litres per hour
LTHA	Long term heat acclimation
MAP	Mean arterial pressure
METs	Metabolic equivalents
Min	Minutes
ml	Millilitres
mOsmol	Milliosmols
NBM	Nude body mass
NHS	National Health Service
NO	Nitric oxide
NOS	Nitric oxide synthase
O_2	Oxygen
ONS	Office of National Statistics
PC	Precooling
PHE	Public Heath England
POAH	pre-optic anterior hypothalamus
PV	Plasma volume
Q_c	Cardiac output
r	Pearson’s correlation
RBC	Red blood cells
RH	Relative humidity
RMR	Resting metabolic rate
RER	Respiratory exchange ratio
RPE	Rating of perceived exertion
rpm	Revolutions per min
s	Seconds
SD	Standard deviation
SkBF	Skin blood flow
STHA	Short term heat acclimation

SV	Stroke volume
T_C	Core temperature
TC	Thermal comfort
TEM	Typical error of the measure
CV %	Coefficient of variation
T_{gi}	Gastrointestinal temperature
T_{ir}	Infrared tympanic temperature
T_{oe}	Oesophageal temperature
T_{or}	Oral temperature
T_{re}	Rectal temperature
TS	Thermal sensation
T_{sk}	Mean skin temperature
µl	Microlitre
UK	United Kingdom
U_{osmo}	Urine osmolality
USG	Urine specific gravity
$\dot{V}O_2$	Oxygen consumption
$\dot{V}O_{2max}$	Maximal oxygen consumption
$\dot{V}O_{2peak}$	Peak oxygen uptake
W	Watts
$W.kg^{-1}$	Watts per kilo gram
WBGT	Wet bulb globe temperature
WBSR	Whole body sweat rate
WHO	World Health Organisation
Y	Young

List of tables

List of figures

List of photos

Acknowledgements

I would like to start by thanking the Brighton Doctoral College for providing me with the Studentship Award and the Eastbourne Leisure Trust for providing a research grant. The finances have supported the research described in this thesis.

I consider myself extremely fortunate to have been given the supervisory '*Dream team'* with Neil, Mark and Peter. I was genuinely surprised when I got the phone call from you Neil, to inform me that I had been successful at interview. It was the easiest and best decision I have made to accept the offer and move to Eastbourne. Since then, you have all played a significant role in the researcher that I am today and I cannot thank you all enough for your support and guidance. I hope the future holds more collaborations between us all.

Neil, all I can do is echo the comments of your previous PhD students. Firstly, you made the transition of me leaving home for the first time and moving to Eastbourne a smooth experience, just one example of how you put my emotional wellbeing first. You allowed me to have full autonomy of my thesis whilst providing guidance on maintaining the '*PhD story'*. I think the highest compliment I can pay you is that by having you as a lead supervisor you made my PhD experience enjoyable.

Mark, your willingness to go above and beyond what is expected of a supervisor to help me, when you were extremely busy, has not gone unnoticed. The comments you provided on my work were always extremely detailed, helping me to progress.

Peter, your ability to look at a research problem in an entirely different way to anyone I know has made me a better researcher. It has been a pleasure to be able to pick your brain during the last 3 years, often over a piece of cake or a cider.

Thank you to the other members of the Environmental Extreme Laboratory team; Ash, Carl, Emily, Ben, Jess, Oli, Alan, Greg, Rebecca and Rosie. You have all contributed to my successes in my PhD journey. A special mention to Lisa who was the first PhD student to talk to me and make me feel welcome, when I arrived at the University of Brighton. Since that day, our friendship has become invaluable. To Jake, Beamsley would not have been the same without you and I am thankful for the support we gave each other. Thank you to my friends from back home; Surya, Amy, Steph and Becky. You were the people I needed when I no longer wanted to discuss ANOVA's and therefore you were a massive part in keeping me sane.

I would also like to show my appreciation for to my participants, who are owed the most important thank you. Without your help I would not have a thesis. The willingness of strangers to engage in research is something I will never forget.

I have saved my last thank you for my incredibly supportive family. It is without question that I would not have been able to produce the work in this thesis without you; Mum, Dad and Daniele. You have financially and emotionally supported every decision I have ever made and never doubted my ability to finish my PhD, even when I did. Know that the decisions I make are to make you proud of the daughter you raised and the big sister you were blessed with.

Declaration

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any other university for a degree, and does not incorporate any material already submitted for a degree.

Signed:

Date:

Contribution to the studies

Study 1 contribution was the designing and development of the heat illness susceptibility questionnaire, assisting the data collection for study 1, part a, coordinating the data collection for study 1, part b and completing all data analysis that are presented in this thesis. Studies 2-4 contribution was leading the study design, collection and analysis and where appropriate was the lead author for the write up of research publications.

Research publications

Waldock, K.A.M., Hayes, M., Watt, P.W. and Maxwell, N. S (2018) Physiological and perceptual responses in the elderly to simulated daily living activities in UK summer climatic conditions. *Public Health.* 1-8 https://doi.org/10.1016/j.puhe.2018.04.012

Conference proceedings

Waldock, K. A. M., Hayes, M., Watt, P. W., Maxwell, N. S. (2018). Comparison of the heat adaptations between the elderly and young using isothermic short term heat acclimation. International Conference on Physiological and Pharmacology of Temperature Regulation, Split, Croatia, 7th-12th October 2018.

Waldock, K. A. M., Hayes, M., Watt, P. W., Maxwell, N. S. (2018). The eldery's physiological and perceptual responses to physical and perceptual cooling during simulated activities of daily living in UK summer climatic conditions. International Conference on Physiological and Pharmacology of Temperature Regulation, Split, Croatia, 7th-12th October 2018.

Waldock, K. A. M., Hayes, M., Watt, P. W., Maxwell, N. S. (2017). Physiological and perceptual responses in the elderly to simulated daily living activities in UK summer climate conditions. International Conference of Environmental Ergonomics (ICEE), Kobe, Japan, 13th-17th November 2017.

Waldock, K. A. M., Willmott, A. G. B., Relf, R. L., Carroll, C., Hayes, M., Webborn, N., Cottingham, R. L., Watt, P. W., Maxwell, N. S. (2017). The validity and reliability of a heat illness susceptibility questionnaire (HIS-Q). British Association of Sport and Exercise Science (BASES) student conference, Plymouth, UK, 12-13th April 2017.

Chapter 1 Introduction

Two hundred and fifty thousand years ago, early *homo sapiens* experienced an extreme shift in environmental conditions from a cool environment to a tropical environment, over a short 100-year period (Tipton *et al.,* 2002; Taylor, 2014a). Consequently, the evolutionary process of natural selection leads to humans having a greater capacity to tolerate hot environments compared to cold, due to the direct influence of the hot environmental conditions (Tipton *et al.,* 2002; Lieberman, 2011; Taylor, 2014a). Through the natural selection process, both behavioural and physiological adaptations were required to protect against the harmful effects of heat (Tipton *et al.,* 2002; Taylor, 2014a). The most notable genotypic adaptation is the ability to sweat rather than pant to lose excess heat (Lieberman, 2011). The skin surface allows for greater heat loss compared to panting which is restricted to the surface area of the respiratory tract and is the heat loss mechanism for all non-human mammals (Lieberman, 2011). Furthermore, the human body has the ability to acquire phenotypic adaptation to the surrounding environment, for example through repeated exposure to hot environments humans can increase sweat loss (Tipton *et al.,* 2002; Taylor, 2014a). The combination of physiological (*i.e.,* genotypic and phenotypic) and behavioural thermoregulation maintains heat balance under hot conditions (Tipton *et al.,* 2002; Lieberman, 2011; Taylor, 2014a). Therefore, evolution and thermoregulatory evidence suggest that humans have the ability to adapt to a warmer climate. However, the extent of the new hot extremes in the Earth's climate is set to overwhelm the human body's physiological ability to thermoregulate.

The Earth's climate is warming, 2017 was the warmest year on record without the temperature increasing effects of El Niño (MET Office, 2018a). The summer of 2018 was the joint hottest summer on record in the United Kingdom (UK), and is predicted to be the 4th consecutive warmest year (MET Office, 2018b). Humans are capable of adapting to relatively minor changes in mean temperature (Taylor, 2014a). However, as the mean global temperature rises so does the frequency, severity and duration of heatwaves (Perkins *et al.*, 2012; Sanderson *et al.*, 2017). This presents a significant health risk to the general population, as heatwaves are the leading cause of death from an environmental disaster (Luber & McGeehin, 2008; Kenney *et al.*, 2014; Sanderson *et al.*, 2017). Mortality statistics from heatwaves highlight the catastrophic impact of such an event, with ~70,000 fatalities during the 2003 European heatwave (Robine *et al.*, 2008; Åström *et al.*, 2011), while a further ~55,000 fatalities occurred during a 2010 heatwave in Russia (Otto *et al.*, 2012). Additionally, the UK suffer from ~2000 heat-related deaths per year, and if effective action to adapt to climate change is not implemented, it is predicted to increase 5-fold by 2080, equating to ~12,700 preventable deaths (Hajat *et al.*, 2014).

The population at greatest risk of suffering from a heat-related death is the elderly, with up to 92% of excess deaths during heatwaves occurring in persons over the age of 65 (Conti *et al.*, 2005; Kenney *et al.*, 2014; Smith *et al.*, 2016; Mora *et al.*, 2017). Additionally, the elderly population are most at risk of developing other heat-related illnesses (Kenney *et al.,* 2014; Smith *et al.*, 2016; McGinn *et al.,* 2017). This is because heat illnesses escalate along a continuum, whereby minor heat illnesses; heat rash and cramps, can develop into severe heat illnesses; heat exhaustion, heat stroke and death, if untreated (Coris *et al.*, 2004; Heled *et al.*, 2004; Howe & Boden, 2007; Luber & McGeehin, 2008). Due to the escalating nature of heat illness, heat-related death is preventable, however, it relies upon people identifying minor heat illness signs and symptoms and having the knowledge of how to prevent them developing into life threatening conditions (Bouchama & Knochel, 2002; Howe & Boden, 2007; Public Health England [PHE], 2015). Coris *et al.* (2006) has pioneered research into the identification of heat illness symptoms with the development of the heat illness symptoms index (HISI), to quantify mild and moderate heat illness symptoms in athletes. To the author's knowledge, the HISI is the only attempt to quantify individual symptoms of heat illness with the application of an ascending severity scale. However, research in our laboratories has found several limitations with the HISI including; index design, selection of symptoms and scale sensitivity (Relf *et al.*, 2017). A reliable and valid tool for assessing minor heat illness signs and symptoms could reduce heat-related morbidity and mortality in various populations, including the most vulnerable, the elderly.

Unsurprisingly, elderly people represent the majority of general practitioner (G.P) and emergency visits during heatwaves (Kenney *et al.*, 2014; Smith *et al.*, 2016). Post-heatwaves, there is a sustained elevation in G.P visits for heat-related illnesses in the elderly population that is not paralleled in any other age group (Smith *et al.*, 2016). Consequently, there has been an emphasis for public health services to provide advice on how the elderly can maintain their health during periods of hot weather (World Health Organisation [WHO], 2011; PHE, 2015). Within the documents, there is valid heat-alleviating advice including, but not limited to; increasing fluid intake, seeking shade during the hottest parts of the day and keeping windows open at night (WHO, 2011; PHE, 2015). Furthermore, there is the advice to decrease activity levels (WHO, 2011; PHE, 2015), resulting in a reduction in metabolic heat production and the risk of heat illness (Sawka & Young, 2000). However, this message encourages sedentary behaviour, in a population that has the highest inactivity rates (British Heart Foundation [BHF], 2012; Sun *et al.,* 2013). Sustained sedentary behaviour can cause other health problems including; increasing the risk of type 2 diabetes, heart disease and obesity as well as social isolation, which can lead to depression (Kohl *et al.*, 2012; Taylor, 2014b). Additionally, less physically fit elderly people could be at a greater risk of heat illness (Semenza *et al.,* 1999; Taylor, 2014a).

Health messages should instead encourage safe exercise all year round, including during periods of hot weather.

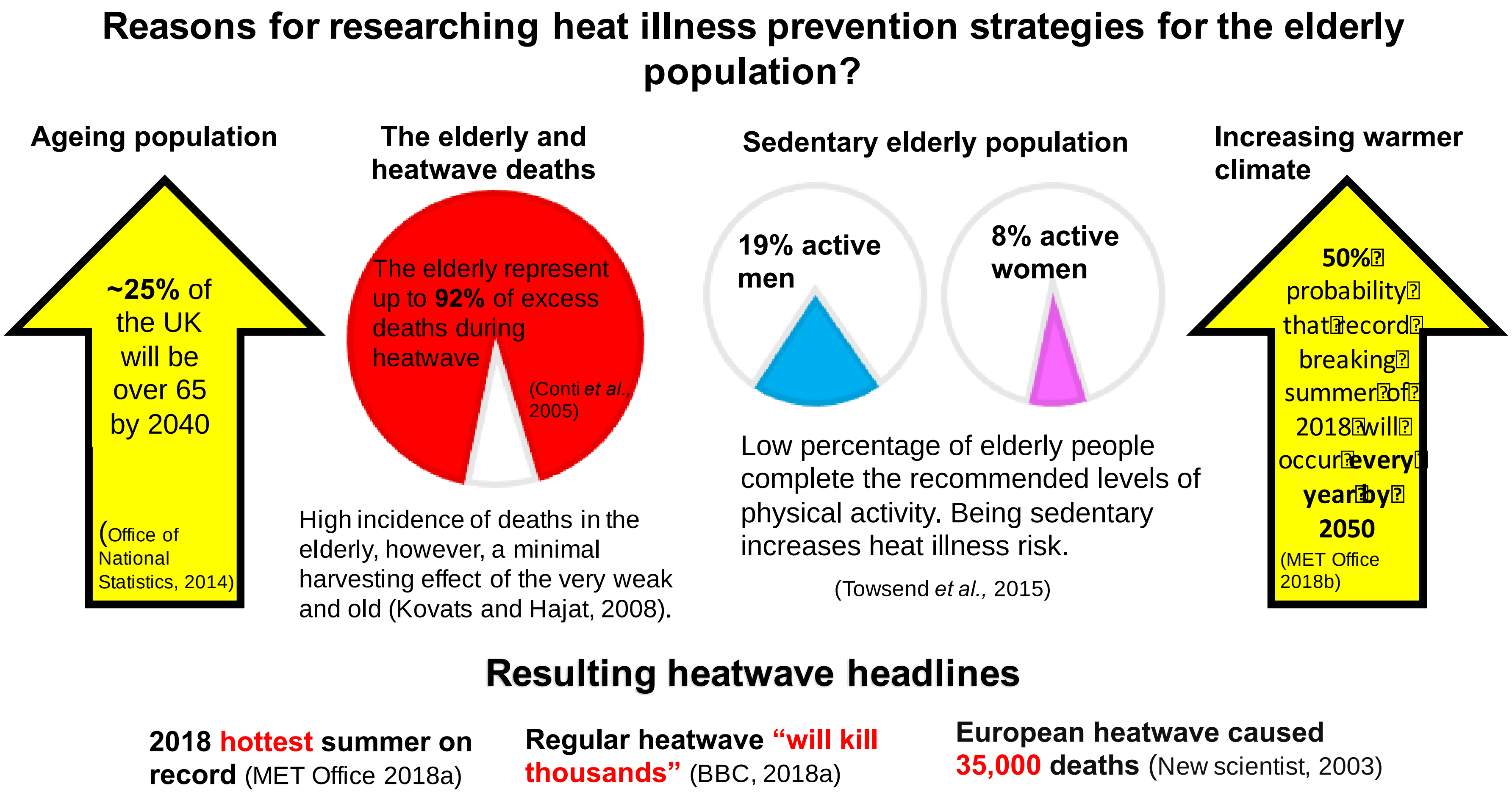
Current research into heat, exercise and elderly health has focused on comparing physiological responses to younger adults (Anderson & Kenney, 1987; Inoue *et al.*, 1995; Larose *et al.*, 2013ab; Stapleton *et al.*, 2014abc; Stapleton *et al.*, 2015; McGinn *et al.,* 2017; Notley *et al.,* 2017). It is now well established that elderly people have attenuated ability to dissipate heat due to their; decreased physical fitness, reduced cutaneous blood flow, deterioration in cutaneous function and decreased sweat gland output, resulting in a decrease in sweat rate compared to younger adults (Kenney & Munce, 2003; Holowatz *et al.,* 2010; Kenney *et al.*, 2014; Rida *et al.*, 2014; Kenney, 2017; Balmain *et al.,* 2018). However, the environments (>35°C and < 20% relative humidity [RH]) and the exercise intensities investigated in the age-comparative research do not accurately reflect the UK summer environment and comparison to activities of daily living of elderly people has not been completed (Larose *et al.*, 2013ab; Stapleton *et al.*, 2014bc; Stapleton *et al.*, 2015; McGinn *et al.,* 2017; Notley *et al.,* 2017). Investigating how the elderly respond physiologically and perceptually to UK summer environments will inform research that can specifically investigate heat-alleviating strategies to prevent heat-related illnesses in the elderly population. Furthermore, public health messages in the UK could be more targeted towards the elderly if the research had been derived from this population, using population relevant exercise-heat stress.

To date there has been extensive research into both acute and chronic heat-alleviating strategies for athletes (Ross *et al.,* 2013; Bongers *et al.*, 2014; Périard *et al.*, 2015; Ruddock *et al.,* 2017). Acute strategies include the use of internal and external; pre-cooling and per-cooling (cooling during exercise) (Lee *et al.*, 2008; Duffield *et al.*, 2009; James *et al.*, 2015; Tyler *et al.*, 2015; Stevens *et al.*, 2017). The purpose of these cooling strategies is to decrease core temperature (T_c), skin temperature (T_{sk}) and thermal sensation (TS) and increase core-to-skin temperature gradient (Bongers *et al.*, 2014). These physiological and perceptual changes can translate into improvements in exercise performance (Lee *et al.*, 2008; Duffield *et al.*, 2009; James *et al.*, 2015; Tyler *et al.*, 2015; Stevens *et al.*, 2017). Additionally, the risk of severe heat illness is reduced through implementing acute cooling strategies (Lee *et al.,* 2008; Bongers *et al.,* 2014; Ruddock *et al.,* 2017). Therefore, adapting a practical cooling strategy for the elderly could benefit individuals by delaying their progression along the heat illness continuum, thus preventing the onset of severe heat illnesses. Despite the potential practical benefits of cooling strategies, there is limited evidence with their use within an elderly population, and the focus to date has been on the safety limits of using electrical fans (Jay *et al.*, 2014; Gagnon & Crandall, 2017).

Heat acclimation (HA) is a chronic heat-alleviating intervention, which has been utilised as part of athlete preparations for competitions in thermally challenging environments (Chalmers *et al.*, 2014; Gibson *et al.*, 2015ab; Périard *et al.*, 2015; Racinais *et al.,* 2015; Willmott *et al.*, 2016; James *et al.*, 2017; Mee *et al.*, 2017). Research suggests that controlled-hyperthermia (*i.e.,* isothermic) is the optimal method for achieving heat adaptations (Taylor, 2014a; Périard *et al.*, 2015). These physiological adaptations include: a decrease in resting and exercise core temperature and heart rate, an earlier onset of sweating, increase in plasma blood volume, decreased rate of perceived exertion and enhanced cellular protection (Sawka *et al.,* 2011; Horowitz, 2014; Taylor, 2014a; Périard *et al.*, 2015). These adaptations lead to an increased heat loss capacity and heat tolerance, resulting in a decreased risk of heat illness (Armstrong & Maresh, 1991; Gosling *et al.*, 2008; Périard *et al.*, 2015; Racinais *et al.*, 2015; Minett *et al.*, 2016). In relation to the elderly population, the optimal and most palatable HA strategy for facilitating heat adaptations is currently unknown. Both active and passive methods have been investigated with mixed outcomes relating to the benefits for elderly people (Pandolf *et al.*, 1988; Armstrong & Kenney, 1993; Inoue *et al.*, 1999; Takamata *et al.*, 1999; Daanen & Herweijer, 2014). Furthermore, within the study methods, there are areas in which future chronic heat-alleviating research with the elderly population should be revised. Firstly, participants among some of the studies were under the age of 65 (Pandolf *et al.*, 1988; Armstrong & Kenney, 1993), above which is when an increase in heat-related morbidity and mortality is evident (Hajat *et al.*, 2014; Kenney *et al.*, 2014; Smith *et al.*, 2016). Secondly, exercise intensity was at a fixed percentage of maximum or peak oxygen consumption ($\dot{V}O_{2max}$ / $\dot{V}O_{2peak}$) (Inoue *et al.*, 1999; Takamata *et al.*, 1999). However, research has since found that isothermic HA could provide a more optimal method for heat adaptations (Taylor, 2014a; Périard *et al.*, 2015). Lastly, Daanen & Herweijer (2014) investigated a modified isothermic HA model, unfortunately no positive phenotypic adaptations developed in the elderly or young participants and this may have been due to insufficient heat exposure.

Research into maintaining physical activity and health for the elderly population in UK summer environments is of current national importance. This is due to headlines such as those depicted in figure 1.1, becoming increasingly more frequent in the media during periods of hot weather. There is the potential for the use of current acute and chronic heat-alleviating strategies used with athletes to be adapted for the elderly, with the aim to prevent heat illness during periods of hot weather. Such strategies should be used alongside public health messages of maintaining physical activity across the life span. This is due to the suggestion that as a population we are becoming increasingly reliant on heat-alleviating strategies (Tipton, 2018). The additional reliance is a consequence of not challenging our bodies enough, physically, to promote physiological adaptations to challenging environments and maintain thermoregulation during periods of heat stress (Tipton, 2018).

As well as this research having national significance, the findings will be applicable to the global elderly community as the impact of climate change effects Earth as a whole.



Reasons for researching heat illness prevention strategies for the elderly population?

Ageing population

~25% of the UK will be over 65 by 2040

(Office of National Statistics, 2014)

The elderly and heatwave deaths

The elderly represent up to **92%** of excess deaths during heatwave

(Conti *et al.*, 2005)

High incidence of deaths in the elderly, however, a minimal harvesting effect of the very weak and old (Kovats and Hajat, 2008).

Sedentary elderly population

19% active men

8% active women

Low percentage of elderly people complete the recommended levels of physical activity. Being sedentary increases heat illness risk.

(Towsend *et al.*, 2015)

Increasing warmer climate

50% probability that record breaking summer of 2018 will occur **every year by 2050**

(MET Office 2018b)

Resulting heatwave headlines

2018 hottest summer on record (MET Office 2018a)

Regular heatwave "will kill thousands" (BBC, 2018a)

European heatwave caused 35,000 deaths (New scientist, 2003)

Figure 1.1: Depiction of the reasons for completing heat illness prevention research with the elderly population.

Chapter 2 Literature review

The purpose of this literature review is to consider the current state of the research pertaining to the prevention of heat illness in the elderly population. Firstly, it will discuss the impact of climate change and an ageing population, from a global and national perspective. It will then explain autonomic and behavioural responses to heat stress in young healthy adults. Thirdly, the review will discuss how the ageing process effects thermoregulation. The review will then explore the current public health advice, as well as, the research-informed advice on how the elderly can avoid heat-related illness during periods of hot weather. Lastly, it will hypothesize how acute and chronic heat-alleviation strategies, used in athletic populations, may be modified for the use of elderly people to prevent the onset of severe heat-related illness.

2.1. Changing world

The world we are living in is changing. There is an increasingly hotter climate (Sanderson *et al.,* 2017), along with a growing ageing population (National Institutes of Health, 2016). These changes will have a negative impact on the prevalence of heat-related morbidity and mortality within the elderly, if effective interventions to prevent heat-related illness are not implemented.

2.1.1. Climate change

Global climate change

Between 1880-2012 climate change increased the global mean temperature by 0.85°C (Sanderson *et al.,* 2017). Depending on the climate change scenario, global temperature is predicted to continue to increase between 1.6-2.6°C, from pre-industrial levels, by 2100 (Sanderson *et al.,* 2017). The uncertainty into the extent of future mean global temperature increase is due to the process of modelling climate change scenarios (Intergovernmental panel on climate change, 2013). Climate change models differ in their predictions of the magnitude of impact of; greenhouse gas emissions, aerosols and natural changes in climate, when predicting future climates (Intergovernmental panel on climate change, 2013). Although humans are capable of adapting to this relatively minimal mean global temperature change, the consequence of an increasing warmer climate is the increase in frequency, intensity and severity of heatwaves and hot weather days (Perkins *et al.,* 2012; Kenney *et al.,* 2014; Arbuthnott *et al.,* 2016; Mora *et al.,* 2017; Sanderson *et al.,* 2017). Mora *et al.,* (2017) reviewed papers between 1980-2014, that reported cases of heat-related mortality due to the environment. The authors analysed the data to find the environments that presented cases of excess mortality and named it the *'deadly threshold'*. Currently, ~30% of the world's population will experience *'deadly threshold'* climatic conditions for 20 days a year, increasing to ~48% and ~74% under scenarios with drastically reducing and growing greenhouse gas emissions by 2100. Therefore, although an average increase in environmental temperature may not strain the thermoregulatory system, the heat stress caused by the hot weather days and heatwaves will.

Climate change and heatwaves

With an increasing global temperature, there will be a greater prevalence of heatwaves. The definition of a heat wave varies within the literature (Åström *et al.,* 2011; Perkins *et al.,* 2012), the MET Office uses; '*A marked unusual hot weather (max, min and daily average) over a region persisting at least two consecutive days during the hot period of the year based on local climatological conditions, with thermal conditions recorded above given thresholds'* (MET Office, 2018c). Heatwaves can be catastrophic and are the leading cause of death by an environmental disaster (Sanderson *et al.,* 2017). The effects of heatwaves are global; in 1995, 696 people died during a Chicago heat wave (Ebi & Meehl, 2007); in Europe, 70,000 people died during the 2003 heat wave (Robine *et al.*, 2008; Åström *et al.,* 2011); in 2010, an estimated 55,000 people died in Russia during a heat wave (Otto *et al.,* 2011). More recently, in 2015, over 3,000 people died during a heat wave in South Asia, with India and Pakistan amongst the countries impacted the most (Clark, 2015).

There is an overwhelming body of evidence of the global impact of heatwaves. Nevertheless, they are still considered a silent killer (Luber & McGeehin, 2008; Kenny *et al.,* 2018) due to the fact that heatwaves do not leave a wake of physical destruction like other environmental disasters (*e.g.,* tornados, hurricanes, wildfires and floods) (Luber & McGeehin, 2008). Recently, hurricane Irma received a lot of international media attention due to the amount of destruction caused by the high velocity winds and flooding (The Guardian 2017; Telegraph, 2017; The New York Times, 2017). Similarly, the recent wildfires in California received significant media attention due to the destruction of homes and loss of life (BBC News, 2018b; CBS News, 2018). In preparation for hurricanes and wildfires, state-wide mandatory evacuations are implemented (Settles, 2012). Currently, these measures are not governmental policy for heatwaves and due to their silent killer nature, people are unprepared for the life-threatening consequences of extremely high ambient temperatures.

UK climate change

The UK has not escaped the effects of an increasing warmer climate (Figure 2.1). Figure 2.1 represents mean temperature over three summers (2001, 2009, 2018) in the UK compared to the average summer temperature between 1961-1990 (MET Office, 2018d). In each year there was an increase in average temperature, with summer 2018 being the joint hottest summer in the UK and the hottest on record for England, with peak temperatures reaching 35.3°C in Kent (MET Office, 2018b). The UK Climate Projections

2018 document (UKCP18), provides the most recent predictions of UK climate under different greenhouse gas emission scenarios (MET Office 2018e). In a high emission scenario, the UK summer temperatures could be 5.4°C hotter by 2070 than the average summer temperatures between 1981-2000 (MET Office 2018e). There is also a 50% probability that summer temperatures will be as hot as the record-breaking summer of 2018 every year by 2050 (MET Office 2018).

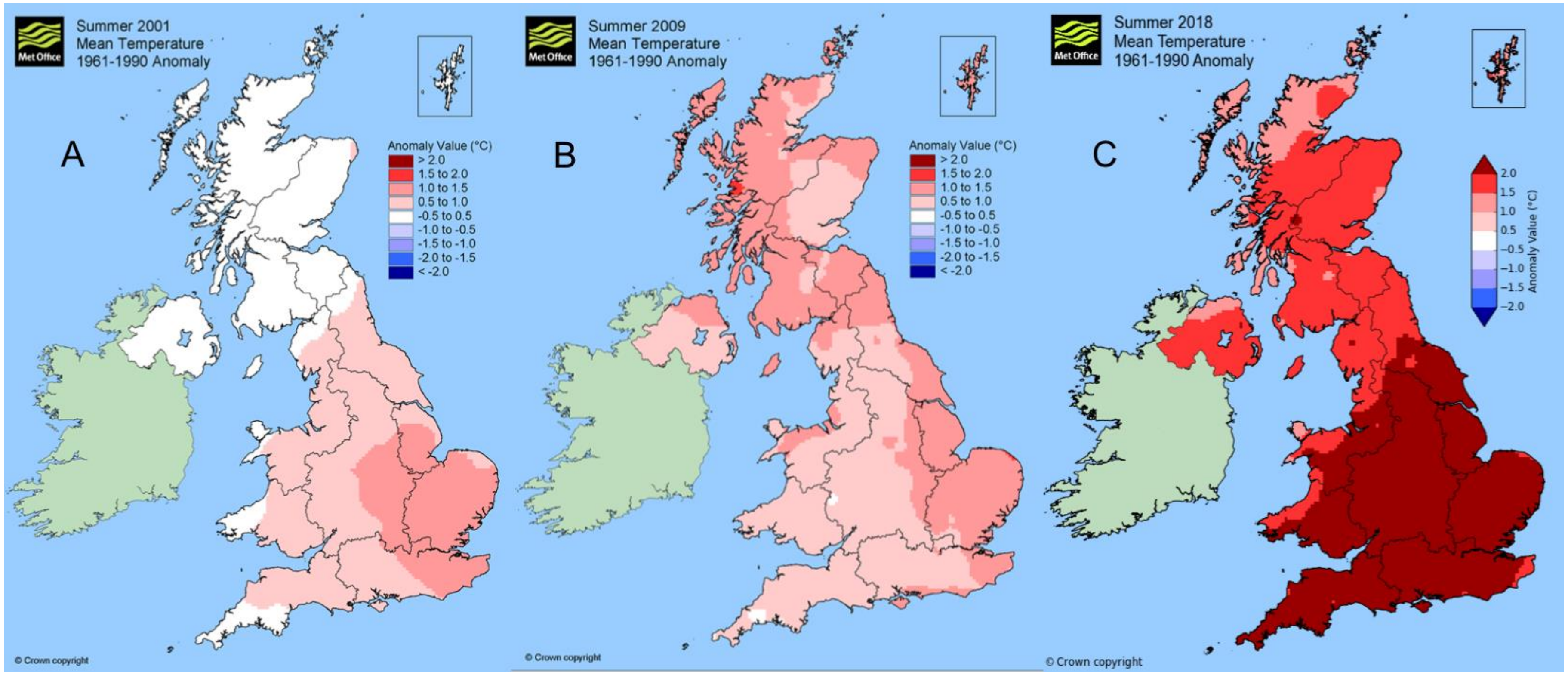


Figure 2.1: Represents mean temperature over three summers: A; 2001, B; 2009, C; 2018 in the UK compared to the average summer temperature between 1961-1990. Figure created from MET Office (2018d) pictures.

2.1.2. Ageing population

Global ageing population

As well as living in an increasingly hotter world, the world's elderly population is growing faster than any other age group (United Nations, 2015). People are living longer due to medical advances and adopting healthier lifestyles (United Nations, 2015). There were 617 million people over the age of 65 living in the world in 2016, representing 8.5% of the global population (National Institutes of Health, 2016). Population forecasts predict an increase in these statistics to 1.6 billion by 2050, representing 17% of the global population (National Institutes of Health, 2016). Furthermore, the number of people who are aged 80 and over (*i.e.,* oldest-old) is also increasing globally, with a predicted increase in the population from 125 million in 2015 to 434 million by 2050 (United Nations, 2015).

UK's ageing population

In the UK the over-65 population grew by 80% between 1951-2011 (Rutherford, 2012). Furthermore, current population statistics state that 11.8 million people over 65 live in the UK, representing 18% of the population (Office of National Statistics, 2017). The growth in the UK's ageing population is predicted to continue to increase, with an estimated 24.2% of people living in the UK being over the age of 65 by 2040 - equating to 16 million people (Office of National Statistics, 2014). The ageing population is expected to have economic, social and political implications on society (United Nations, 2015). One of these issues could be, how do we as a society protect our elderly population from the dangers of hot weather?

The impact of hot weather is evident in the number of heat-related deaths, which is currently ~2000 a year in the UK (Hajat *et al.,* 2014). The mean predicted increase in heat-related deaths is ~66%, ~257% and ~535% in the 2020's, 2050's and 2080's. These suggested increases equate to 3,281, 7,040 and 12,538 mean heat-related deaths (Hajat *et al.,* 2014). Figure 2.2 highlights that there is minimal risk of heat-related mortality if a person is under the age of 65 (Hajat *et al.,* 2014). Furthermore, it highlights that risk increases with advanced age, for example in the 2000's there were 4 heat-related deaths for every 100,000 people in the UK in the 65-74 age group, compared to 79 deaths in the 85+ age group. This data indicates that the elderly are the most vulnerable to heat-related mortality. Additionally, in line with the predicted increase in number of hot weather days, there is increased risk of heat-related death with time, therefore it can be predicted that there will be future vulnerability for the elderly (Hajat *et al.,* 2014).

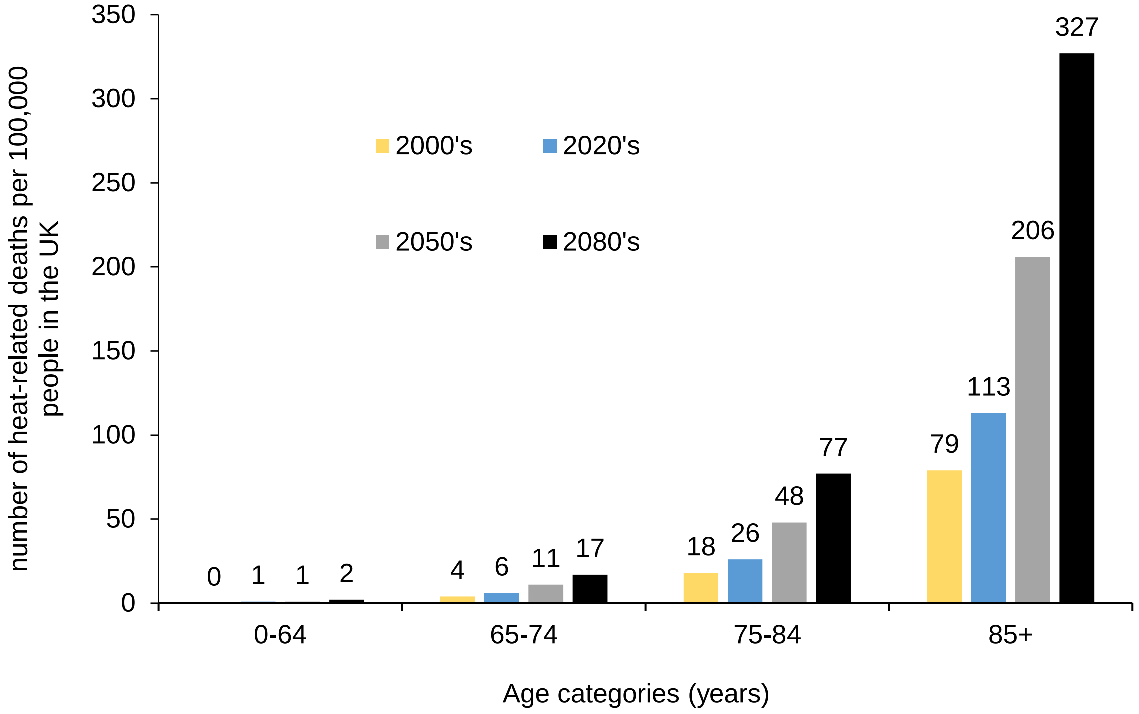


Figure 2.2: Mean estimate of heat-related deaths in the UK per year per 100,000 people, by age group in the UK. Figure reproduced from Hajat *et al.,* (2014).

Classification of the elderly

As well as advanced age increasing heat stress vulnerability, so does the elderly person's classification. In the UK, elderly people can be classified under three different categories; entering old age, transitional phase and frail (Department of Health, 2001). These groups have a progressively increased vulnerability to heat stress. People are defined as entering old age when they have completed their career in paid employment and/or child rearing (Department of Health, 2001; British Heart Foundation [BHF], 2010). These people are active and independent and there is no consensus on the age a person is when they become classified as entering old age, it can be as young as 50 years old or at state retirement age (currently between 60-65 yrs, Government, 2018) (Department of Health, 2001; BHF, 2010).

Elderly people who are frail have full-time care, often in care homes, and have needs associated with their poor health (Department of Health, 2001; BHF, 2010). These needs can develop from physical illness such as stroke or heart attack or through mental illnesses such as dementia and Alzheimer's (Department of Health, 2001; BHF, 2010). Frailty tends to happen in the later stages of life, 80+ years (Department of Health, 2001; BHF, 2010). All ages for the classifications are given as guidelines, as there are elderly people that remain physically active and independent well into late old age and vice versa where younger older people are dependent on full-time health care (Department of Health, 2001; BHF, 2010).

2.2. Thermoregulation

An increasing warmer climate will challenge the body’s ability to thermoregulate and maintain a heat balance. This section will review autonomic and behavioural thermoregulation of young healthy adults. Thermoregulation is the homeostatic measure for regulating core body temperature. Whilst at rest, homeostasis maintains a core body temperature of 37.0 ± 1.0°C (Sawka & Young, 2006; Cheung, 2010; Parsons, 2014; Balmain *et al.,* 2018). When thermoregulation is challenged, via external (*i.e.,* high or low environmental temperature) or internal (*i.e.,* higher metabolic heat production) factors, the parameters of a normal core temperature are extended to between 35-39°C (Sawka & Young, 2006; Taylor, 2006; Parsons, 2014; Balmian *et al.,* 2018). However, if core temperature is < 35°C (hypothermia) or > 39°C (hyperthermia) thermoregulation is no longer maintained and severe cold and heat-related injuries or illness may develop (Sawka & Young, 2006; Taylor, 2006).

The pre-optic anterior hypothalamus (POAH), located within the brain, has the function of maintaining thermal homeostasis (Sawka & Young, 2006; Sawka *et al.,* 2011; Tansey & Johnson 2015). The POAH detects temperature changes in the blood perfusing the brain, whilst also relying upon thermoreceptors located within the peripheral (*e.g.,* skin) and central nervous system (CNS) (*e.g.,* spinal cord) to send afferent signals regarding temperature changes of the external and internal environment (Sawka & Young, 2006; Sawka *et al.,* 2011; Tansey & Johnson 2015). Whilst there are other thermoregulation theories, the most accepted model of thermoregulation is the *‘set point’ theory.* The *‘set point’* theory proposes that when the blood or the afferent signals from the thermoreceptors detect a temperature above the *‘set point’* threshold then a ‘*load error’* has occurred (Figure 2.3) (Sawka & Young, 2006; Sawka *et al.,* 2011). The POAH then initiates the required behavioural and physiological responses to effectively maintain a normal core temperature (Sawka & Young, 2006; Sawka *et al.,* 2011). When core temperature is too high the efferent response is to lose the excess amount of heat being stored, this is to prevent the onset of heat illness (Sawka & Young, 2006; Sawka *et al.,* 2011). The efferent responses are explained in further detail in the autonomic (Section 2.2.2) and behavioural thermoregulation (Section 2.2.3) sections.

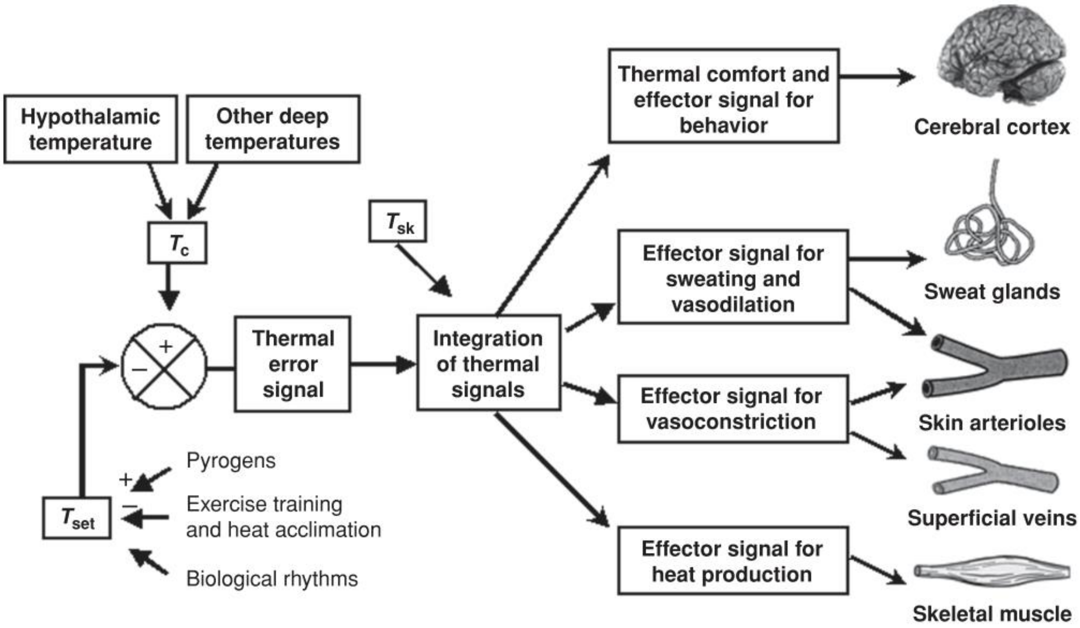


Figure 2.3: Thermoregulation, T_c; core temperature, T_{set}; set point temperature, T_{sk}; skin temperature (Sawka & Young, 2006).

.2.1. Heat balance

Core temperature increases when body heat storage is greater than body heat loss (Parsons, 2014; Tansey & Johnson, 2015; Charkoudian, 2016). This is either due to a high ambient temperature and/or high metabolic heat production (Tansey & Johnson, 2015; Charkoudian, 2016). Consequently, for the body to regain a thermal equilibrium it either has to increase the amount of heat lost through radiation, conduction, convection or evaporation (*i.e.,* autonomic thermoregulation) (Parsons, 2014; Tansey & Johnson, 2015; Charkoudian, 2016), or decrease the amount of heat gained from the environment by removing itself from the heat or decreasing the amount of metabolic heat production through a reduction in physical activity (*i.e.,* behavioural thermoregulation) (Schlader *et al.,* 2010; Tansey & Johnson, 2015). The balance between heat loss and heat gain is summarised in the heat balance equation (Equation 2.1).

Equation 2.1: Heat balance equation (Kenny & Jay, 2013)

$$S\ (\text{Watts}) = M - (\pm W) \pm (R + C) \pm K - E$$

Where: S = rate of body heat storage in Watts, M = rate of metabolic energy expenditure, W = mechanical work, R + C = rate of radiant and convective energy exchanges, K = rate of conduction, E = rate of evaporative loss.

Humans are inefficient at completing mechanical work, with the most efficient tasks only utilising 20% of energy for work (Sawka & Young, 2006; Kenny & Jay, 2013). The remainder of energy is released within the body as heat (Kenny & Jay, 2013). This heat is referred to as metabolic heat production ($\dot{H}_{prod}$) and is the difference between metabolic energy expenditure (M) and the energy used to complete mechanical work (W) (M-W) (Kenny & Jay, 2013).

When $\dot{H}_{prod}$ is equal to heat dissipation then the environmental conditions and exercise intensity are defined as compensable and thermal homeostasis is maintained (Sawka *et al.,* 2011). Therefore, a steady-state core temperature is sustained. However, when $\dot{H}_{prod}$ exceeds that rate in which heat is being dissipated then the environmental and exercise conditions are uncompensable (Cheung *et al.,* 2000). Uncompensable conditions are those in which the amount of evaporative heat loss required to maintain thermal homeostasis is greater than the maximal evaporative capacity of the environment (Cheung *et al.,* 2000). Consequently, body heat storage accumulates, increasing core temperature until exhaustion or there is a decrease in environmental temperature (Cheung *et al.,* 2000). There are two methods for calculating body heat storage, during compensable and uncompensable conditions, direct and indirect calorimetry.

Direct calorimetry

The most accurate method for measuring body heat storage and therefore the change in body heat content over time is direct calorimetry (Snellen *et al.,* 1983; Kenny & Jay, 2013; Kenny *et al.,* 2017). Direct calorimetery utilizes whole body calorimeters and simultaneously calculates the internal heat generated (*i.e.,* metabolic heat production) and the total heat being lost to the environment (*i.e.,* heat dissipation) (Snellen *et al.,* 1983; Kenny & Jay, 2013; Parsons, 2014; Kenny *et al.,* 2017). The continuous measure of heat produced *vs*. heat loss gives an accurate measurement of the heat balance equation (Snellen *et al.,* 1983; Kenny & Jay, 2013; Kenny *et al.,* 2017).

Although, whole body direct calorimetry is the gold standard measure for determining body heat storage, it does have its limitations. Firstly, the equipment required to conduct direct calorimetry is expensive, therefore, the use within the literature is limited to a few select laboratories (Kenney *et al.,* 2015; Kenny *et al.,* 2017). Furthermore, whilst direct calorimetry can provide accurate measurements for resting metabolism and steady-state aerobic exercise, metabolic energy expenditure is not adequately measured during intermittent exercise (Parsons, 2014; Kenney *et al.,* 2015; Kenny *et al.,* 2017). This is because direct calorimetry cannot calculate rapid changes in metabolic energy expenditure, that occur during intermittent exercise (Kenney *et al.,* 2015; Kenny *et al.,* 2017). Lastly, in addition to the body heat loss that is being calculated, there is heat being produced by the exercise equipment within the calorimeter (Kenney *et al.,* 2015). The additional heat needs to be accounted for when calculating body heat storage (Kenney *et al.,* 2015). Therefore, it has been suggested that it is easier and less expensive to measure energy expenditure via indirect calorimetry (Kenney *et al.,* 2015).

Indirect calorimetry

Indirect calorimetry is the most accurate way of determining metabolic energy expenditure and therefore, $\dot{H}_{prod}$ when direct calorimetry is unavailable (Equation 2.2) (Kenny & Jay, 2013). Open-circuit spirometry is the most common method for determining metabolic energy expenditure during exercise (Kenny *et al.,* 2017). The open-circuit spirometry method was developed by Voit and Pettenkofer in the 1800's (Kenny *et al.,* 2017). The technique was pioneering as it allowed the measurement of oxygen (O_2) consumption and carbon dioxide (CO_2) production (Kenny *et al.,* 2017). Indirect calorimetry utilises the principle that the rate of O_2 and CO_2 exchanged in the lungs equates to the O_2 used and CO_2 released within the body (Kenney *et al.,* 2015; Kenny *et al.,* 2017). Therefore, the calculation of the respiratory exchange between O_2 and CO_2 provides an estimation of energy expenditure (Kenney *et al.,* 2015).

Similar to direct calorimetry, indirect calorimetry has its limitations. Firstly, in order for accurate measurements of energy expenditure, the exercise needs to be aerobic due to respiratory gas from anaerobic exercise underestimating energy expenditure (Kenney *et al.,* 2015). Furthermore, expired air via the open-circuit spirometry could escape through connective tubing, mouth pieces and unsecured nose clips leading to inaccurate estimation of energy expenditure (Parsons, 2014). Thirdly, experimental error could also lead to inaccurate results, for example the process of measuring expired air could differ between experimenters and/or how experimenters calibrate the gas analyser (Parsons, 2014). Lastly, indirect calorimetry does not measure metabolic heat production, therefore inaccuracies in measuring both energy expenditure and external work will lead to inaccurate estimation of metabolic heat production (Parsons, 2014; Kenny *et al.,* 2017). Therefore, it is essential to minimise the aforementioned limitations prior to data collection.

Equation 2.2: Calculation for metabolic energy expenditure (Kenny & Jay, 2013)

$$\mathrm{M} = \frac{\dot{\mathrm{V}}\mathrm{O}_2\left(\frac{\mathrm{RER}-0.7}{0.3}\ \mathrm{e_c}\right)+\left(\frac{1-\mathrm{RER}}{0.3}\ \mathrm{e_f}\right)}{60}\mathrm{Watts}$$

Where: M is the metabolic energy expenditure, $\dot{V}O_2$ is volume of oxygen measured in $L.min^{-1}$, RER is the respiratory exchange ratio, e_c is the caloric equivalent per litre of oxygen for the oxidation of carbohydrates (21130 J), and e_f is the caloric equivalent per litre of oxygen for the oxidation of fat (19630 J).

2.2.2. Autonomic thermoregulation

The calculation of heat lost to the environment during direct calorimetry is an assessment of the body's total heat loss through: radiation, conduction, convection and evaporation

(Kenny & Jay, 2013; Parsons, 2014). Heat is transferred down a temperature gradient, whereby, something that has a greater temperature will transfer the additional heat to that which is cooler (Parsons, 2014). In conduction, this is when two solid objects are in contact and one has a greater temperature compared to the other (Bligh & Johnson, 1973; Kenny & Jay, 2013; Tansey & Johnson, 2015). Similarly, convection is the transfer of heat from a solid to a fluid, which includes; water, air and blood. The rate of heat transfer via convection is increased if the surrounding water or air has a greater movement compared to the solid (*e.g.,* wind) (Bligh & Johnson, 1973; Kenny & Jay, 2013; Tansey & Johnson, 2015). There is radiant heat loss when the surrounding environmental temperature is lower than body temperature (Bligh & Johnson, 1973; Kenny & Jay, 2013; Tansey & Johnson, 2015). Heat loss through radiation, conduction and convection is collectively known as dry heat exchange (Bligh & Johnson, 1973; Kenny & Jay, 2013; Tansey & Johnson, 2015). Evaporation is when liquid transitions into a vapour. When a person sweats the evaporation of sweat transfers excess body heat into a vapour (Bligh & Johnson, 1973; Kenny & Jay, 2013; Tansey & Johnson, 2015) (Figure 2.4). During rest, 80-90% of heat loss is via dry heat exchange, this value significantly decreases during exercise to 20%, due to 80% of heat loss during exercise being via evaporation (Kenney *et al.,* 2015). Figure 2.4 represents the interaction of heat loss mechanisms during exercise performed outside.

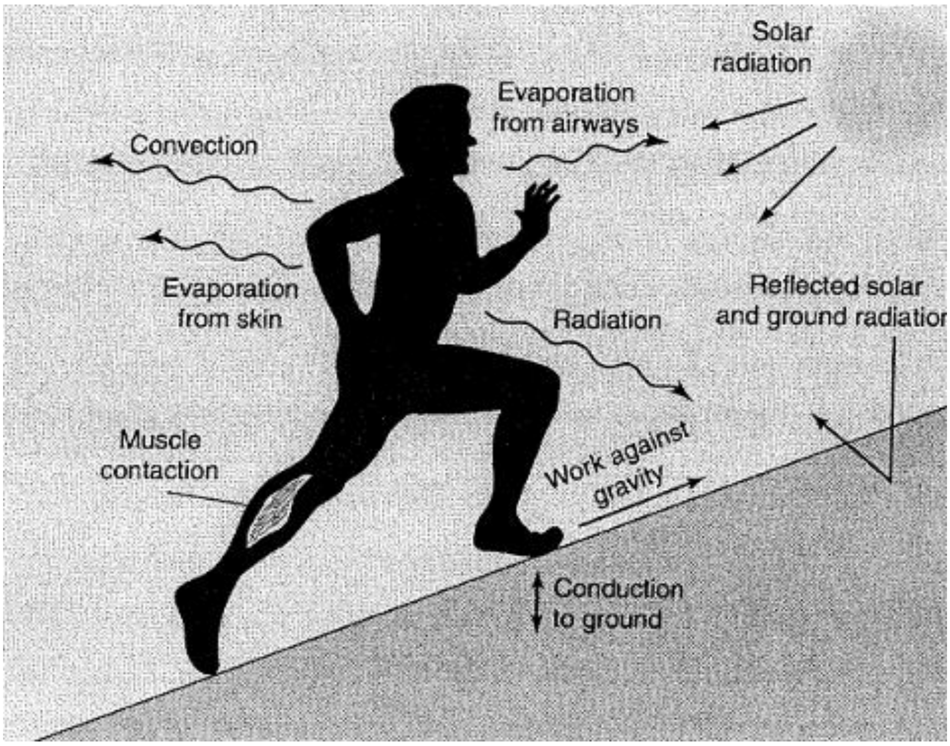


Figure 2.4: The avenues of heat exchange with the environment, whilst performing exercise outside (Sawka & Young, 2006).

When environmental temperature is near or above core temperature, the body utilises convective and evaporative heat loss (Holowatz *et al.,* 2010; Kenney & Jay, 2013; Tansey

& Johnson, 2015). When core temperature rises, there is an autonomic response to increase skin blood flow (SkBF) (Holowatz *et al.,* 2010; Tansey & Johnson, 2015). The mechanism for SkBF increase is predominately (>80%) via the activation of the sympathetic active vasodilator system and the remainder of the increase is through the inhibition of the sympathetic vasoconstrictors (Charkoudian, 2016). Active vasodilation is mediated by the co-transmission of acetycholine and an unknown neurotransmitter(s) from sympathetic cholinergic active vasodilator nerves (Holowatz *et al.,* 2010; Tansey & Johnson, 2015; Charkoudian, 2016). Acetylcholine primarily mediates the sweating response and facilitates the initial phases of vasodilation, and the unknown neurotransmitter(s) mediates the remainder of active cutaneous vasodilation (Holowatz *et al.,* 2010). Although the specific neurotransmitter(s) for vasodilation currently remain elusive, research has identified the importance of nitric-oxide (NO) for maximum SkBF, as its inhibition can reduce SkBF by up to 40% in young healthy adults (Holowatz *et al.,* 2010). There is also a role for cyclo-oxygenase (COX)-dependent vasodilation and SkBF, whereby the inhibition of COX attenuates vasodilation (Holowatz *et al.,* 2010). These pathways alongside the unknown neurotransmitter(s), provide the maximum increase in SkBF. The greater cutaneous blood flow results in excess heat being transferred from the core to the skin, down the temperature gradient (Holowatz *et al.,* 2010; Tansey & Johnson, 2015; Charkoudian, 2016). Furthermore, the greater SkBF heats up the skin which increases the thermal gradient between the skin and the environment, therefore dissipating the excess heat via convection when environmental temperature is below skin temperature (Sawka *et al.,* 2011; Parsons, 2014; Tansey & Johnson 2015).

The most effective mechanism for heat loss when external temperature exceeds core temperature is evaporation of sweat (Sawka *et al.,* 2011; Taylor, 2014a; Tansey & Johnson, 2015). Evaporation is the transfer of heat from the body to the environment by converting sweat molecules on the skin into vapour (Kenny & Jay, 2013; Tansey & Johnson, 2015). Thermal sweating is initiated when core temperature increases to an individual’s sweating threshold (Shibasaki *et al.*, 2006; Shibasaki & Crandall, 2010; Sawka *et al.,* 2011). Firstly, the neurotransmitter; acetylcholine is released by the cholinergic sudomotor nerves. Proceeding acetylcholine release, it binds to muscarinic receptors on the eccrine gland to activate sweating (Shibasaki *et al.*, 2006). Sweat rate, and therefore heat loss capacity, is highly individualised due to the quantity and size of sweat glands among different people (Shibasaki *et al.*, 2006; Tansey & Johnson, 2015). The number of sweat glands can range from 1.6 - 4.0 million and the diameter and length can range from 30 - 50µm and 2 - 5mm (Shibasaki *et al.,* 2006; Tansey & Johnson 2015). There is a significant positive correlation (*r* =0.81) between the size of a sweat gland and the maximum sweat output that the gland can produce (Sato & Sato, 1983). Consequently, the larger and greater number of sweat glands an individual has, the greater genetic capacity they have for sweating and heat loss.

This is evidenced by the variation in the total maximum sweating that can be achieved, with sweat rates in excess of 3 L.h^{-1} and an average sweat rate ~1.4 L.h^{-1} (Shibasaki *et al.*, 2006). For every litre of sweat evaporated, 680 watts (W) / 580 kcal of heat is lost, thus, if total sweat rate is reduced, the total capacity to lose heat is also reduced (Wenger, 1972; Kenney *et al.,* 2015).

Convective and evaporative heat loss mechanisms place substantial strain on the cardiovascular system (Sawka *et al.,* 2011; Charkoudian, 2016). The change from a thermoneutral to a high cutaneous blood flow for convective heat loss can lead to venous blood pooling (Charkoudian, 2016). Additionally, high sweat rates, without adequate fluid replacement, will lead to dehydration and a decrease in plasma volume, resulting in a decrease in venous return (Sawka *et al.,* 2007; Cheuvront & Kenefick, 2014; Charkoudian, 2016). Costill & Fink (1974) investigated the effect of decreasing body weight by 4% over 2 hours either via; exercise exposure in normothermic conditions or by intermittent extreme heat exposure (65-75°C) on plasma volume. Findings suggested a post exposure decrease in plasma volume of 16-18% in both conditions. As a consequence, to a decreased plasma volume, there is increased cardiovascular strain to maintain cardiac output (Q_c) and arterial pressure (Sawka *et al.,* 2011; Charkoudian, 2016). Therefore, heart rate at rest (+7 b.min^{-1}, Crandall & Wilson, 2015), and at a given intensity (+20 - 30 b.min^{-1}, Figure 2.5, Rowell *et al.,* 1966) are elevated during heat stress and vasoconstriction is minimised to maintain Q_c and arterial pressure (Sawka *et al.,* 2011; Charkoudian, 2016).

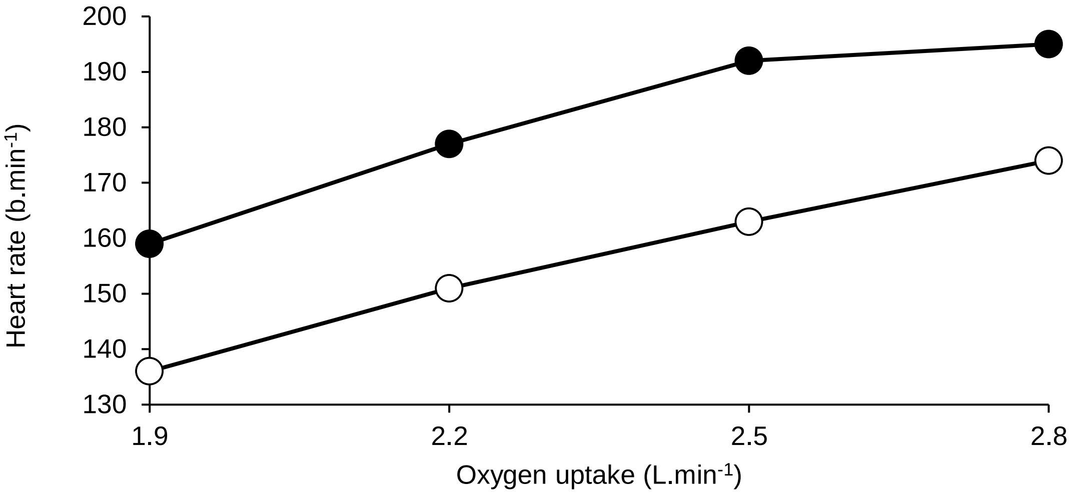


Figure 2.5: Impact of graded aerobic exercise on heart rate during hot (43.3°C) (closed circles) and thermoneutral conditions (25.6°C) (open circles). Data taken from Rowell et al., (1966).

Although there is an increase in cardiovascular strain, the heat loss mechanisms are vital for maintaining thermal homeostasis and health during periods of hot weather and/or intense exercise (Sawka & Young, 2006; Kenny & Jay, 2013; Tansey & Johnson, 2015; Charkoudian, 2016). A body with no heat loss mechanism would store all metabolic heat produced, in addition to the heat gained from the environment (Parsons, 2014). When the heat loss mechanisms of: radiation, conduction, convection and evaporation are inhibited or at maximum heat loss capacity for reasons such as: high relative humidity, high environmental temperature, high metabolic heat production and reduced capacity to sweat, then the body will start to store heat and core temperature will rise (Kenny & Jay, 2013; Parsons, 2014).

2.2.3. Behavioural thermoregulation

Behavioural thermoregulation is the process of establishing the optimum conditions for heat exchange between the environment and the body, and depending on the circumstance (*i.e.,* the environmental conditions, task being completed and external clothing) this could include situations requiring heat loss, gain, or balance (Schlader *et al.,* 2010; Flouris, 2011). Due to the near infinite number of conscious behaviours available to prevent the rise of core temperature, it is considered the '*first line of defence'* in maintaining a heat balance (Schlader *et al.,* 2010; Flouris, 2011; Schlader, 2014; Flouris & Schlader, 2015). Figure 2.6 represents how autonomic and behavioural thermoregulation respond to maintain heat balance across environmental temperatures (Schlader, 2014). Figure 2.6 also highlights how behaviour thermoregulation responds before the need for autonomic responses (*i.e.,* shivering/ sweating), depending on the environment. Behavioural responses include; the removal of excess clothing, allowing for: less insulation, less sweat absorption by the clothing and more skin exposure, resulting in a greater sweat evaporative surface area (Cheung *et al.,* 2000; Schlader *et al.,* 2010; Sawka *et al.,* 2011). Additionally, individuals can remove themselves from the heat exposure by seeking; shade (Schlader *et al.,* 2010; Flouris, 2011; Sawka *et al.,* 2011), or a cooler environment such as, an air-conditioned room (Smoyer-Tomic & Rainham 2001; Schlader *et al.,* 2010; Kenney *et al.,* 2014). Furthermore, individuals can reduce physical activity levels, consequently metabolic heat production is reduced requiring less excess heat dissipation (Sawka & Young, 2006; Schlader *et al.,* 2010; Flouris & Schlader, 2015).

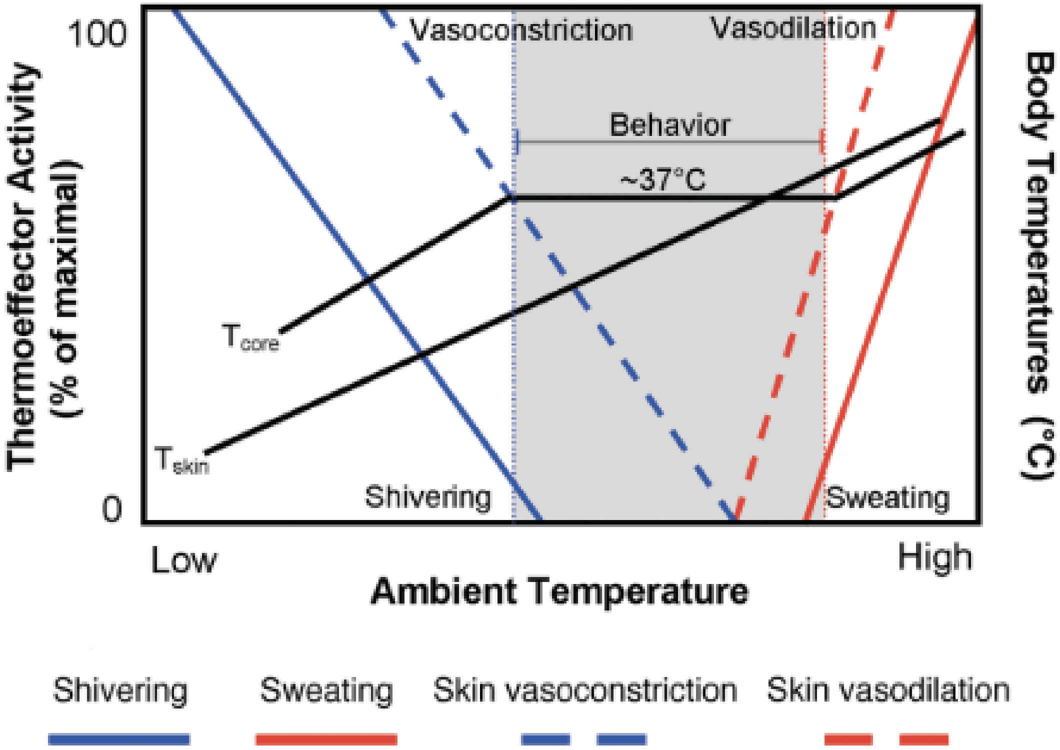


Figure 2.6: Relationships between changes in body temperatures (skin temperature [T_{skin}] and core temperature [T_c]) and autonomic thermoregulation (*i.e.,* shivering, sweating, skin vasoconstriction, and skin vasodilation) when humans are given the opportunity to implement behavioral thermoregulation (Schlader, 2014). The grey shaded area of the figure represents how behavioural thermoregulation can maintain a core temperature of approximately 37°C across a range of ambient temperatures before autonomic response of shivering and sweating are required at more extreme ambient temperatures.

Schlader *et al.,* (2009) investigated the driver of thermoregulatory behaviour at rest in young adults. The '*shuttle-box'* experiment enabled the participants to move freely between a hot environment (45°C, 10% relative humidity [RH]) and a cool environment (10°C, 50% RH) at their own discretion. Participants were sat on a stool that was attached to an automated conveyor belt, that the participant activated to move them from the hot to the cool environment (H→C) when they felt 'too warm' and vice versa (C→H) when they felt 'too cool'. Rectal temperature (T_{re}), mean skin temperature (T_{sk}) and thermal sensation (TS) were monitored throughout the experiment. The strength of the research design, the ability to freely move from one environment to the other, allowed for greater interpretation of the physiological and perceptual state of an individual at the point of consciously deciding to change the environment to improve thermal comfort (*i.e.,* thermoregulatory behaviour). The main findings were; T_{re} was not significantly different at the point of exit from H→C to C→H environments, 37.0 ± 0.2°C *vs.* 37.0 ± 0.2°C. However, T_{sk} and TS were significantly higher from H→C compared C→H (34.0 ± 1.1°C *vs.* 29.4 ± 0.9°C and 7.3 ± 0.6 *vs.* 3.0 ± 0.6) (Figure 2.7). Schlader *et al.,* (2013) completed the same experiment with the addition of oesophageal temperature (T_{oe}), as a faster responding core temperature measurement.

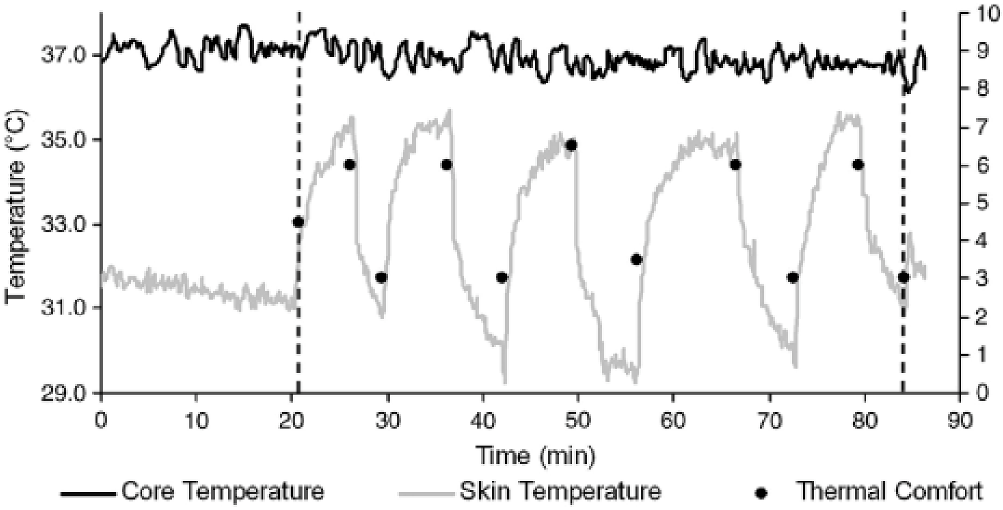


Figure 2.7: Core temperature (*i.e.,* rectal temperature), skin temperature and thermal comfort during the '*shuttle-box'* experiment as a function of thermoregulatory behaviour in one subject. Dashed lines represent the beginning (left) and completion (right) of the '*shuttle- box'* experiment. Data from Schlader *et al.,* (2009), figure from Schlader *et al.,* (2010).

Similar, to Schlader *et al.,* (2009) T_{re} was not different between H→C and C→H (37.1 ± 0.2°C *vs*. 37.1 ± 0.2°C) and T_{oe} was only slightly lower in H→C compared to C→H (36.8 ± 0.2°C *vs*. 36.9 ± 0.2°C). Also similar to Schlader *et al.,* (2009) was the difference in T_{sk} at the point of exit from H→C compared to C→H environments, 35.0 ± 0.6°C *vs.* 28.4 ± 0.9°C. Schlader *et al.,* (2013) measured TS and thermal comfort (TC). TS was significantly different between H→C and C→H (warm *vs*. cool), TC was not different between groups, both groups felt an equal level of discomfort at the point of initiating thermoregulatory behaviour (between '*slightly uncomfortable'* and '*uncomfortable*'). These findings suggest that the driver of thermoregulatory behaviour at rest is changes in thermal perception (*i.e.,* TS and TC) initiated by changes in T_{sk} (Figure 2.8).

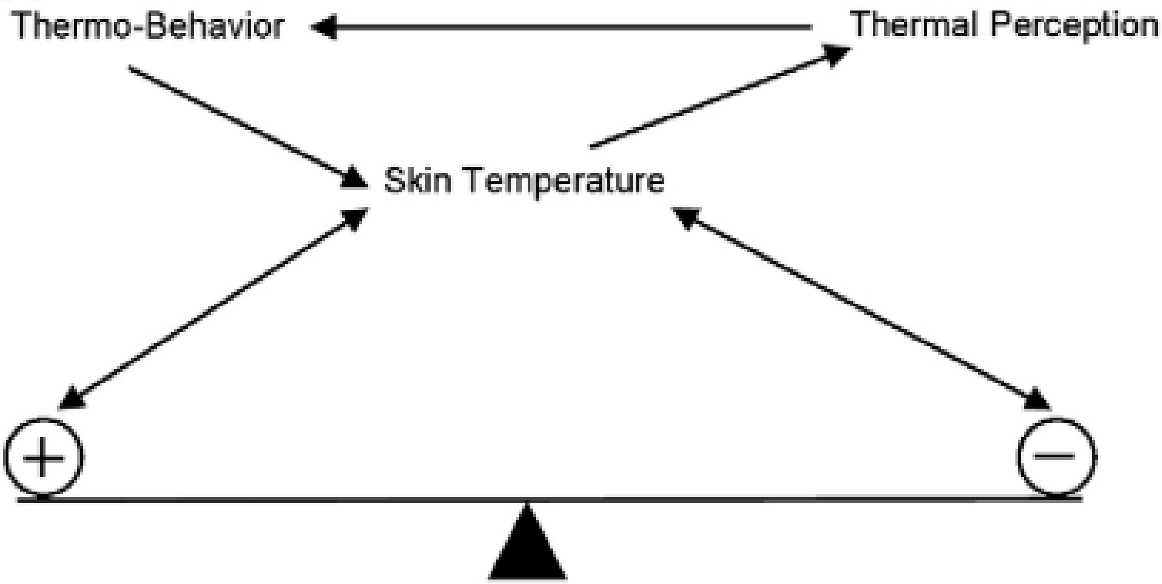


Figure 2.8: Behavioural thermoregulation during rest. The balance represents core temperature, the plus (+) represents an increase in core temperature and the minus (-) represents a decrease in core temperature (Schlader *et al.,* 2010).

Vargas *et al.,* (2018) continued the research into the drivers of initiating thermoregulatory behaviour. In a repeated measures design, participants completed 60-min of passive heat exposure to a 32°C, 20% RH environment and a 42°C, 20% RH. Participants received 30-s of neck cooling if they clicked a button 100 times. The main finding was a significant difference in the number of clicks from 20-min in to passive heat exposure onwards (42°C; 180 ± 155 clicks, 32°C; 0 ± 0 clicks). There was also a difference in T_{sk} throughout the trials, with an end T_{sk}; 42°C; 36.3 ± 0.5°C and 32°C; 34.5 ± 0.5°C. Furthermore, core temperature, measured via gastro intestinal pill (T_{gi}), was not different from baseline for the first 50-min of the 42°C trial. The perceptual results were; a significant increase in discomfort (3.5 ± 0.9 *vs*. 2.5 ± 0.4) and warmth (6.2 ± 0.3 *vs*. 5.1 ± 0.4) in the 42°C compared to 32°C. This data suggests that participants were more motivated to implement thermoregulatory behaviour (*i.e.,* greater number of button clicks to receive neck cooling) when their T_{sk} was greater and when they felt more uncomfortable and hotter. These results support Schlader *et al.,* (2009 & 2013) that also found T_{sk} to be the driver of thermoregulatory behaviour at rest.

When thermoregulatory behaviour is assessed during self-paced exercise in hot and cold environments, athletes reduce and increase their exercise intensity (Parsons, 2014). These behaviours positively affect thermoregulation, whereby, the total amount of internal metabolic heat production either decreases to reduce the amount of excess heat required for dissipation or increases to keep the athlete warm, consequently heat balance and thermal comfort is maintained (Parsons, 2014).

Schlader *et al.,* (2011) conducted further research into thermoregulatory behaviour during exercise. The study investigated the initiation of thermoregulatory behaviour during physical and perceptual face cooling and heating during exercise in thermoneutral conditions (20.3 ± 0.2°C, 48 ± 3% RH). Participants were instructed to maintain a rating of perceived exertion (RPE, Borg, 1982) of 16 (intensity between *'hard'* and '*very hard'*). The power output at an RPE of 16 was measured during the first 3-min of each trial and was averaged to calculate a starting mean power output. Participants cycled until their power output fell to a value corresponding to 70% of the starting power output for 3 consecutive minutes. The experimental trials consisted of facial; perceptual cooling and heating via the application of L-menthol and capsaicin and physical cooling and heating via fan cooling and fan heating and a control trial. The findings were a significant reduction in total work done in the perceptual (178.8 ± 17.5 kJ) and physical (160.0 ± 13.9 kJ) heating trials compared to the perceptual (228.7 ± 23.7 kJ) and physical (223.2 ± 21.1 kJ) cooling trials. No difference was observed for work done between the perceptual and physical heating trials and the perceptual and physical cooling trials. When compared to the control (189.4 ± 16.7 kJ) physical heating was significantly reduced and physical and perceptual cooling was significantly improved. This study shows that RPE and thermal perception (*i.e.,* thermal discomfort and sensation) are important determinants of behavioural thermoregulation during exercise, without the need for physical change in T_{sk} or core temperature (Figure 2.9).

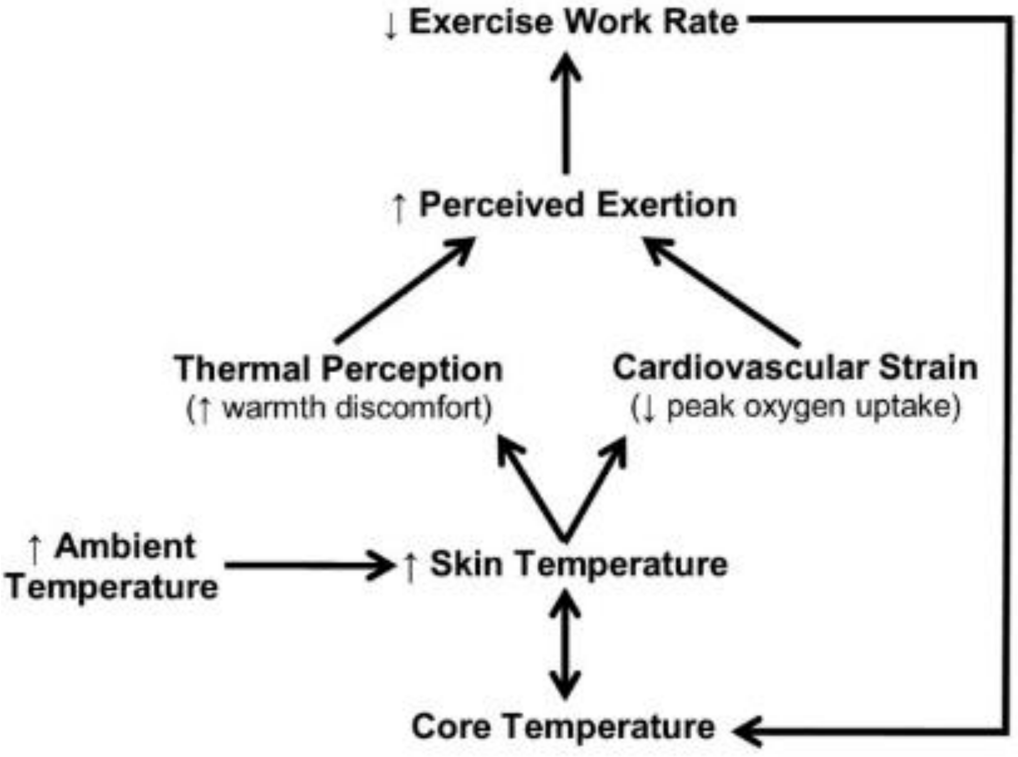


Figure 2.9: Factors that influence behavioural thermoregulation during exercise (Flouris & Schlader, 2015).

Behavioural thermoregulation at rest and during exercise relies upon an individual feeling uncomfortable enough to implement thermoregulatory behaviours (Flouris, 2011; Schlader, 2014; Flouris & Schlader, 2015). During rest, this is predominately driven by changes in skin temperature whereby heat exposures increase skin temperature, leading to an unpleasant feeling of being too warm. This level of discomfort results in a change of behaviour to reduce thermal strain. Likewise, during exercise, intensity (*i.e.,* thermoregulatory behaviour) is driven by skin temperature. This is because a rise in skin temperature, results in a change in thermal perception (*i.e.,* thermal discomfort and sensation), leading to an increase in RPE (Figure 2.9). To reduce RPE a person will decrease their exercise intensity, consequently metabolic heat production decreases and heat balance is maintained through the behaviour change. Consequently, if individuals fail to detect skin temperature changes as *'uncomfortable'* they will not implement the behavioural strategies to decrease heat gained from the environment. It is inviting to speculate, that in light of the thermoregulatory impairments that have been observed amongst the elderly, that there is an age-related decrease in their behavioural thermoregulatory response during periods of hot weather (Section 2.3.2).

2.3. Ageing thermoregulation

2.3.1. Autonomic thermoregulation

The process of ageing deteriorates the autonomic thermoregulatory system (Kenney & Munce, 2003; Kenney *et al.,* 2014). Consequently, during periods of heat stress the elderly are at increased risk of not maintaining their heat balance. This section explains how physiological changes due to ageing result with an increase in heat strain.

Cardiovascular responses

Minson *et al.,* (1998) investigated age-related differences in the cardiovascular response to passive heat stress, using a water perfused suit (50°C). The study measured cardiac output (Q_c), skin blood flow (SkBF), oesophageal temperature (T_{oe}) heart rate (HR), stroke volume (SV) and individual limit of thermal tolerance time. The limit of thermal tolerance was defined as; the point in which the participant expressed they were too *'uncomfortable'* to continue, their T_{oe} was above 39.5°C, or the participant was unable to control hyperventilation. The findings suggested no age-related difference in thermal tolerance time, $T_{sk,}$ and HR. However, due to an age-related decline in maximum HR, the elderly (70 ± 3 yrs) relied on a greater percentage of their HR reserve during passive heating. Furthermore, Q_c was significantly reduced in the elderly compared to young (23 ± 1 yrs), 7,400 ± 200 $ml.min^{-1}$ *vs.*

11,100 ± 700 ml.min^{-1}(Figure 2.10). The authors suggested an age-related decrease in Q_c was due to a lower SV, 99 ± 7 ml.beat^{-1} *vs.* 68 ± 4 ml.beat^{-1}. There was also a reduction in the redirection of blood flow from the renal and splanchnic circulations to the skin in the elderly compared to young men; 720 ± 100 ml.min^{-1} and 960 ± 80 ml.min^{-1} (Figure 2.10). Consequently, a reduced SV and a limited redirection of blood flow to the skin, resulted in a significant decrease in SkBF in the elderly (2,700 ± 300 ml.min^{-1}) compared to the young (5,800 ± 700 ml.min^{1}) (Figure 2.10).

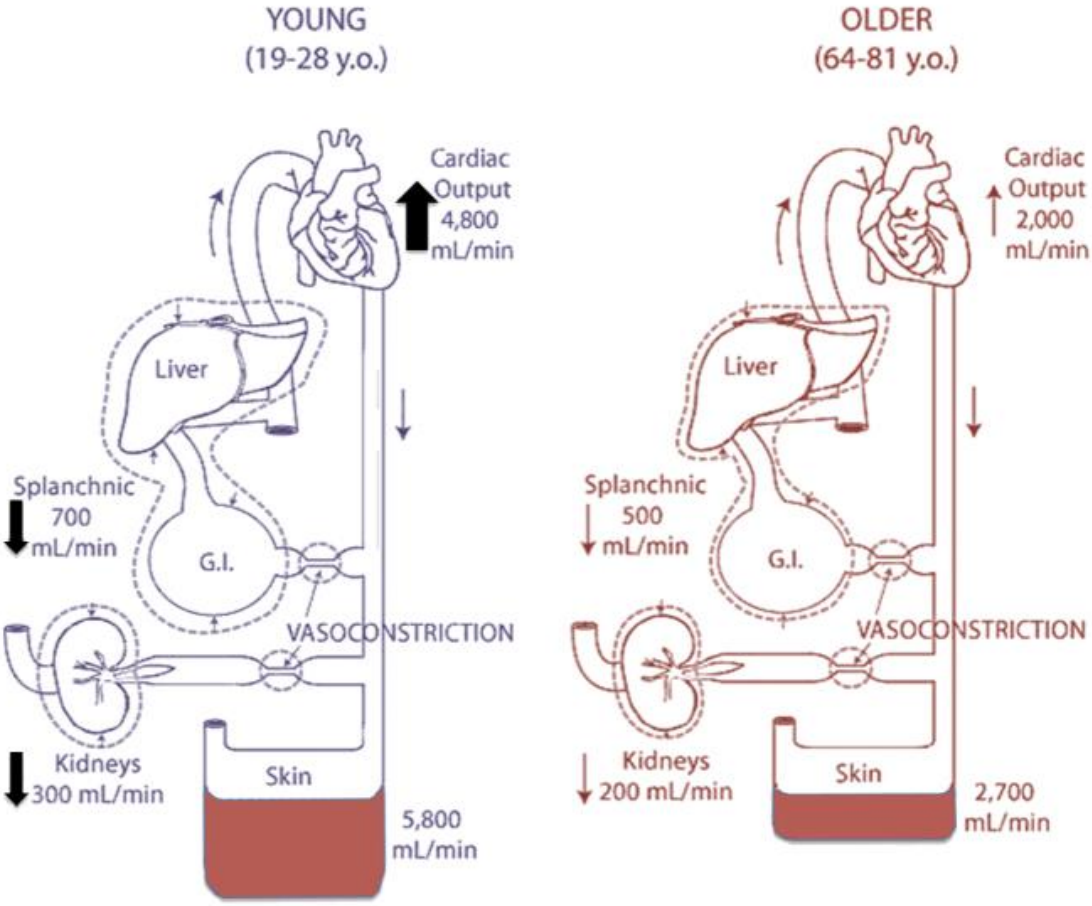


Figure 2.10: Redirection of skin blood in young (left diagram) and elderly (right diagram) during passive heating. Data from Minson *et al.,* (1998) figure from Kenney *et al.,* (2014).

Gagnon *et al.,* (2016) also investigated the age-associated difference in cardiac function during passive heat stress. Similar, to Minson *et al.,* (1998) they found a decrease in Q_c between young and elderly participants (~50%). Contrary to the study, the decrease was not aligned to an attenuation in SV, as SV during heat stress (76 ± 8 ml) was maintained to near normothermic values (74 ± 8 ml). Instead, they contribute the Q_c decline to a reduced HR that was not present in the Minson *et al.,* (1998) investigation. Both studies used the same protocol for heating participants, with a water perfused suit (50°C). However, they differed on how and when they measured Q_c. The differences within the studies could have contributed to the differences in the results, whereby there is an ongoing debate to the physiological mechanism for the decline in Q_c. Regardless, of the mechanism elderly people are at a cardiovascular disadvantage of losing excess heat. This is because the centrally driven reduction in SkBF decreases the capacity for convective heat loss, whereby, the thermal gradient produced between the core and the skin is less efficient at transferring heat to the skin, when SkBF is reduced (Charkoudian, 2003). Additionally, when environmental conditions allow (*i.e.,* skin temperature higher than environmental temperature) the reduction in elderly SkBF will lead to a reduced thermal gradient between the skin and the external environment compared to the young, leading to less convective heat loss. Therefore, under the same hot environmental conditions the elderly will experience greater cardiovascular strain compared to young adults.

Skin blood flow responses

Maximum SkBF decreases linearly with age (Martin *et al.,* 1995; Holowatz *et al.,* 2010; Holowatz & Kenney, 2010). This is partly due to structural deterioration of the blood vessels. These deteriorations include; vascular smooth muscle hypertrophy, a decrease in capillary density due to a flattening of the underside of the epidermis and reduction of the microcirculatory loops (Holowatz *et al.,* 2010). Maximum SkBF is also determined by the sensitivity of the vasodilator vessels to the; axon reflex response, acetycholine, NO and COX. Holowatz *et al.,* (2010) explained that there is no age-related difference in the sensitivity of vasodilator vessels to acetycholine in the initial phases of increasing SkBF. Also, Holowatz *et al.,* (2009) found no separate contribution of COX-dependent to NO-dependent pathways to cutaneous vasodilation in older adults (53 ± 2 yrs) during a 1°C change (Δ) in oral temperature (T_{or}) through passive heating, albeit the older adults in the study were not over the age of 65. The authors suggested that the alteration in SkBF were derived from differences in the axon reflex response to local heating and the NO-dependent pathway during prolonged heating.

Minson *et al.,* (2002) investigated the age-related response to localised heating (42°C) applied to the forearm of young (22 ± 2 yrs) and elderly (77 ± 5 yrs) participants. The findings were an age-related decrease in the axon reflex and the NO-dependent vasodilatory responses. Measurements were expressed as a percentage of the maximum cutaneous vascular conductance (CVC_{max}) which is a measurement of maximum SkBF, determined from the SkBF plateau phase once heated to 42°C. The young participants' axon reflex responses was 61 ± 2% CVC_{max} compared to the elderly 46 ± 4% CVC_{max}, in the initial peak in SkBF. Additionally, NO-dependent vasodilation was reduced in relation to age: young; 75.0 ± 2.3% CVC_{max} *vs.* elderly; 61.1 ± 4.5% CVC_{max}. This was determined through administering 10 mM NG-nitro-L-arginine methyl ester (L-NAME) to inhibit NO-dependent vasodilation and assessing the difference between CVC_{max} with no L-NAME and with L-NAME. The diminished vasodilatory responses of the axon reflex and NO-dependent pathway resulted in, a reduction in the maximum SkBF and heat loss that could be achieved in the elderly.

Age-related reduction in the NO-dependent cutaneous vasodilation response is due to a diminished NO bioavailability (Holowatz *et al*., 2006a, b; Holowatz *et al.,* 2010; Holowatz & Kenney 2010; Kenney, 2017). The decrease in NO bioavailability is due to an increased upregulation of arginase and increased oxidative stress (Holowatz *et al*., 2006a b; Holowatz *et al.,* 2010; Holowatz & Kenney 2010; Kenney, 2017). Arginase and NO-synthase (NOS) require the substrate L-arginine for the production of urea and NO. Consequently, the augmented arginase, attenuates NO bioavailability for cutaneous vasodilation (Holowatz *et al.,* 2006a; Holowatz *et al.,* 2010; Holowatz & Kenney 2010; Kenney, 2017). Furthermore, reactive oxygen species (ROS) (*i.e.,* oxidative stress) increases with age. Superoxide is a ROS that increases in production with ageing skin, additionally the superoxide scavenging enzymes that break down superoxide decrease with age. Superoxide reacts with NO in the skin to produce peroxynitrite, thereby decreasing the NO available for cutaneous vasodilation (Holowatz *et al.,* 2006b; Holowatz & Kenney 2010; Kenney, 2017).

Holowatz *et al.,* (2006a) were the first to assess the age-related effects of arginase on SkBF in the young (18-27 yrs) and elderly (65-72 yrs). The study consisted of 5 trials in which participants were passively heated in a water perfused suit until their T_{or} changed by 1°C. The experimental trials utilised microdialysis to inhibit; NOS (L-NAME), arginase (I-arg), also to infuse L-arginine (L-arg), and to inhibit arginase whilst infusing L-arginine (I-arg + L-arg). These trials were compared to a control trial, whereby participants were heated to a 1°C change in T_{or}. The findings were, young (Y) had a greater cutaneous vasodilation response to heating compared to the elderly (E) (Y, 42 ± 1, *vs.* E, 30 ± 1% CVC_{max}) and that the infusion of L-NAME decreased CVC in young (22 ± 2 %CVC_{max}) and elderly (18 ± 2 %CVC_{max}). The inhibition of arginase, the infusion of L-arginine and the inhibition of arginase with the addition of L-arginine infusion restored %CVC_{max} in the elderly to a similar percentage as the young control (YCON) trial: I-arg; 46 ± 4% CVC_{max}, L-arg; 44 ± 4% CVC_{max}, I-arg + L-arg; 46 ± 5% CVC_{max}, YCON; 42 ± 1% CVC_{max}. This study supports a diminished NO-availability due to the upregulation of arginase because when arginase is inhibited or when there is greater availability of the substrate L-arginine the elderly are able to maintain SkBF to a similar level as young adults.

Holowatz *et al,* (2006b) completed a further study assessing the effects of oxidative stress on NO-dependent cutaneous vasodilation. Similar to Holowatz *et al,* (2006a), microdialysis was used to infuse L-ascorbate (*i.e.,* antioxidant) (L-asc) and L-ascorbate with an inhibitor of arginase (L-asc + I-arg). Findings suggested an increase in %CVC_{max} that was similar to the young control trial (37 ± 3 % CVC_{max}) when elderly participants were given L-asc (35 ±

4 % CVC_{max}) and that this was further improved when L-asc + l-arg was administered (41 ± 3 % CVC_{max}). Furthermore, the increase in % CVC_{max} in the intervention trials for the elderly were a significant improvement on the elderly control trial (28 ± 3 % CVC_{max}). This study supports the notion that increased oxidative stress with age decreases NO bioavailability, resulting in a decrease in cutaneous vasodilation.

Although the elderly have a decreased NO bioavailability, it is the mechanism which they rely the most on to increase SkBF (Holowatz *et al.,* 2010; Holowatz & Kenney, 2010). Holowatz *et al.,* (2003) found that when NO was inhibited, after T_{or} was increased by 1°C, in the young (23 ± 2 yrs) and the elderly (71 ± 6 yrs), that the elderly had a greater decrease in maximum SkBF (-60%) compared to the young (-23%). This finding highlights the greater contribution NO-dependent pathways have on maximum SkBF in the elderly compared to the young.

Sudomotor responses

An age-related reduction in maximum SkBF effects the amount of sweat available for evaporation during rest and exercise in the heat (Inoue *et al.,* 1998; Stapleton *et al.,* 2014a; Fujii *et al.,* 2015). Inoue *et al.,* (1998) investigated the age-related difference in local and whole body sweat rates (WBSR) and SkBF of participants exposed to passive hot water (42°C) immersion of the lower limbs for 60-min. Findings suggested a significant age-related decrease in sweat rate locally, at all the measured sites (Figure 2.11), and WBSR (Table 2.1). Additionally, there was a significant age-related decrease in SkBF at the; thigh, chest, back and forearm (Figure 2.12).

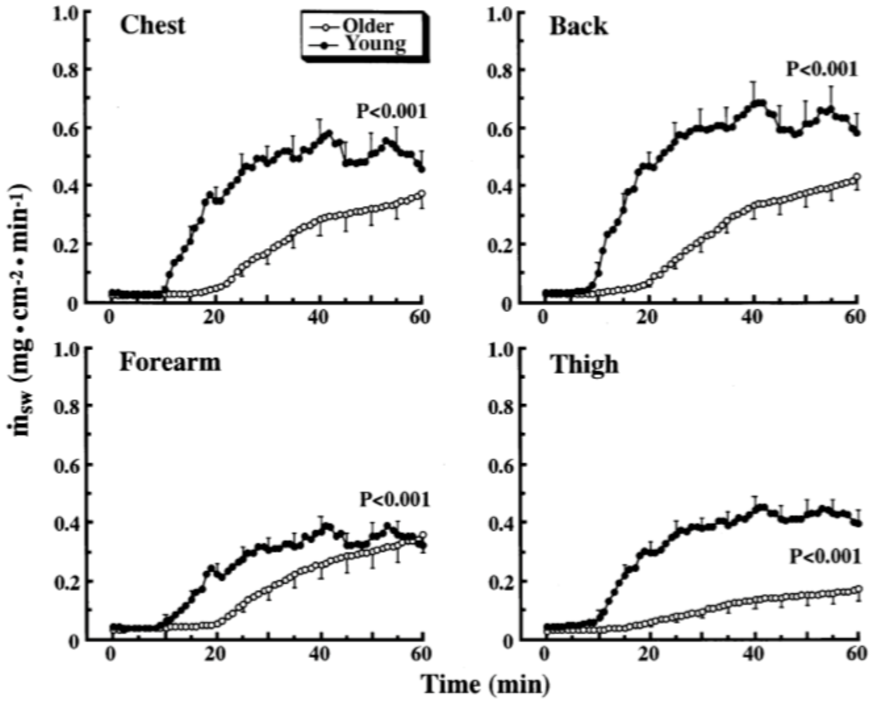


Figure 2.11: Time-course of local sweat rate (msw) on the chest, back, forearm and thigh in the young (closed circles) and elderly men (open circles). The *p* values represent overall group effect for the 60-min exposure. Figure taken from Inoue *et al.,* (1998).

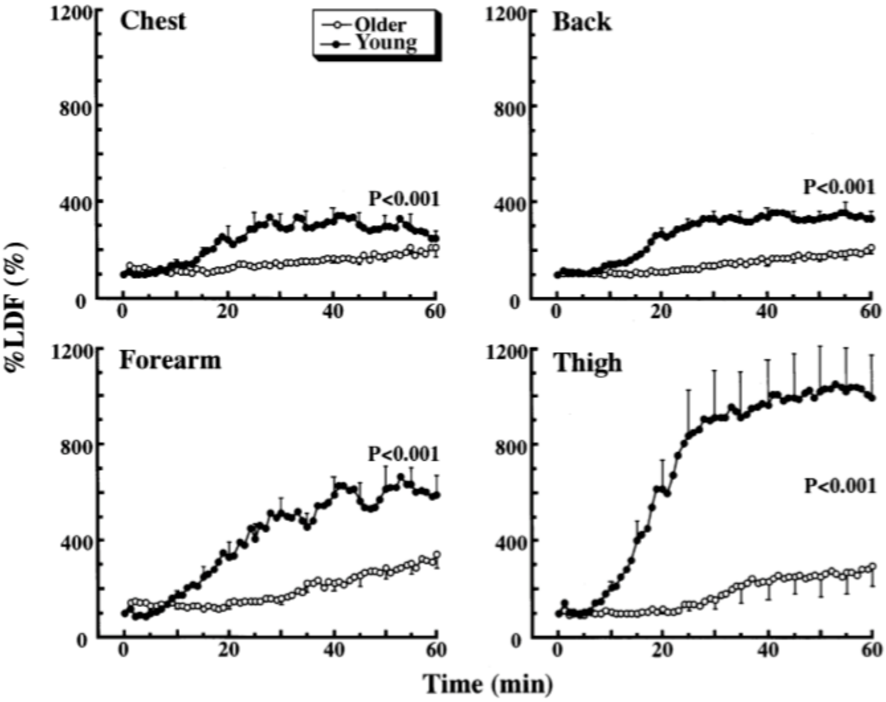


Figure 2.12: Time-course of the percentage change in skin blood flow by laser Doppler flowmetry relative to the baseline value (%LDF) on the chest, back, forearm and thigh in the young (closed circles) and older men (open circles). The *p* values represent overall group effect for the 60-min exposure. Figure taken from Inoue *et al.,* (1998).

Stapleton *et al.,* (2014a) investigated the age-related effects of NO on sweating by comparing sweat rates during intermittent exercise in the heat, with and without the inhibition of NO. There was a significant age-related difference in sweat rate at the end of the first exercise bout in the control condition (Table 2.1). This indicates an age-related decrease in sweat rate during exercise in the heat. Secondly, the young had a significant decrease in sweat rate when NO was inhibited (iNO) across all exercise bouts. This was not matched in the elderly group, whereby iNO had no significant effect of sweat rate across exercise bouts. These results show the importance of NO bioavailability on sweat rate because when NO is diminished due to ageing or inhibition, sweat rate decrease.

Fijii *et al.,* (2015) further investigated the mechanism of sweating and SkBF in the elderly population. Similar to Stapleton *et al.,* (2014a), sweat rate was not different at the end of exercise in the iNO compared to the control trial (Table 2.1). Findings also suggested no sweat differences compared to the control trial when COX was inhibited (iCOX) or when iNO + iCOX were administered (Table 2.1). Therefore, ageing, without disease, results in COX not contributing to sweating in the elderly completing exercise. The study also found that SkBF was significantly reduced compared to control in the iNO and iNO + iCOX trials, but not in the iCOX trial (Table 2.1). The data supports the resting data from Holowatz *et al.,* (2009) that COX has no contribution to SkBF in elderly people and also reiterates the contribution of NO on cutaneous vasodilation.

Furthermore, elderly people have a decreased sweat gland output compared to young adults (Anderson & Kenney, 1987; Inoue *et al.,* 1996; Kenney & Fowler, 1988; Kenney & Munce, 2003; Balmain *et al.,* 2018). Anderson & Kenney (1987) investigated sweat gland output between postmenopausal (52-62 yrs) and young women (20-30 yrs). The study compared the density of heat activated sweat glands and the sweat rate from the glands post walking (~40% $\dot{V}O_{2max}$) for 2 hours in 45°C. The main findings were; an 18% lower sweat rate in older compared to younger participants due to a decreased sweat output per gland (Table 2.1). The findings should be interpreted with caution as the method of matching aerobic fitness via $\dot{V}O_{2max}$ does not account for difference in metabolic heat production that can lead to difference in sweat rate independent of the age factor being assessed (Cramer & Jay, 2014). However, Kenney & Fowler (1988) stimulated sweat glands pharmaceutically in young and elderly adults and found supporting evidence of a decrease in sweat gland output (Table 2.1). When the sweat glands were pharmaceutically stimulated, there was no age-related difference in sweat gland density, however sweat gland output was significantly lower in the elderly (Table 2.1). Similarly, Inoue *et al.'s* (1996) 5 year longitudinal, repeated measures, study on sweat gland activation during passive heating in elderly men, resulted in progressive decreases in sweat gland output due to age (Table 2.1). The results were a significant decrease in whole body sweat loss from year one. These studies highlight the decreased sweat gland output with age irrespective of sex (Table 2.1).

Table 2.1: Summary of studies investigating sudomotor responses during heat stress in young and elderly adults.

Study	Study design	Young results	Elderly results	Study summary
Inoue *et al.*, (1998)	Age: Y = 20-25 yrs, E = 64-76 yrs Exercise: Passive Environment: 42°C Intervention: Lower limb hot water immersion for 60-min.	WBSR: 192 (SEM 14) g.m^{-2}.h^{-1},	WBSR: 114 (SEM 14) g.m^{-2}.h^{-1},	Significant age-related decrease in local (Figure 2.11) and whole body sweat rate and SkBF (Figure 2.12) during passive heating.
Stapleton *et al.*, (2014a)	Age: Y = 23 ± 3yrs, E = 64 ± 4 yrs Exercise: 3 x 15-min at 300 ± 2 Wm^{-2} $\dot{H}_{prod}$ Environment: 35°C, 20%RH Interventions: CON, iNO	WBSR: CON end EX1: 0.90 ± 0.17 mg.min^{-1}.cm^{-2} CON end EX3: 1.03 ± 0.21 mg.min^{-1}.cm^{-2} iNO end EX3: 0.78 ± 0.20 mg.min^{-1}.cm^{-2}	WBSR: CON end EX1: 0.69 ± 0.19 mg.min^{-1}.cm^{-2} CON end EX3: 0.94 ± 0.38 mg.min^{-1}.cm^{-2} iNO end EX3: 0.84 ± 0.31 mg.min^{-1}.cm^{-2}	Significant age-related difference in sweat rate during exercise. iNO significantly decreased sweat rate during exercise in young but not in the elderly.
Fijii *et al.*, (2015)	Age: 62 ± 7 yrs Exercise: 2 x 30-min at 400W $\dot{H}_{prod}$ Environment: 35°C, 20%RH Interventions: CON, iNO, iCOX, iNO + iCOX	N/A	WBSR: CON: 0.80 ± 0.06 mg.min^{-1}.cm^{-2} iNO: 0.74 ± 0.07 mg.min^{-1}.cm^{-2} iCOX: 0.77 ± 0.07 mg.min^{-1}.cm^{-2} iNO + iCOX: 0.77 ± 0.07 mg.min^{-1}.cm^{-2} SkBF: CON: 69 ± 6% CVC$_{max}$ iNO: 49 ± 8% CVC$_{max}$ iCOX: 66 ± 4% CVC$_{max}$ iNO + iCOX: 54 ± 8% CVC$_{max}$	NO and COX have no effect on sweat rate in the elderly. COX has no effect on elderly SkBF. However, NO significantly contributes to maximum SkBF.

Anderson & Kenney (1987)	Age: Y = 20-30 yrs, E = 52-62 yrs Exercise: Walking at ~40% $\dot{V}O_{2max}$ for 2 hours Environment: 45°C Intervention: N/A	18% higher sweat rate than the elderly.	18% lower sweat rate than the young.	Elderly females had a reduced sweat rate compared to the young due to decreased sweat rate per gland.
Kenney & Fowler (1988)	Age: Y = 22-24 yrs, E = 58-67 yrs Exercise: N/A Environment: N/A Intervention: pharmaceutically (MCh) activated sweat glands.	Sweat gland density: 2-min after the injection of MCh (0.1% concentration), 45 ± 7 glands.cm^2 were activated. Sweat gland output: 91 ±11 ng.gland	Sweat gland density: 2-min after the injection of MCh (0.1% concentration), 42 ± 5 glands.cm^2 were activated. Sweat gland output: 39 ± 4 ng.gland	No age related difference in sweat gland density. Sweat gland output decreases with age.
Inoue *et al.*, (1996)	Age: 65-70 Exercise: passive Environment: 42°C Intervention: lower limb hot water immersion for 60-min.	N/A	Repeated measures study completed 5 years a part. WBSR year 1: 253 (SEM 16) g.m^{-2}.h^{-1} WBSR year 5: 210 (SEM 13) g.m^{-2}.h^{-1}	Progressive decrease in sweat rate with increasing age

Abbreviations: Y; young, E; Elderly, WBSR; whole body sweat rate, SkBF; skin blood flow, $\dot{H}_{prod}$; metabolic heat production, CON; control, iNO; inhibited nitric-oxide, iCOX; inhibited cyclooxygenase, NO; nitric-oxide, COX; cyclooxygenase, $\dot{V}O_{2max}$; maximum oxygen consumption, MCh; acetyl-β-methylcholine chloride.

The combination of; an attenuated reflex response, reduced redirection of blood flow to the skin, decreased $Q_{c,}$ deterioration of the cutaneous blood vessels and reduced sweat rate, results in a reduced age-related capacity to thermoregulate (Kenney & Munce, 2003; Kenney *et al.,* 2014). Heat storage increases because these mechanisms facilitate heat loss via convection and evaporation. Consequently, an increase in heat storage leads to a rise in core temperature and the increased risk of suffering a heat-related illness.

2.3.2. Behavioural thermoregulation

Whilst there has been a wealth of research investigating the age-related deterioration of autonomic thermoregulation, there is a scarcity of research investigating the potential age-related differences in behavioural thermoregulation (types of behavioural thermoregulation are discussed in detail on p20). Changes in skin temperature stimulate changes in thermoregulatory behaviour in young people at rest (Schlader *et al.,* 2009; Schlader *et al.,* 2013; Vargas *et al.,* 2018). It has been suggested that greater changes in body temperatures stimulate thermoregulatory behaviours in elderly people, in warm/hot environments (Taylor *et al.,* 1995). Changes in skin temperature occur prior to changes in body temperature, consequently there could be an age-related delay in implementing thermoregulatory behaviours. Taylor *et al.,* (1995) demonstrated age-related differences in thermoregulatory behaviour by enabling elderly and young people to control room temperature. Although average core temperature (T_c) was similar between groups (E; 36.8°C and Y; 36.9°C), the maximum (E; 37.8 ± 0.1°C and Y; 37.3 ± 0.1°C) and minimum (E; 36.4 ± 0.2°C and Y; 35.9 ± 0.2°C) T_c significantly differed, indicating larger changes in T_c among the elderly when trying to remain in the thermoneutral zone. This data should be interpreted with caution due to the aural measurement used as an estimation of T_c, which is less accurate compared to other measures of T_c such as rectal and oesophageal (Robinson *et al.,* 1998; Ganio *et al.,* 2009).

Schlader *et al.,* (2017) furthered their previous '*shuttle-box'* research with young healthy individual's by conducting a similar study comparing thermoregulatory behaviour between young (25 ± 4 yrs) healthy people to elderly (67 ± 4 yrs) people with cardiovascular co-morbidities; hypertension, type two diabetes and hypercholesterolaemia. Participants were able to freely move between a hot environment (40°C, 20% RH) and a cool environment (18°C, 30% RH) at their own discretion. The main findings from the study were an elevated T_c when moving from hot to cool in the elderly compared to the young, contributing to a longer duration in the hot environment for the elderly compared to the young, albeit not significantly longer (Table 2.2). Furthermore, there was no significant age-related difference in thermal discomfort, sensation or mean skin temperature (Table 2.2). The authors highlighted possible areas for future research to determine the effects of age and cardiovascular co-morbidities on resting behavioural thermoregulation. Importantly, the sample of elderly people contained more than one cardiovascular co-morbidity, therefore isolating the co-morbidities would provide greater specific knowledge of a behavioural thermoregulation response. Additionally, the co-morbidities were compared to healthy young controls to investigate behavioural thermoregulatory differences, however this does not directly evaluate the relationship between behavioural thermoregulation and the ageing process. Thus, it remains unclear to the extent of the age-related and cardiovascular co-morbidities-related effect on the decision making process to implement a thermoregulatory behaviour at rest.

Table 2.2: Data from Schlader *et al.,* (2017) of when participant decided to move from hot to cold.

Variable	Young	Elderly
Duration before moving from H→C (min)	14.5 ± 4.3	18.9 ± 18.4
Core temperature change before moving from H→C (°C)	-0.1 ± 0.2	0.1 ± 0.3
Thermal discomfort at the point of moving from H→C (a.u)	2.1 ± 0.2	2.7 ± 0.5
Thermal sensation at the point of moving from H→C (a.u)	5.7 ± 0.4	5.8 ± 0.4
Change in mean skin temperature at the point of moving from H→C (°C)	2.7 ± 0.6	2.9 ± 1.9

Abbreviations: H; hot, C; cold, min; minutes, a.u; arbitrary units

There is a current dearth of knowledge pertaining to the behavioural thermoregulation of elderly people. Behavioural thermoregulation is the *'first line of defence'* for preventing an increase in core temperature and there is a near infinite number of conscious behaviours, leading to a greater capacity to lose excess heat compared to autonomic thermoregulation (Schlader *et al.,* 2010; Flouris, 2011; Schlader, 2014; Flouris & Schlader, 2015). Consequently, a greater understanding of behavioural thermoregulation in the elderly is essential, because if there is an age-related delay in resting or exercise behavioural thermoregulation, it could lead to greater heat storage and heat-related illness in the elderly population.

2.3.3. Ageing and heat balance

Ageing and heat balance at rest

There are age-related differences in heat storage during two hours of passive heat exposure to hot-dry (36.5°C, 20%RH) and hot-humid (36.5°C, 60%RH) environments (Figure 2.13) (Stapleton *et al.,* 2014b). Body heat content was significantly elevated in the elderly compared to young at the end of heat exposure in the hot-dry and hot-humid environment (Figure 2.13) (Stapleton *et al.,* 2014b). The elevation in the hot-dry and hot-humid environments were due to a higher net heat gain in the elderly compared to young; 13W and 11W. Secondly, heat storage was greater in the hot-humid environment compared to hot-dry for the young and elderly. This is likely due to the reduction in evaporative heat loss in the humid environment. The short exposure time highlights how quickly healthy elderly people start to store greater amounts of heat compared to the young, when environmental conditions are hot.

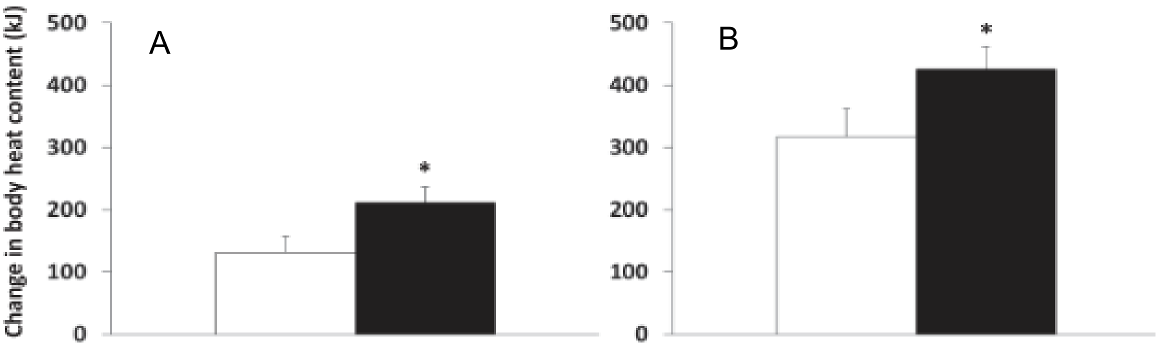


Figure 2.13: Change in body heat content after 2 hours of passive heat exposure in a hot-dry (36.5°C, 20%RH) (A) and hot-humid (36.5°C, 60%RH) (B) environment for young (white bars) and elderly (black bars) participants. * represents a significant group difference. Figure taken from Stapleton *et al.,* (2014b).

Furthermore, Kenny *et al.,* (2016) investigated the age-related differences in heat storage over a longer (3-h) and hotter (44°C, 30%RH) period of passive heat exposure, with the addition of females. Findings suggested a significant decrease in evaporative heat loss (*i.e.,* sweating), after the first 30-min, in the elderly (55 ± 73 yrs) compared to the young (19 ± 28 yrs). This is in contrast to Larose *et al.,* (2014) that found no age-related difference in evaporative heat loss during the 2-h heat exposure in the hot dry environment (average evaporative heat loss in the Larose *et al.,* (2014) study: Y; 104 ± 7W, E; 103 ± 7 W). The differences between the studies could be due to additional evaporative requirement of a hotter and slightly more humid environment, highlighting the age-related deterioration in evaporative heat loss. Similar to Stapleton *et al.,* (2014b), Kenny *et al.,* (2016) found a significant increase in heat gain for the entirety of the heat exposure. Consequently, the elderly had a significantly greater change in body heat storage and lower rate of total heat loss, at all 30-min measurement time points, compared to the young. There were also significant differences in T_{re} from 30-min to the end of exposure (end T_{re}: Y; 37.6 ± 0.2, E; 37.8 ± 0.3). However, these T_{re} are not considered hyperthermic and there was no difference in core temperature change when assessed from baseline to end of heat exposures (Y; Δ0.4°C, E; Δ0.5°C). Although the T_{re} was not hyperthermic, the elderly were unable to regain heat balance during the 3 hours, unlike the young who regained heat balance after 2 hours. Therefore, the study predicted a change in mean body temperature > 39°C within an eight hour exposure to the heat, based on the heat gained from the last hour of exposure. Consequently, without behavioural thermoregulation to reduce thermal stress, an extended period of heat exposure, with the addition of greater metabolic heat production (*e.g.,* exercise/completing daily tasks), has the potential to result in even greater heat storage and the risk of heat-related illness, in the elderly compared to young adults.

Ageing and heat balance during exercise

A series of studies from the same research group have investigated the point of greater heat storage in elderly compared to young adults during exercise at different intensities, durations and environments. Firstly, Larose *et al.,* (2013a) compared heat storage in males ranging from 20-70 years old in a 35°C, 20%RH environment completing intermittent exercise (4x15-min at 400W $\dot{H}_{prod}$, 15-min rest in between each exercise bout). The main finding was a significant increase in cumulative heat storage in all age groups over 40 years old (40-44, 45-49, 50-54 and 55-70 yrs) compared to the 20-31 year olds. This finding was representative of a difference in evaporative heat loss and therefore sweating, whereby, the 20-31year old group sweated significantly more than the other age groups. Interestingly, there were no differences in T_{re} between groups or exercise bouts. Likewise, Larose *et al.,* (2013b) completed the same protocol with different defined aged groups; young (20-30 yrs), middle aged (40-45 yrs) and elderly (60-70 yrs). Similar, to Larose *et al.,* (2013a) the elderly stored greater amounts of heat (+39%) compared to the young, as a result of decreased evaporative heat loss during each bout of exercise (1st: 283 ± 10 *vs.* 332 ± 11 kJ, 2nd: 334 ± 10kJ *vs.* 379 ± 5 kJ, 3rd: 347 ± 11 *vs*. 392 ± 5 kJ, and 4th: 347 ± 10 *vs.* 387 ± 5 kJ). Similarly, to Larose *et al.,* (2013b) there were no differences in T_{re} between groups or exercise bouts.

Stapleton *et al.,* (2014c) continued this area of research by comparing heat storage in a hotter environment (40°C, 15% RH) between the young (Y), elderly (E), and trained (TMA) and untrained middle aged males (UMA), with exercise bouts of increasing $\dot{H}_{prod}$ (3x30-min at, 300, 400 and 500W $\dot{H}_{prod}$, 15-min rest in between each exercise bout). The purpose was to evaluate the exercise intensity in which elderly people stored greater amounts of heat compared to the young and middle aged males. When exercising at 300W $\dot{H}_{prod}$ all groups were able to maintain a similar level of evaporative heat loss to offset heat storage. During exercise bouts 2 (Ex2) and 3 (Ex3) the E (Ex2: 424 ± 38; and Ex3: 485 ± 44 W) and UMA (Ex2: 426 ± 34; and Ex3: 497 ± 17 W) had a significantly lower evaporative heat loss compared to the Y (Ex2: 472 ± 42; and Ex3: 558 ± 51 W) and TMA (474 ± 21; Ex3: 552 ± 23 W). Consequently, the E and UMA had a significantly greater accumulation of heat storage and oesophageal temperature (T_{oe}) at the end of Ex3 compared to Y and TMA. Therefore, elderly and untrained middle aged males start to store greater amounts of heat compared to young and middle aged trained men from an exercise intensity above 300W $\dot{H}_{prod}$ and is clearly evident at an exercise intensity of 400W $\dot{H}_{prod}$. These results are comparable to Larose *et al.,* (2013ab) which also found decreases in evaporative heat loss and increases in heat storage at 400W $\dot{H}_{prod}$ in the elderly compared to young adults. Furthermore, the decrease in evaporative heat loss due to ageing can be attenuated with greater levels of fitness, as shown with differences in middle aged trained and untrained men.

Lastly, Stapleton *et al.,* (2015) adapted the exercise intensities (250, 325 and 400W $\dot{H}_{prod}$), to test young and elderly females in the same environmental conditions (40°C, 15% RH). Similarly, to the elderly men the elderly females had significantly reduced evaporative heat loss compared to the young after the second (Ex2: E; 343 ±39 W, Y; 383 ± 34 W), and third bout of exercise (Ex3: E; 389 ± 29 W, Y; 437 ± 36 W). This resulted in an increase in heat storage for elderly women at the end of the third exercise bout and a significant difference between groups in end T_{oe} (E; 37.91 ± 0.41°C *vs*. Y; 37.56 ± 0.29°C).

It is noteworthy, that in the Larose *et al.,* (2013ab) studies there were no differences in the change or absolute in T_{re} between groups from the commencing and ceasing of exercise. However, there were difference in T_{oe} in Stapleton *et al.,* (2014c, 2015) at the end of exercise. The difference between the T_c results could be due to the longer duration and higher exercise intensity exercise with the hotter environment, resulting in greater difference in heat storage between young and elderly in the Stapleton *et al.,* (2014c, 2015) studies leading to a significant difference in T_{oe}. Alternatively, the T_{oe} is a faster responding T_c measurement, therefore it could detect the differences in the T_c more rapidly at the end of exercise than T_{re} (Robinson *et al.,* 1998).

These series of studies have indicated that there is an increased risk of heat accumulation and potential heat illness after eight hours of heat exposure at rest. Furthermore, there is greater heat storage during exercise that increases the chance of a heat illness in a shorter duration in the elderly compared to the young during physical activity in periods of hot weather.

2.3.4. Factors associated with ageing and heat balance

Hydration status

Dehydration is an acute total body water deficiency (Kenney & Chiu, 2001; Sawka *et al.,* 2007; Cheuvront & Kenefick, 2014). The physiological changes during dehydration are a decrease in plasma volume and an increase in plasma osmolality, in proportion to percentage of total body water loss (Kenney & Chiu, 2001; Sawka *et al.,* 2007; Cheuvront & Kenefick, 2014). The resulting hyperosmolality delays cutaneous vasodilation and sweating (Kenney & Chiu, 2001; Sawka *et al.,* 2007; Cheuvront & Kenefick, 2014). Consequently, there is an increase in heat storage via the reduction in evaporative heat loss (*i.e.,* reduced sweating) (Cheuvront & Kenefick, 2014). Montain & Coyle (1992) demonstrated the relationship between dehydration and heat storage. The study dehydrated young participants on four separate occasions, whereby, there was a decrease in body mass by ~4, ~3, ~2 and ~1% after two hours of cycling (65% $\dot{V}O_{2max}$) in hot environment (33°C, 50% RH). The main findings were; an increase in end T_{oe} with increased dehydration (1%; 37.9 ± 0.1°C, 2%; 38.2 ± 0.1°C, 3%; 38.5 ± 0.1°C, and 4%; 38.7 ± 0.1°C) and a significant correlation between T_{oe} and magnitude of dehydration, $r = 0.98$. As core temperature (*i.e.,* T_{oe}) is an indicator of heat storage, this study suggests that heat storage increases with dehydration.

A rising core temperature is a sign of dehydration (*i.e.,* objective evidence of dehydration), other symptoms of dehydration include: dry, scratchy mouth and throat, dry lips, light-headedness, dizziness, tiredness, irritability, headache and loss of appetite (*i.e.,* subjective evidence provided by the patient of dehydration) (Kenney & Chiu, 2001; Jequier & Constant, 2010). The signs and symptoms of dehydration are avoided when fluid loss (*e.g.,* sweating and urine output) is matched by fluid replacement (*i.e.,* drinking fluids), therefore the fluid balance is maintained (Kenney & Chiu, 2001). Fluid replacement is directly influenced by the sensation of thirst, a sensation which manifests through the interaction of behavioural and physiological cues (Kenney & Chiu, 2001). The main source of behavioural fluid replacement is during social interactions (*e.g.,* meal times), in these incidences dehydration is not required to initiate fluid replacement, unlike the physiological feeling of thirst cues (Kenney & Chiu, 2001; Rikkert *et al.,* 2009).

The two physiological mechanisms for the detection of dehydration are; increases in cellular tonicity and decreases in extracellular fluid volume cues (Kenney & Chiu, 2001; Sawka *et al.,* 2007) (Figure 2.14). Osmoreceptors, located in the central nervous system, sense increases in cellular tonicity beyond the thirst threshold, triggering the single negative feedback loop to the hypothalamus (Figure 2.14) (Kenney & Chiu, 2001). The hypothalamus stimulates the sensation of thirst to regain fluid balance. Decreases in extracellular volume stimulate two negative feedback loops to the hypothalamus (Figure 2.14) (Kenney & Chiu, 2001). Firstly, decreases in blood volume are sensed by the baroreceptors, located in large blood vessels, consequently thirst sensation is increased, to increase extracellular and blood volume (Figure 2.14) (Kenney & Chiu, 2001). Secondly, a decrease in renal perfusion stimulates the hormonal system, renin-angiotensin-aldosterone (Kenney & Chiu, 2001). The hormonal changes increase a person's salt appetite, initiating an increase in salt intake, leading to plasma volume expansion and the avoidance of hypernatremia (Figure 2.14) (Kenney & Chiu, 2001).

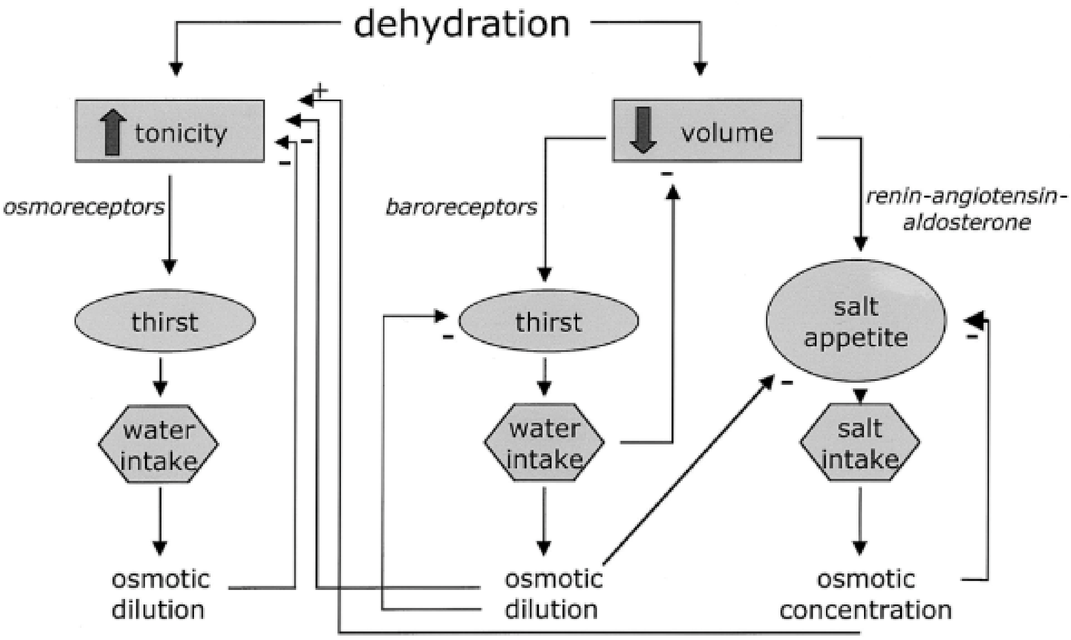


Figure 2.14: The physiological model of controlling thirst during dehydration. The left negative feedback loop is increases in cellular tonicity, whereas the two right feedback loops are decreases in extracellular fluid volume (Kenney & Chiu, 2001).

During day-to-day life, when adequate hydration is available and there is no external stressor to hydration (*e.g.,* hot climate), the elderly are able to maintain fluid balance (Sawka *et al.,* 2007; Rikkert *et al.,* 2009). Hydration is maintained predominately through fluid consumption and the water content of food, during meal times (Rikkert *et al.,* 2009). Therefore, during day-to-day life, there is no fluid deficiency that would require the physiological responses to increase thirst and fluid intake.

Age-related differences in thirst are evident when there is an external stressor (*e.g.,* heat stress, exercise and fluid deprivation) effecting the maintenance of fluid balance. Phillips *et al.,* (1984) stressed the thirst mechanisms by depriving access to all fluids for 24 hours and controlling food intake, within elderly (65-75 yrs) and young (20-31 yrs) participants. The groups lost a similar percentage of body mass post intervention (E; 1.8 ± 0.2%, Y; 1.9 ± 0.1 %). However, thirst sensation and then fluid intake during the 60-min rehydration period (E;

$3.4 \pm 0.7 ml.kg.^{-1}$, Y; $8.5 \pm 0.8 ml.kg.^{-1}$), were significantly lower in the elderly compared to the young group. Therefore, elderly people feel less thirsty when they are dehydrated, leading to a decrease in fluid uptake.

In situations where there is an external stressor, both cellular tonicity and decreases in extracellular fluid are stressed to drive increases in thirst perception. Strenchenfeld *et al.,* (1996, 1997) investigated the age-related mechanistic differences in thirst perception. Stachenfeld *et al.,* (1996) found evidence, that there was no age-related difference in thirst perception or water intake, when cell hydration was decreased. Therefore, the mechanism for decreased thirst perception in the elderly is not related to detecting cellular tonicity. Stachenfeld *et al.,* (1997) investigated the changes in baroreceptor pressure and age-related decreases in thirst sensation. This study showed that when pressure is increased in the blood vessels (*i.e.,* mimicking hydration), the thirst perception decreases in young but not in the elderly. Therefore, it is the reduced sensitivity of the baroreceptors to decreases in extracellular fluid volume (*i.e.,* blood volume) that reduces the thirst response in the elderly compared to young adults.

There is also an age-related decline in kidney function (Jequier & Constant, 2010; El-Sharkawy *et al.,* 2015). The kidneys excrete more water compared to younger adults, due to a decreased sensitivity to the antidiuretic hormone and the reduced renal ability to concentrate urine (Jequier & Constant, 2010; El-Sharkawy *et al.,* 2015). Additionally, elderly people have low secretion of aldosterone, which controls salt and water balance, consequently increasing the risk of dehydration. Furthermore, certain medication can exacerbate the risk of dehydration in the elderly, these include; diuretics, laxatives and sedatives (Ferry*,* 2005; Rikkert *et al.* 2009; Jequier & Constant, 2010). Lastly, there is the notion that elderly people restrict their fluid intake due to the fear of incontinence (Ferry*,* 2005; Jequier & Constant, 2010).

One of the main causes of hospital admissions during periods of hot weather is dehydration (Semenza *et al.,* 1999; Rikkert *et al.,* 2009). The elderly are at the greatest risk of the dehydration during periods of hot weather. This is because one of the external stressors to hydration is heat stress, due to reduced sensitivity of the baroreceptors and renal function the elderly are at risk of not feeling thirsty and retaining their fluid balance. As a consequence of the dehydration they will increase their heat storage (*i.e.,* increase core temperature) which is further exacerbated in the heat, by the greater heat storage due to age-related physiological deterioration in thermoregulatory control. The increase in heat storage results in an increased risk of heat-related illness in the elderly.

Aerobic fitness

There is an age-related decline in aerobic fitness (Wilson & Tanaka, 2000; Huggett *et al.,* 2005). Stapleton *et al.,* 2014c highlighted the difference in heat storage accumulation between trained and untrained, middle aged men with trained men accumulating less heat than untrained men. The strength of the study is in the use of metabolic heat production to match exercise intensities between two groups of middle aged men, with significantly different $\dot{V}O_{2max}$ values, to isolate age as the independent variable. Cramer & Jay (2014) explained that studies that match participants for aerobic fitness (*i.e.,* $\dot{V}O_{2max}$) fail to match metabolic heat production. Therefore, increases in core temperature and sweat rates could be due to difference in metabolic heat production, rather than as a result of the independent variable being assessed (*e.g.,* age). A recent review by Balmain *et al.,* (2018) on ageing and thermoregulation during exercise found that there are no current studies investigating differences in thermoregulation between two groups of elderly people with varying aerobic fitness (*i.e.,* $\dot{V}O_{2max}$), matching for age and exercise intensity, through metabolic heat production. This type of study would evaluate a fitness-related difference in thermoregulation between elderly individuals. Consequently, if fitness is a determinate for greater thermoregulation in the elderly then aerobic fitness advice can be given to older people to maintain a greater level of fitness.

Summary

Elderly people store greater amounts of heat than their younger counterparts during rest and exercise due to greater heat gain from the environment and a reduced capacity for evaporative heat loss via reduced sweating. Age-related decreases in thirst perception and aerobic fitness further augment the thermoregulatory process of maintaining heat balance. Therefore, strategies to maintain fluid balance and retain physical fitness into older age may somewhat offset the age-related decline in thermoregulation. However, more research where elderly participants are matched for $\dot{H}_{prod}$ with differences in aerobic fitness ($\dot{V}O_{2max}$) is warranted to confirm the fitness-related difference in heat storage in the elderly.

Furthermore, the series of research by Larose *et al.,* (2013ab) and Stapleton *et al.,* (2014c, 2015) accurately assesses the point of greater heat storage in moderately fit elderly people in resting and exercise conditions. However, the environments and exercise intensities used do not accurately reflect the environments and activities of daily living, likely to be experienced by elderly people in the UK during periods of hot weather. In addition, the advanced technique of measuring heat storage via direct calorimetry, is not widely accessible. Therefore, further research that investigates elderly peoples heat storage within UK summer climatic conditions during exercise intensities that equate to activities of daily living is warranted.

2.4. Heat-related illnesses

The consequence of a heat imbalance and therefore, greater heat storage is the increased risk of heat-related illness. The term heat-related illness encapsulates several different types of heat illnesses that range in severity (Coris *et al.,* 2004; Howe & Boden 2007; Nadir *et al.,* 2016). Minor heat illnesses include; heat rash, heat cramps, heat odema and heat syncope, whereas severe heat illnesses include; heat exhaustion and heat stroke, which are life threatening (Table 2.3) (Coris *et al.,* 2004; Howe & Boden 2007; Nadir *et al.,* 2016). Furthermore, heat illnesses occur along a continuum whereby, minor heat illnesses can develop into a more severe heat illness, if untreated (Figure 2.15) (Coris *et al.*, 2004; Heled *et al.*, 2004; Luber & McGeehin, 2008; Porcari *et al.,* 2015). Heat stroke is the most severe heat illness and in some cases leads to death (Nadir *et al.,* 2016). Fatalities are a result of either: exertional heat stroke (EHS), which develops during strenuous physical activity, with or without the addition of heat stress (Heled *et al.,* 2004; Armstrong *et al.,* 2007; Jay & Brotherhood, 2016) or classic heat stroke, which affects vulnerable populations who have an attenuated ability to dissipate heat gained from the environment (Table 2.4) (Bouchama & Knochel, 2002; Flynn *et al.*, 2005). The risk factors associated with developing exertional, classic and both types of heat stroke are presented in table 2.4. It is evident that many of the risk factors associated with classic heat stroke could apply to the elderly population (*e.g.,* social isolation, confined to a bed, debilitated and cardiopulmonary disease), further increasing the risk of classic heat stroke in the elderly population. Exertional and classic heat stroke are diagnosed when a patient exhibits signs of; neurological dysfunction, a $T_c >$ 40°C and multi-organ failure (Grogan & Hopkins, 2002; Bouchama & Knochel, 2002; Luber & McGeehin, 2008; Nadir *et al.,* 2016). If a person presents with signs and symptoms (Table 2.3) of severe heat illness (*i.e.,* heat exhaustion or heat stroke) then rapid cooling and urgent medical attention are required.

Table 2.3: Criteria for diagnosing different heat illnesses. Table adapted from Howe & Boden (2007).

Illness	Core Temperature	Symptoms	Signs
Heat Odema	Normal	No symptoms	Swelling (ankles, feet, hands)
Heat Rash	Normal	Pruritic rash	Papulovesicular skin eruption over clothed areas
Heat Syncope	Normal	Dizziness and general weakness	Fainting, rapid mental status recovery once supine
Heat Cramps	Normal or slightly elevated <40°C	Painful muscle contractions (calf, quadriceps, abdominals)	Affected muscles may feel firm
Heat Exhaustion	37-40°C	Dizziness, malaise, fatigue, nausea, vomiting, headache	Flushed, profuse sweating, cold clammy skin, normal mental status
Heat Stroke	>40°C	Possible history of heat exhaustion symptoms before mental status change	Hot skin with or without sweating, CNS disturbance (confusion, ataxia, irritability, coma)

Abbreviations: CNS; central nervous system.

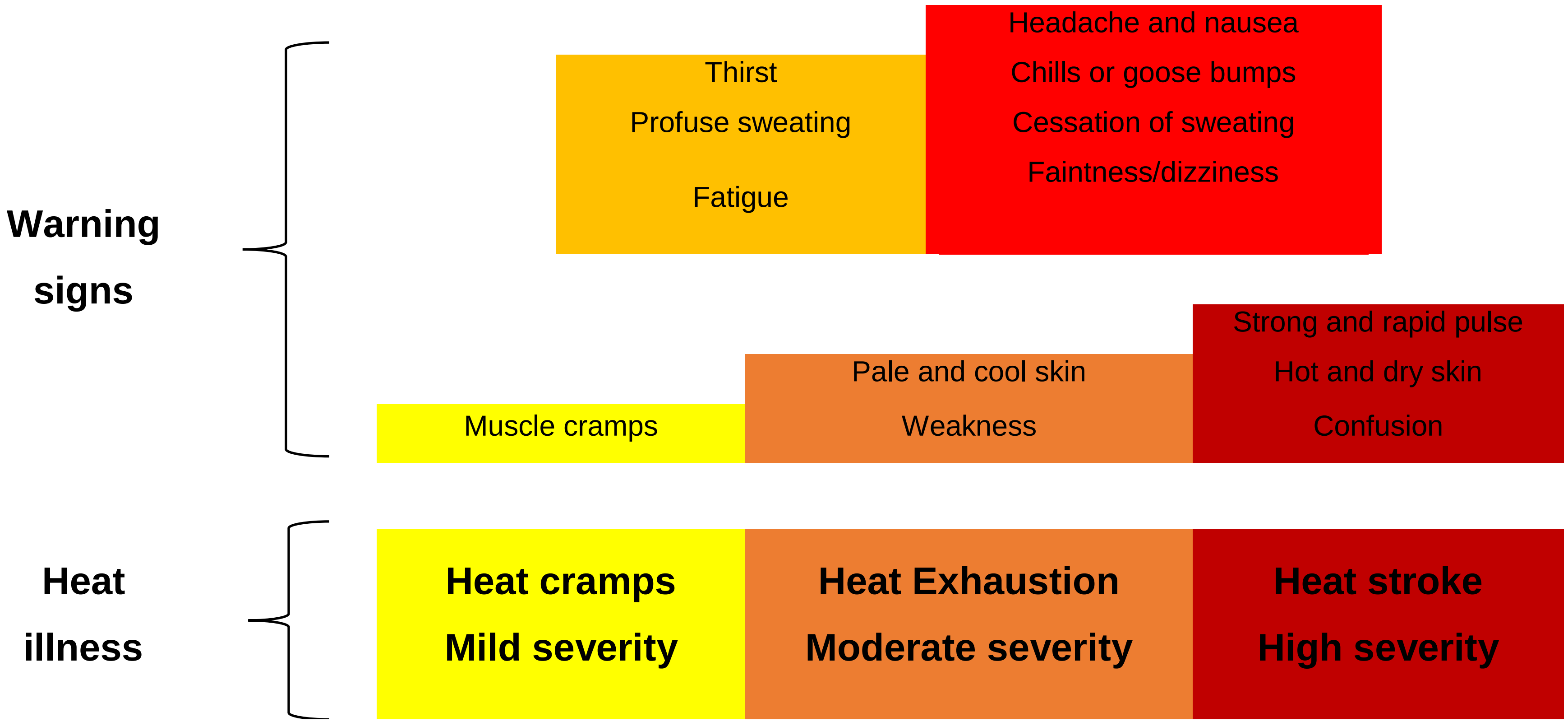


Figure 2.15: The heat illness continuum, with increasing severity from left to right. Figure redrawn from Porcari *et al.,* (2015).

Table 2.4: Risk factors associated with the development of classic, exertional and both types of heat stroke. Table recreated from Younggren & Yao, (2006).

Classic	Both	Exertional
• Elderly • Children • Social isolation • Confined to a bed • Debilitated • Lack of air conditioning • Live on the top floor of a building • Heatwaves • Chronic mental illness • Cardiopulmonary disease • Chronic illness	• Drugs (prescription and illegal) • Obesity • Current febrile illness • Prior dehydrating illness • Skin diseases • Metabolic diseases that increase heat production (*i.e.,* thyrotoxicosis) • Lack of heat acclimatization • Prior heat stroke • Previous days heat exposure • Elevated heat index	• Protective clothing • Recent alcohol consumption • Lack of sleep, food or water • Lack of physical fitness • Lighter skin pigmentation • Motivation to continuously push physical limits • Reluctance to report problems • Lack of coach or athlete education regarding heat illness.

Public Health England (PHE) publish weekly reports on the most prevalent reasons to seek medical attention from; general practitioners (G.P), out of hours G.P's, the accident and emergency department (A & E) and calls to the National Health Service's (NHS) 111 non-emergency number (Appendices A-D, p255-258). The out of hours G.P reports state the number of cases of each illness and if that was an increase or decrease from the previous week (Appendix A, p255). The data is available for the past 4 years (2015-2018) (Figure 2.16). Figure 2.16 represents a fairly consistent number of heat stroke consultations given by out of hours G.P's to patients during the summers (June-August) of 2015, 2016 and 2017 (~111 each year). There was a large spike in heat stroke consultations in 2018 (230), this is consistent with the hottest summer on record for England. The figure highlights the impact of hot weather on the number of heat-related illnesses and impact this can have on the NHS.

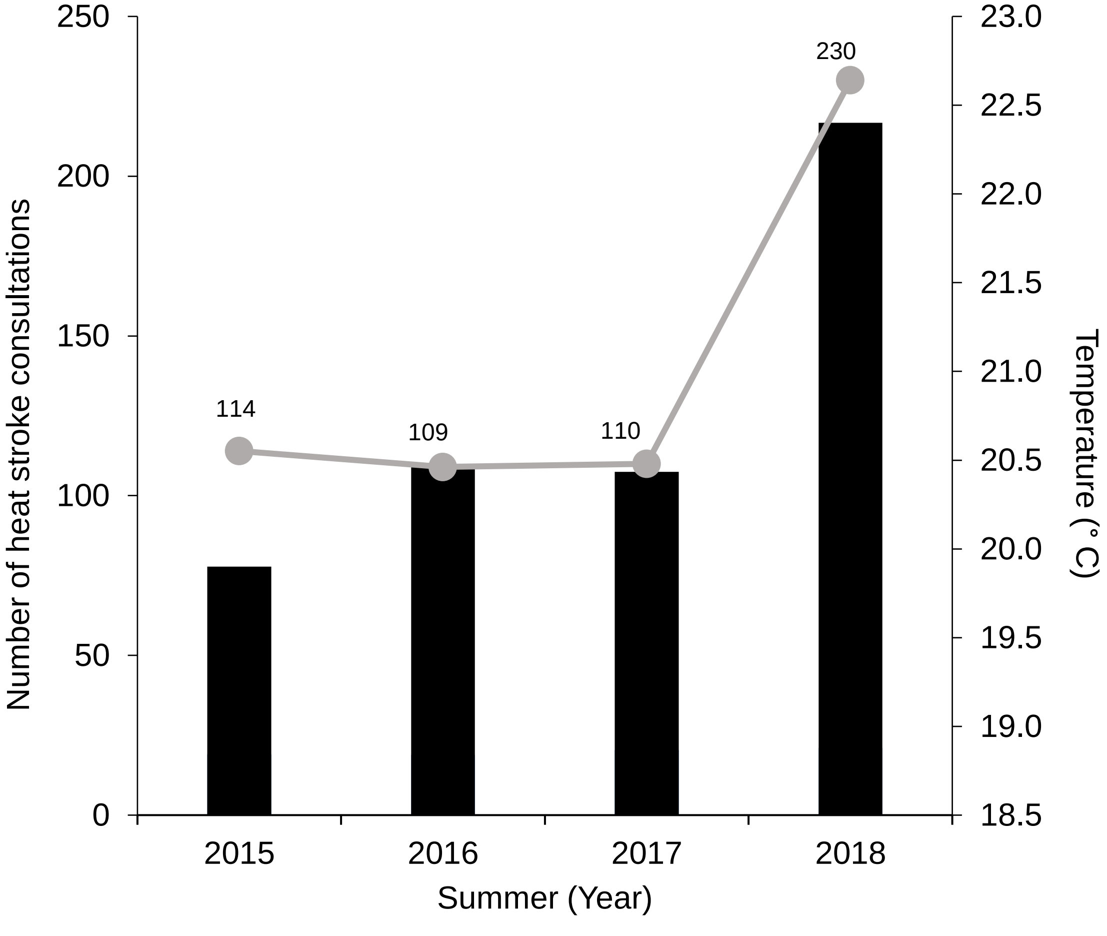


Figure 2.16: Heat stroke consultation given by out of hours G.P during the summer months (June-August) between 2015-2018 (line graph). It also represents the average maximum summer temperature between 2015-2018 (bar graph). Data taken from PHE's out of hours G.P. reports and the MET Office's monthly temperature statistics. Data assessed in 2018.

2.4.1. Ageing and heat-related illness risk-mortality and morbidity

People over the age of 65 represent the most A & E and G.P visits for heat-related illnesses, during periods of hot weather (Kenney *et al.,* 2014; Smith *et al.,* 2016). Smith *et al.,* (2016) collated the data on the time spent by G.P's consulting with different age groups on heat-related illnesses during the UK summer of 2013 (Figure 2.17). The data for the 65-74 year olds indicate a peak in heat-related illness consultations towards the end of the hot weather. The over 75's had their peak in heat-related illness visits during the hottest period of weather and were the second highest age group to visit the G.P for heat-related illnesses (Figure 2.17). Interestingly, the over 75's had a delay in returning to baseline heat-illness visits compared to the other age groups. The delays in peak (65-74 yrs) and return to baseline (>75 yrs) could represent an elderly person's delay in seeking heat-related illness treatment, possibly because they do not want to burden the NHS (Smith *et al.,* 2016). This data suggests that the elderly are among the highest age group to visit their G.P for heat-related illnesses in the UK but that they may delay their visit (Figure 2.17).

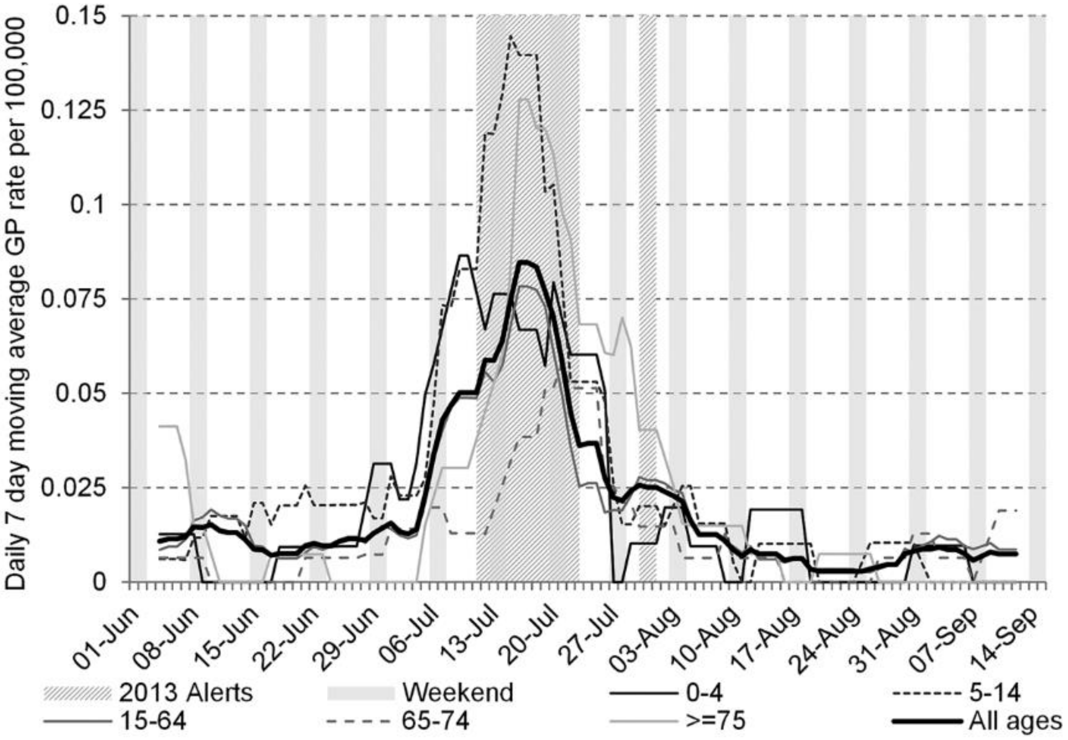


Figure 2.17: Represents the time that G.P's spent consulting on heat-related illness, by age group, during the UK summer 2013 (Smith *et al.,* 2016).

In addition to the increase risk in heat-related illnesses, the elderly are also at increased risk of heat-related mortality (Hajat *et al.,* 2014; Kenney *et al.,* 2014; Arbuthnott & Hajat, 2017). This is evidence by the over 65's contributing up to 92% of excess deaths during heatwaves (Conti *et al.,* 2005; Kenney *et al.,* 2014). The risk of heat-related illness and mortality is further exacerbated in the elderly if they have other poor; economic, social and co-morbidities factors (Waters, 2001; Bouchama & Knochel, 2002; Hajat *et al.,* 2007; Luber & McGeehin 2008; Kenny *et al.,* 2010; Åström *et al.,* 2011). Firstly, living in residential care homes increases heat-related illness risk due to the associated poor health of the people needing to live in a care home and the staff who are often insufficiently trained to manage vulnerable patients exposed to the heat (Hajat *et al.,* 2007; Luber & McGeehin 2008). Secondly, conditions such as; obesity, cardiovascular disease, respiratory disease and diabetes mellitus, decrease the body's ability to thermoregulate and therefore increases risk of heat-related illnesses (Waters, 2001; Kenny *et al.,* 2010). Thirdly, having a low income increases heat-related illness risk due to reduced access to a cool environment such as air conditioned rooms to prevent heat storage (Hajat *et al.,* 2007; Kenny *et al.,* 2010). Other elderly associated heat illness risk factors include; taking medications that influence thermoregulation (*e.g.,* diuretics), having a mental illness (*e.g.,* dementia), living in urban areas (*i.e.,* heat island effect) and living alone (Waters, 2001; Bouchama & Knochel, 2002; Kenny *et al.,* 2010; Åström *et al.,* 2011). Therefore, the elderly are the population most at risk of suffering minor and severe heat-related illnesses during periods of hot weather (Conti *et al.,* 2005; Ebi & Meehl, 2007; Hajat *et al.,* 2014; Kenney *et al.,* 2014; Smith *et al.,* 2016; Arbuthnott & Hajat, 2017).

2.5. Public health advice for the prevention of heat-related illness

The catastrophic 2003 heatwave in Europe initiated action from public health organisations to review their heatwave policies. The aim of the World Health Organisation (WHO) and Public Health England (PHE) was to provide guidance to the NHS, general public, social care worker and voluntary organisations to reduce the health-related harm during periods of hot weather (PHE, 2015; WHO, 2015).

As an outcome of reviewing the polices and advice, PHE developed the Heatwave Plan for England (HPE) which includes the Heat Health Watch System (HHWS) (PHE, 2015). The aim of the HPE is to attenuate the adverse health problems due to hot weather (Table 2.5) (PHE, 2015). The HPE allows for a coherent response across the country on the protocols and procedures that should be adhered to during periods of hot weather (PHE, 2015). The HHWS is a tiered heat-related alert system, of escalating severity (Table 2.5). The UK is on a level 1 alert from 1st June – 15th September, there is no immediate risk to heath, however, people should be prepared for potential hot weather. Level 2 is activated based on a 60% probability of a heatwave in the next 2 to 3 days, level 3 is activated when there are specific high temperatures (Table 2.6) and level 4 is the most severe category of alert and is activated during prolonged heatwaves (PHE, 2015).

Table 2.5: The Heat Health Watch System (HHWS). Table adapted from PHE (2015).

Level 0	Long term planning- all year round includes: painting houses a light colour to reflect heat and putting in insulation.
Level 1	Heatwave and summer preparedness programme: 1st June – 15th September
Level 2	A heat wave is forecast- alert and readiness- 60% risk of heat wave in the next 2 to 3 days.
Level 3	Heatwave action- temperature reached in one or more MET Office National Severe Weather Warning Service regions (NSWWS) (Table 2.6)
Level 4	Major incident- emergency response- central government will declare a level 4 alert in the event of severe or prolonged heatwave affecting sectors other than health.

Table 2.6: The HHWS level 3 activation temperature points based on region in the country. Table adapted from PHE (2015).

Region of the country	Level 3 activation temperature point during the day (°C)	Levels 3 activation temperature point during the night (°C)
London	32	18
South East	31	16
South West	30	15
Eastern	30	15
West Midlands	30	15
East Midlands	30	15
North West	30	15
Yorkshire and Humber	29	15
North East	28	15

In addition to the coherent response across the UK to hot weather, the HPE has general population advice on how to avoid heat-related harm (PHE, 2015). This advice is disseminated via the '*beat the heat'* campaign (Appendices E - G, p259-261). The campaign has posters and checklist, in leaflet form, highlighting key messages for remaining safe during periods of weather and sign-posting the public to further information (*e.g.,* the MET

Office website) (Appendices E - G, p259-261). The advice includes, but is not limited to; listening to weather forecast updates, planning the day (*e.g.,* to avoid being outside during the hottest temperatures), drink plenty of fluids whilst avoiding alcohol, dress in light loose clothing and check on vulnerable family and friends (*e.g.,* the elderly) (Appendices E – G, p259-261).

Furthermore, there is a document for care home providers on best practice for caring for the vulnerable, specifically the frail elderly population, during periods of hot weather, which includes a poster and checklist for the carers (Appendices H and I, p263-263). The admission of increased vulnerability is a strength of the HPE as this increases the awareness of health care providers of the dangers of hot weather on the population they have a duty of care to. Within the care home providers document, it has a step-by-step guide on how to be ready and care for people at each tier of the HHWS (Table 2.5) (Appendix I, p263). One of the guidelines is to ensure there is a cool room (< 26°C) for elderly care home residence to reside in when it is hot. The advice is based on reducing thermal strain from the external environment, for elderly people to maintain a heat balance under less thermal stress. The information given in the care home document has the potential to reduce heat-related harm in elderly residences. However, there is minimal evidence provided for the reason to complete certain heat-alleviating strategies. Furthermore, the information that is given to the general public also highlights that the elderly are at risk but does not provide specific evidence informed advice on how the elderly should cope during periods of hot weather. Therefore, to improve the HPE more research-informed advice for coping in hot weather should be provided for vulnerable populations, including the elderly.

One of the areas for improvement in the HPE is how the HHWS alert system increases from a level 2 to a level 3 alert. Currently, it is based only on area specific daytime and evening temperatures (Table 2.6). To improve the alert system other environmental factors should contribute to an increasing level of environmental stress (*e.g.,* humidity for its contribution to heat stress). The improvement of adding humidity to the HHWS is in relation to the effect it has on the mechanisms of heat loss (Hayes *et al.,* 2014), particularly within an elderly population (Larose *et al.* 2014). Therefore, PHE could utilise the wet bulb globe temperature index (WBGT):

Equation 2.3: Wet bulb globe temperature index (WBGT) (Parsons, 2014):

$$WBGT = 0.7t_{nwb} + 0.2t_g + 0.1t_a$$

Where: t_{nwb} is the temperature of a naturally ventilated wet bulb thermometer, t_g is the temperature of a 150mm diameter black globe thermometer and t_a is the air temperature.

The wet bulb globe temperature index includes humidity, temperature and solar radiation, allowing for a more comprehensive evaluation of the environmental stressors (Parsons, 2014). Consequently, its potential use in the HHWS could improve the accuracy of escalating a level 2 to a level 3 alert. Additionally, the HHWS has overlooked the value of specific critical heat stress for vulnerable populations. The standardised set of procedures in the HPE and HHWS allows for cohesive action to be taken by the NHS, the public and social care facilities. However, the generalisation of the HHWS tiered alert system, has the potential of placing elderly people at greater risk of heat-related illness. The greater risk would be due to being unable to implement tier 3 precautions early enough for the elderly. Consequently, the magnitude of heat stress could cause heat-related illness in the elderly due to delaying the application of the appropriate heat-alleviating strategies. In summary, there should be a review of the HHWS tiered alert system, in relation to the heat stress required to trigger a greater alert and whether there should be age specific heat stress trigger values. The greater specificity has the potential to reduce the amount of heat-related illness by encouraging elderly people to implement heat- alleviating strategies earlier.

Another area for improvement in the HPE is the specificity of advice. The HPE advises not to use electrical fans when temperatures exceed 35°C, without any source of information to explain why fans should not be used (PHE, 2015). The theory being, fan use over 35°C would accelerate heat gained because skin temperature would be lower than the environmental temperature and the air movement from the fan would accelerate the heat gained by the body. However, this does not account for elevations in evaporative heat loss when fans are used (Jay *et al.,* 2014). Moreover, a 2012 Cochrane review assessed the literature pertaining to the impact of using electric fans during heatwaves and concluded that there was no evidence to suggest that using an electric fan is further detrimental to public health during heatwaves (Gupta *et al.,* 2012). Jay *et al's.,* (2014) mathematical model supports the review with results indicting that dry and evaporative heat loss are facilitated with the use of an electric fan for environments ranging from 26 - 60°C, 10-100% RH for young (20 - 40 yrs) and elderly people (>75 yrs) (Figure 2.18). Ravanelli *et al.,* (2015) also supported the use of fans in healthy men (23 ± 3 yrs) in environments up to 80% RH at 36°C and 50% RH at 42°C. The investigation found that fans delayed elevations in HR and T_c (*i.e.,* signs of physiological stress). The majority of this research was available before the HPE of 2015 was published. This highlights the requirement for enhanced relationships between researchers and policy writers to ensure the correct research-informed advice is being provided to the general public.

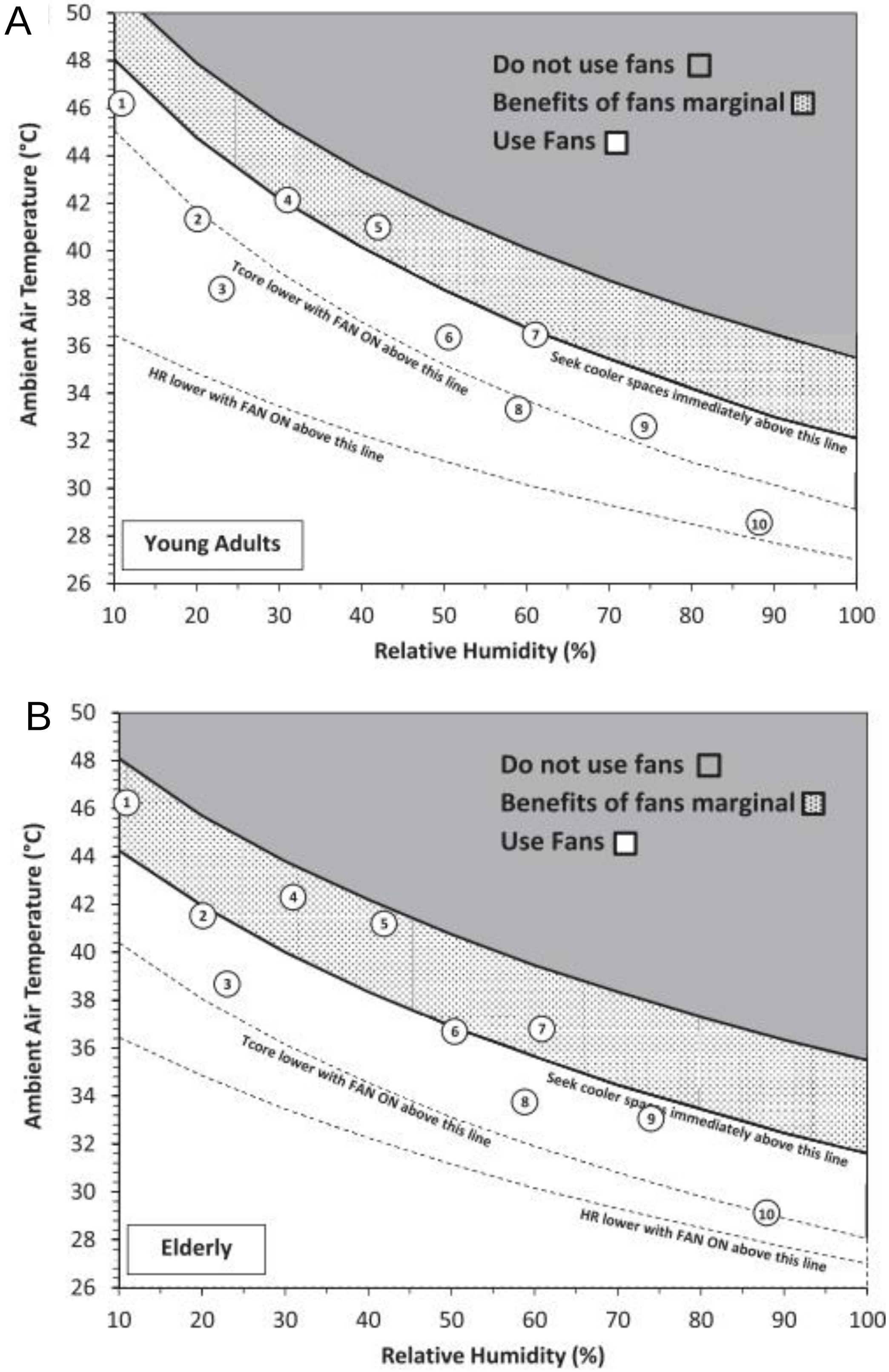


Figure 2.18: Jay *et al.,* (2014) predicted critical environmental limits that the use of electric fans are: 1) advised (white area); 2) advised, but cooler spaces must be sought immediately as severe heat-related illness will eventually develop (dotted area); and 3) not advised, since fans will accelerate the onset of severe heat-related illness (grey area) for the young (A) and elderly (B). Numbers represent peak hourly outdoor heat wave conditions for: Sydney, 2013 (1); Washington DC, 2012 (2); Paris, 2003 (3); Newark, 2011 (4); Chicago, 1995 (5); New York, 2006 (6); Chicago, 1999 (7); Washington DC, (night) 2012 (8); Chicago (night), 1999 (9); Paris (night), 2003 (10). Figure from Jay *et al.,* (2014).

Lastly, the HPE could improve the specificity of advice for the elderly population. As discussed, the elderly are at an increased risk of heat-related illness, partly due to a greater susceptibility to dehydration during periods of hot weather (Kenney & Chiu 2001; Ferry, 2005; Maughan, 2012). The HPE recognises the increased risk to the elderly population and advises people to drink plenty of water and to ensure that the elderly have an adequate water supply within their homes (PHE, 2015). However, the elderly have attenuated thirst response and reduced ability to retain their fluid balance, due to the baroreceptors being less sensitive to hypovolemia (Stachenfeld *et al.,* 1996; Stachenfeld *et al.,*1997; Kenney & Chiu 2001; Ferry, 2005) and reduced renal function (Kenney & Chiu 2001; Jequier & Constant, 2010; El-Sharkawy *et al.,* 2015). Consequently, the elderly have to be more dehydrated than young people to feel thirsty enough to seek fluids (Phillips *et al.,* 1984; Kenney & Chiu 2001; Ferry, 2005). Therefore, regardless of the amount of water or fluids the elderly have available, they may not drink sufficient amounts to remain hydrated during periods of hot weather. The lack of acknowledgement of the age-related physiological deterioration of the thirst response within the HPE, highlights the need for more research-informed interventions to be implemented amongst the elderly.

Moreover, the HPE also advices people to limit the amount of physical activity during periods of hot weather (PHE, 2015). Reducing physical activity during hot weather will decrease metabolic heat production and therefore an individual will require less heat to be dissipated to maintain a heat balance and a normal core temperature (Sawka & Young, 2006). However, there is an age-related deterioration in cardiovascular fitness (*i.e.,* maximum aerobic capacity declines with age) (Wilson & Tanaka, 2000; Huggett *et al.,* 2005). The decline in fitness is accelerated due to sedentary behaviour of elderly adults, the over 75’s are the most sedentary population, with only 19% of men and 8% of women completing the recommended levels of physical activity (Towsend *et al.,* 2015). Public Health England and the NHS recognise that the elderly can gain potential health benefits from completing regular physical activity, 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, improving mental health and reducing frailty (Scarborough *et al.,* 2011; Kohl *et al.,* 2012; PHE, 2016). Additionally, PHE and the NHS have several health campaigns that encourage exercise in all age groups, including the elderly, these campaigns include; Change4Life (NHS, 2009), One You, which includes the Couch to 5K campaign (PHE, 2016). Therefore, current health messages from PHE are contradictory. With the climate getting hotter and record breaking summer temperatures potentially being the norm in 30 years (MET Office, 2018e), PHE should provide strategies that allow the maintenance of safe and effective exercise all year round. This will best negate the harmful effects of heat (*i.e.,* heat stroke) whilst avoiding the potential long term negative consequences of be inactive (*i.e.,* social isolation, depression, chronic illness and decreased physical capacity), in an elderly population.

In summary, the 2015 HPE has advanced the UK's readiness for periods of hot weather, as a lack of preparation most likely contributed to the number of heat-related illnesses, including heat-related mortality, during the 2003 European heat wave. There is now the opportunity to improve upon the HPE by given even greater recognition to the most vulnerable population to heat stress (*i.e.,* elderly). The opportunity is to provide research informed evidence on how best the elderly can cope with heat stress. This advice is going to become increasingly important with the advanced ageing of the UK's population and with climate change evoking increasingly greater number of hot weather days.

2.6. Questionnaire for the prevention of heat-related illness

Although the elderly are the population at greatest risk of heat-related mortality, it is preventable (Bouchama & Knochel, 2002; Hajat *et al.,* 2014; Nadir *et al.,* 2016). The best treatment for the prevention of heat-related mortality, in any population, is to avoid an increase in core temperature (Bouchama & Knochel, 2002; Nadir *et al.,* 2016). As discussed previously (Section 2.2.3), the *'first line of defence'* for preventing core temperature increases are behavioural thermoregulation strategies (Schlader *et al.,* 2010; Flouris & Schlader, 2015). Behavioural strategies include; the removal of excess clothing, seeking; shade or an air-conditioned room, and or reducing activity levels (Smoyer-Tomic & Rainham 2001; Bouchama & Knochel, 2002; Flouris, 2011; Sawka *et al.,* 2011; Kenney *et al.,* 2014). If an individual feels uncomfortably warm then they are more likely to implement behavioural thermoregulation strategies (Schlader *et al.,* 2010; Flouris, 2011; Flouris & Schlader, 2015). However, as also discussed previously, there is a notion that there is an age-related delay in implementing thermoregulatory behaviours (Taylor *et al.,* 1995; Schlader *et al.,* 2017). Consequently, the elderly population require additional heat-illness prevention strategies because relying on behavioral thermoregulation could place them at risk of heat-related illness.

One strategy for the prevention of severe heat illness is the detection of minor heat-related illness signs and symptoms. Early detection and corrective responses to minor heat illness signs and symptoms could prevent progression to more severe heat illnesses (Coris *et al.,* 2006). There is minimal research into minor heat illness signs and symptoms detection. Coris *et al.,* (2006) devised the heat illness symptoms index (HISI) to quantify mild and moderate heat-related illness (HRI) symptoms in athletes. The HISI comprised of thirteen heat illness symptoms and a ten-point severity scale for assessing each symptom. The thirteen symptoms were; '*feeling tired, swelling, cramps, nausea, dizziness, thirst, vomiting, confusion, muscle weakness, heat sensations on the head or neck, chills, stopping sweating and feeling lightheaded'*. The severity of each symptoms was measured from; '*0 = no symptoms, 3 = mild symptom that do not interfere with practice, 5 = moderate symptoms, 7 = severe symptom that require a break from practice, 10 = had to stop practice.'* American football athletes completed the HISI after 9 practice sessions, wearing full protective clothing for the first time that summer, across one week in August. The total responses were 557, after initial correlation analysis the symptoms; *'stopping sweating'* (r = 0.17) and *'swelling'* (r = 0.26), were removed because of the weak correlation with overall HISI scores. Construct validity analysis of HISI scores found significant, although weak, correlations with; sweat loss (r = 0.21), heat index (r = 0.13), weight loss during practice (r = 0.13) and RPE (r = 0.21). Interestingly, Coris *et al.,* (2006) did not use T_c as a construct for validity, this is surprising because T_c is a marker of heat strain. Therefore, it is reasonable to assume that heat illness risk correlates with T_c, the authors did acknowledge that the exclusion of T_c was a limitation. Furthermore, Relf *et al.,* (2017) reported low HISI scores (a maximum of 58 out of 130) despite high physiological strain; heart rate (HR) >180 $b.min^{-1}$ and $T_{re} >$ 39.5°C. This possibly indicates that the HISI is not sensitive enough to detect minor signs of heat-related illness and this could be due to symptoms such as vomiting and chills within the HISI being more indicative of severe heat-related illnesses. Lastly, the structure of the HISI can result in ambiguity in how individuals should categories the severity of their symptoms, due to minimal explanation of the difference between a mild, moderate or severe symptom. Consequently, the HISI relies on the subjectivity of the individual to a greater extent, which is likely to differ between individuals. The structure could be further improved with the separation of heat illness signs and symptoms. Symptoms of mild heat illness are and can be self-reported, however, when an individual is suffering from confusion, as is common in heat stroke, they cannot self-diagnose this sign, therefore, requiring an observer to report on their HRI signs.

Interestingly, to the researcher's knowledge there has been no further advancements in quantifying minor HRI symptoms. A reliable and valid tool for the assessment of HRI has the potential to prevent severe HRI such as heat stroke, in all populations including vulnerable populations such as the elderly.

2.7. Acute heat-illness prevention strategies

Research with athletic and occupational (*i.e.,* firefighters) populations have demonstrated a decrease risk of developing severe heat-related illnesses when acute physical cooling interventions are applied (Lee *et al.,* 2008; Bongers *et al.,* 2014; Ruddock *et al.,* 2017). To date, there is minimal evidence of using acute physical cooling interventions to prevent heat-illness in the elderly population. Therefore, this section reviewed the acute physical cooling interventions used with athletes, before reviewing the limited elderly specific acute cooling research.

Cooling strategies can be applied; pre, during (*i.e.,* per-cooling), post exercise-heat exposure or as any combination of the three time-points (*i.e.,* combination of pre and per-cooling) (Bongers *et al.,* 2014; Brearley & Walker, 2015; Tyler *et al.,* 2015; Ruddock *et al.,* 2017). Furthermore, cooling can be implemented externally, internally or combined (*i.e.,* mixed methods). It is widely accepted, that post cooling via external cold water immersion is the *'gold standard'* method for rapidly reducing core temperature when it is suspected that a patient is suffering from heat stroke, to prevent heat-related mortality (Armstrong *et al.,* 2007; Casa *et al.,* 2007; Gagnon *et al.,* 2010). Consequently, strategies to prevent the development of heat stroke via pre and per-cooling are evaluated in this section.

Recent research has also examined perceptual cooling interventions to improve athletic performance (Stevens *et al.,* 2015; Flood *et al.,* 2017; Steven & Best, 2017; Barwood *et al.,* 2018a; Best *et al.,* 2018; Jeffries *et al.,* 2018). Perceptual cooling strategies can also be applied externally and internally and this section will review the literature on the mechanisms of perceptual cooling and how this relates to the elderly population.

2.7.1. Physical cooling strategies for the prevention of heat-related illness

The majority of research into the heat-alleviating effects of physical cooling has been within athletic and occupational populations, such as firefighters (Bongers *et al.,* 2014; Brearley & Walker, 2015; James *et al.,* 2015; Tyler *et al.,* 2015; Ruddock *et al.,* 2017; Stevens *et al.,* 2017; Watkins *et al.,* 2018). The purpose of physical cooling for those populations is to reduce physiological strain and specifically for athletes, improve performance (Duffield *et al.,* 2011; Lee *et al.,* 2013; James *et al.,* 2015; Stevens *et al.,* 2017). One method of physical cooling is external application of cooling devices which include; cooling garments, cooling packs, cold water immersion (local and whole body) and cold towels (Tyler *et al.,* 2010; Tyler *et al.,* 2015; Duffield *et al.,* 2011; Ross *et al.,* 2013; Faulkner *et al.,* 2015). When these methods are applied as a pre-cooling method, physiological strain is reduced by lowing absolute core temperature and skin temperature prior to exercise (Bongers *et al.,* 2014; Tyler *et al.,* 2015). Cooling develops through the heat transfer from the warm body to the cooling device. Consequently, a greater capacity for heat storage prior to exercise develops (Bongers *et al.,* 2014; Tyler *et al.,* 2015). Bongers *et al.,* (2014) found that literature investigating the use of external pre-cooling had reductions in peak core temperature between -0.1 and -0.4°C. Furthermore, external per-cooling had peak core temperature changes between +0.2 and -0.3°C, and a maximum HR decrease of 5 b.min^{-1}. These results are based on one pre or per-cooling technique being used during experimental testing.

Bongers *et al.,* (2014) also reviewed mixed methods cooling approach. These approaches have the potential to further increase the capacity for heat storage via the application of multiple cooling methods over a greater surface area of cooling. The review found the greatest improvement in performance (+7.3%) when mixed method pre-cooling approaches were applied. Additionally, that the average decrease in maximum core temperature was -0.3°C and that HR decreased by -3 b.min^{-1} after pre-cooling with mixed methods external cooling. James *et al.* (2015) later supported the ergogenic effect of 20-min mixed methods pre-cooling, with an approach consisting of; cold towels, forearm immersion, ice vest and cooling shorts. The main finding was an increase in speed (+0.3 km.h^{-1}) at a fixed lactate concentrations of 2 mmol.L^{-1}. Also there was an attenuation in rise of core temperature during exercise compared to control, 1.01 ± 0.25°C *vs.* 1.11 ± 0.29°C. Although, external pre and per-cooling have reduced thermal strain and improved performance the type of cooling technique is important to consider, especially for the target population within this thesis, the elderly. It is unrealistic to expect the elderly to wear a cooling garment whilst completing activities of daily living in the summer, or complete cold water immersion to prevent a rise in thermal strain. Especially, as research has found these techniques as impractical for the use of athletes, due to the cost, weight, storage, feasibility, accessibility and discomfort of a cold garment on the body (Ross *et al.,* 2013; Tyler *et al.,* 2015; Ruddock *et al.,* 2017).

In athletic populations there has been an emphasis on practical internal cooling techniques, including ice slurry and cold water ingestion. Ice slurry ingestion as a method of pre-cooling has received considerable attention in the literature (Siegel *et al.,* 2010; Siegel *et al.,* 2012; Ross *et al.,* 2013; Bongers *et al.,* 2014; Morris *et al.,* 2016; Ruddock *et al.,* 2017). Ice slurries typically reduce core temperature between 0.3–0.6°C, prior to exercise in the heat (Siegel *et al.,* 2010; Siegel *et al.,* 2012). Although, ice slurry research has seen improvements in exercise performance in hot environments and reductions in physiological strain, there are reports of ice slurry leading to gastrointestinal distress in participants (Ross *et al.,* 2013; Stevens *et al.,* 2015). Conversely, cold fluid ingestion has minimal gastrointestinal discomfort. Studies have investigated the effects of fluid temperature on heat loss, across a range of fluid temperatures (1.5°C-50°C) (Mündel *et al.,* 2006; Lee *et al.* 2008; Bain *et al.,* 2012; Barwood *et al.,* 2018b).

The temperatures with the greatest practical application is refrigerated beverages (~4°C). Mündel *et al.,* (2006) investigated time to exhaustion when cycling at 65% of peak aerobic power in a 34°C, 28% RH, when drinking either cold (4°C) or control (19°C), orange carbohydrate drink *ad libitum*. The study found that the participants drank more cold compared to control temperature fluid; 1.3 ± 0.3 $L.h^{-1}$ *vs.*1.0 ± 0.2 $L.h^{-1}$. Furthermore, that physiological strain was reduced, end exercise T_{re} (-0.25°C) and HR were lower (-5 $b.min^{-1}$), compared to the control condition. Likewise, Lee *et al.,* (2008) investigated the effects of different temperature water (4°C *vs.* 37°C) ingested periodically (every 10-min) during rest and exercise. The rest was 30-min and participants drank 300ml of water every 10-min, followed by cycling exercise at 65% $\dot{V}O_{2max}$ to exhaustion where participants drank 100ml of water every 10-min. The cold water trial reduced T_{re} (-0.5 ± 0.1°C) and HR (-8 $b.min^{-1}$), at the end of rest compared to the 37°C trial. Furthermore, T_{re} was significantly lower in the cold water trial compared to control from 10-min into rest until 45-min into exercise and HR was reduced from 25-min into rest until 35-min into exercise. Consequently, cold fluid ingestion at 4°C could provide the most practical and comfortable intervention to attenuate the rise in markers of heat illness in the elderly. Additionally, it could also improve hydration as research suggests greater fluid intake at 4°C than at 19°C (Mündel *et al.,* 2006).

2.7.2. Elderly and physical cooling strategies for the prevention of heat-related illness

As identified, the elderly suffer the greatest health consequences during periods of hot weather (Conti *et al.,* 2005; Hajat *et al.,* 2014; Kenney *et al.,* 2014). Therefore, it is surprising the lack of research investigating acute heat-alleviating strategies for the elderly population. To date, the research has focused on when and when not to use fans (Jay *et al.,* 2014; Gagnon *et al.,* 2016; Gagnon & Crandall, 2017). Gagnon *et al.,* (2016) investigated the use of fans with elderly people (68 ± 4 yrs) at 42°C at different relative humidities (30-65%) (Figure 2.19). The findings were that the use of fans increased HR and core temperature at relative humidities of 55% and 65% compared to not using a fan. This supports Jay *et al.,* (2014) theoretical model that the use of a fans would not be of benefit within those environmental conditions for the elderly (Figure 2.19). It is noteworthy, that the study highlights that the extreme conditions replicated in the experiment have only been evident in two heatwaves in past 20 years and therefore elderly people should not dismiss the use of fans in less extreme conditions which are common in the UK in the summer months. Figure 2.19 presents how Gagnon *et al's.,* (2016) findings effect the research of Jay *et al.,* (2014) model.

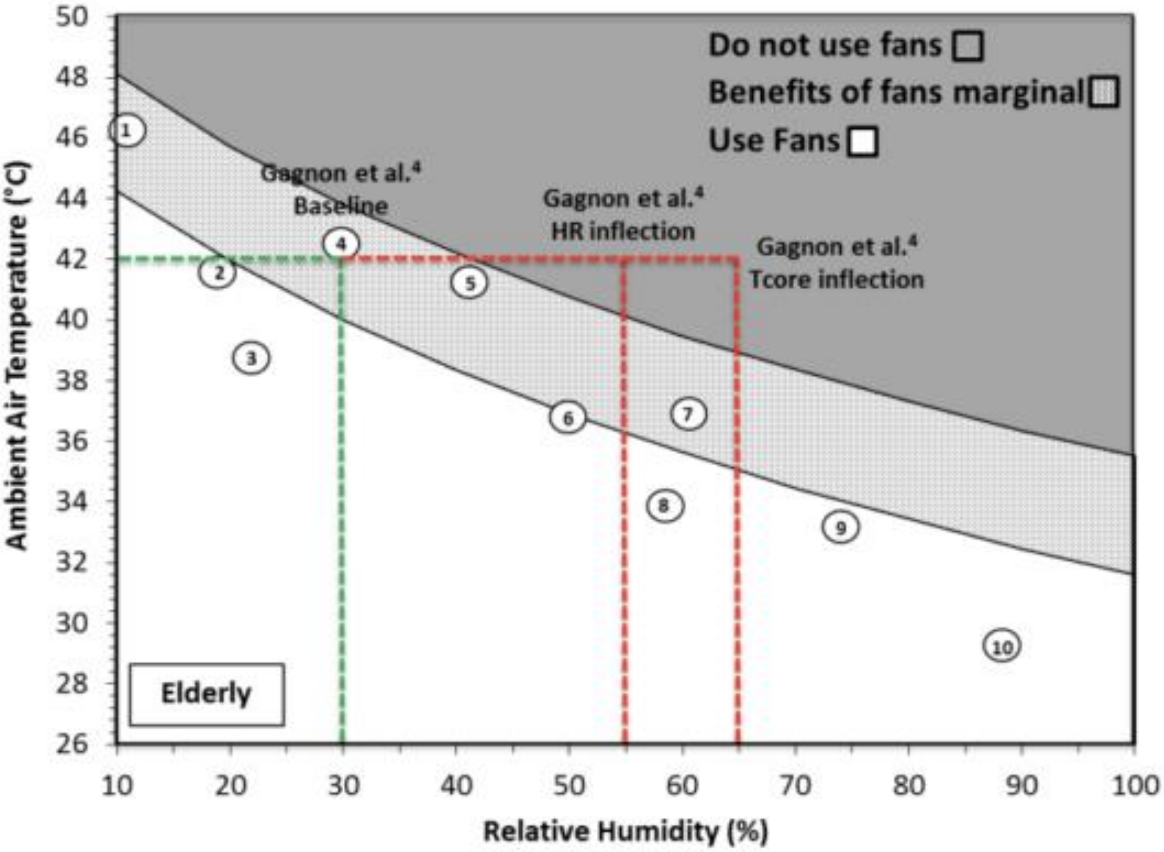


Figure 2.19*:* Predicted environmental limits at which fan use is either: beneficial (white area), marginally beneficial (light grey area), or detrimental (dark grey area) for the elderly. The green dashed lines represent the baseline environmental conditions of the Gagnon *et al.,* (2016) protocol (42°C, 30% RH). The red dashed lines represent the environmental conditions at which an increase in heart rate (HR; 42°C, ~55% RH) and core temperature (T_c; 42°C, ~65% RH) occurred during a step-wise increase in relative humidity. The circled numbers indicate the peak outdoor conditions for 10 of the most severe heatwaves in the past 20 years: (1) Washington, DC, 2012 (day); (2) Paris, France, 2003 (day); (3) Newark, NJ, 2011; (4) Chicago, IL, 1995; (5) New York, NY, 2006; (6) Chicago, IL, 1999 (day); (7) Washington, DC, 2012 (night); (8) Chicago, IL, 1999 (night); (10) Paris, France, 2003 (night). Figure taken from Gagnon & Crandall (2017).

Air-conditioning has also been used as an effective acute cooling strategy for the prevention of heat-related illness in the elderly population (Theocharis *et al.,* 2013). However, in the UK the vast majority of homes are not equipped with air conditioning (<1%, BBC, 2013). Furthermore, countries where air-conditioning is common place, find that elderly people are less likely to put it on, for the fears of not being able to afford the running costs (Sampson *et al.,* 2013). Therefore, simple, practical and cost-effective acute cooling interventions such as; cold water ingestion, should be investigated for the UK elderly population.

2.7.3. The effect of perceptual cooling

Perceptual cooling has also been investigated in athletic populations to improve performance (Stevens *et al.,* 2015; Flood *et al.,* 2017; Steven & Best, 2017; Barwood *et al.,* 2018a; Best *et al.,* 2018; Jeffries *et al.,* 2018). To evoke a cooling sensation, the transient receptor potential melastatin-eight (TRPM8) ion channels require a thermal (*i.e.,* physical cooling) or chemical (*i.e.,* perceptual cooling) impulse (Peier *et al.,* 2002). Menthol can provide the chemical impulse to activate the TRPM8 ion channels to elicit a cooling sensation (Peier *et al.,* 2002). Although, menthol is found in a number of active forms, the L isomer produces the strongest cooling sensation (Eccles *et al.,* 1988).

A number of recent research studies have used L-menthol to improve exercise performance (Stevens *et al.,* 2015; Flood *et al.,* 2017; Steven & Best, 2017; Barwood *et al.,* 2018a; Best *et al.,* 2018; Jeffries *et al.,* 2018). The cooling sensation that L-menthol provides, can lead to a greater feeling of comfort during exercise (Steven & Best, 2017). Improved thermal comfort changes the behavioural thermoregulation of the athlete, thereby they feel like they can increase the work done leading to performance improvements (Steven & Best, 2017; Best *et al.,* 2018). Menthol can be applied externally to the skin, as a spray or cream or internally as a mouth swill (Best *et al.,* 2018). Improvements in performance have been seen in both external (0-21%, Schlader *et al.,* 2011; Steven & Best, 2017; Barwood *et al.,* 2015, 2018a) and internal methods (3-9%, Best *et al.,* 2018; Jeffries *et al.,* 2018; Steven & Best, 2017; Stevens *et al.,* 2015). Although, external methods can have an ergogenic effect, they should be used with caution as they can cause irritation to the skin (Gillis *et al.,* 2010).

The additional work done during L-menthol application trials have resulted in an increase in thermal strain, evidenced by significantly greater core temperatures (Gillis *et al.,* 2010; Schlader *et al.,* 2011; Lee *et al.,* 2012; Gillis *et al.,* 2016). This is because of a behavioural thermoregulatory change to the athlete, whereby they do not feel uncomfortable enough to perceive the need to slow down (Flouris, 2011; Schlader, 2014; Flouris & Schlader, 2015). Therefore, they have the capacity to increase the amount of work completed, consequently there is an accumulation of metabolic heat and an elevation in core temperature (Gillis *et al.,* 2010; Schlader *et al.,* 2011; Lee *et al.,* 2012; Gillis *et al.,* 2016). Schlader *et al.,* (2011) demonstrates this by an increase in absolute work done and change in exercise core temperature in menthol (MENT) compared to control (CON) trials, during cycling exercise with a RPE clamp of 16: MENT; 228.7 ± 23.7 kJ and 0.97 ± 0.13°C, CON; 187.4 ±16.7 kJ and 0.74 ± 0.06°C.

It is noteworthy that not all L-menthol application studies found an ergogenic effect on performance. Gibson *et al.,* (2018) found that intermittent sprint performance, determined by peak power output and work done, in the heat (40°C, 50%RH) was not improved compared to water swill and placebo, when L-menthol was swilled every 10-min. Furthermore, Bright *et al.,* (2019) found no additional performance benefit when administering neck cooling plus L-menthol compared to the control trial, despite neck cooling plus L-menthol having a greater perceptual cooling effect. Therefore, not all perceptual cooling effects result in improvements in performance.

2.7.4. The potential effect of perceptual cooling on the elderly population

The increase in thermal strain is important when considering acute cooling for the elderly population because L-menthol is an active substance within some commercially available cooling products (Physicool^{TM} and Magicool^{TM}) that they could purchase to alleviate their heat strain. To the researcher's knowledge there is no research investigating the effects L-menthol on function or heat perception in an elderly population. The potential consequence of these products may be to worsen behavioural thermoregulation in an elderly population, by delaying the life-saving thermoregulatory behaviours such as; seeking shade, taking extra layers of clothing off and opening windows (Smoyer-Tomic & Rainham 2001; Bouchama & Knochel, 2002; Flouris, 2011; Sawka *et al.,* 2011; Kenney *et al.,* 2014). These thermoregulatory behaviours attenuate heat illness risk, therefore if the elderly do not feel uncomfortable enough to implement them, they are unknowingly putting themselves at greater risk of heat illness.

2.8. Chronic strategies for the prevention of heat-related illness

The risk of developing severe heat-related illnesses is also reduced through implementing chronic heat-alleviating strategies (Armstrong & Maresh, 1991; Gosling *et al.,* 2008; Minett *et al.,* 2016). Heat acclimatisation and heat acclimation (HA) are chronic heat-alleviating interventions, in which physiological adaptations to the heat can develop (Daanen *et al.,* 2011; Taylor, 2014a; Périard *et al.,* 2015). Acclimatisation is when adaptation to an environment occurs naturally through exposure to the environment (Daanen *et al.,* 2011; Taylor, 2014a; Périard *et al.,* 2015). Whereas, acclimation is when an artificial climate exposure, generally conducted within a climatic controlled chamber, is used (Daanen *et al.,* 2011; Taylor, 2014a; Périard *et al.,* 2015). Similar to acute cooling strategies the majority of research into the heat-alleviating benefits of HA has been within athletic populations to improve performance (Lorenzo *et al.,* 2010; Garrett *et al.,* 2014; Taylor, 2014a; Gibson *et al.,* 2015ab; Mee *et al.,* 2015; Tyler *et al.,* 2016; Willmott *et al.,* 2016; James *et al.,* 2017). Therefore, this section will review the HA literature of athletes to understand the mechanisms that underpin the adaptation process, before reviewing the limited HA research with the elderly.

2.8.1. Heat acclimation adaptations

During heat stress or exercise-heat stress the primary sensors (*i.e.,* blood pressure sensors, osmoreceptors and thermoreceptors) send afferent signals to the medulla oblongata and hypothalamus (Figure 2.20) (Taylor, 2014a), The response is to initiate a corresponding efferent signal to maintain thermal homeostasis (Taylor, 2014a). When the adaptation impulse is maintained (*e.g.,* HA) then adaptations to the five regulated variables will develop (*e.g.,* mean body temperature will decrease), to better maintain thermal homeostasis (Figure 2.20) (Taylor, 2014a). These adaptations occur to the; thermoregulatory system, cardiovascular system, sudomotor function, perception of the exercise and environment (Armstrong & Maresh 1991; Taylor, 2000; Sawka *et al.,* 2011; Taylor, 2014a; Périard *et al.,* 2015) (Figure 2.20). There are also metabolic adaptations and enhanced cellular protection, however, these are beyond the scope of this literature review (Sawka *et al.,* 2011).

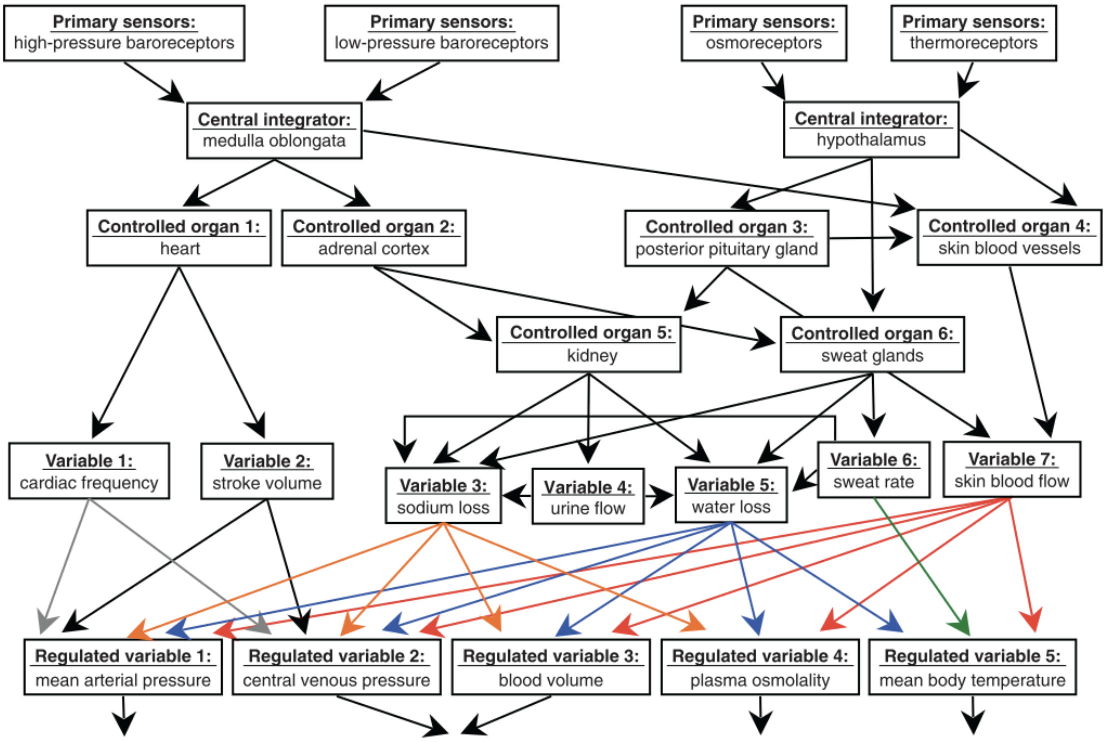


Figure 2.20: An integrated overview of the homeostatic mechanisms and physiological responses accompanying heat stress. Figure from Taylor, (2014a).

Thermoregulatory adaptation

Thermoregulatory adaptation includes; increased skin blood flow, reduced skin temperature and reductions in resting and exercise intensity specific core temperature (Sawka *et al.,* 2011; Taylor, 2014a). Increases in skin blood flow supplies a greater about of heat from the core to the skin surface for subsequent sweat evaporation and therefore cooling (Sawka *et* *al.,* 2011; Taylor, 2014a). Changes in skin blood flow occur centrally and peripherally. The central adaptation is reduced core temperature for the onset of skin blood flow, post HA (Figure 2.21) (Taylor, 2014a). The peripheral change is an increase in sensitivity of the blood vessels, whereby there is greater vasodilation and therefore skin blood flow at a given core temperature (Figure 2.21) (Taylor, 2014a). Skin temperature reduces post HA (Tyler *et al.,* 2016). The reduction is associated with a greater efficiency to lose heat at the same relative skin blood flow (Tyler *et al.,* 2016). These changes and the ones to be described below, result in a reduction in resting (-0.18 ± 0.14°C) and exercise (-0.34 ± 0.24°C) intensity specific core temperature (Tyler *et al.,* 2016).

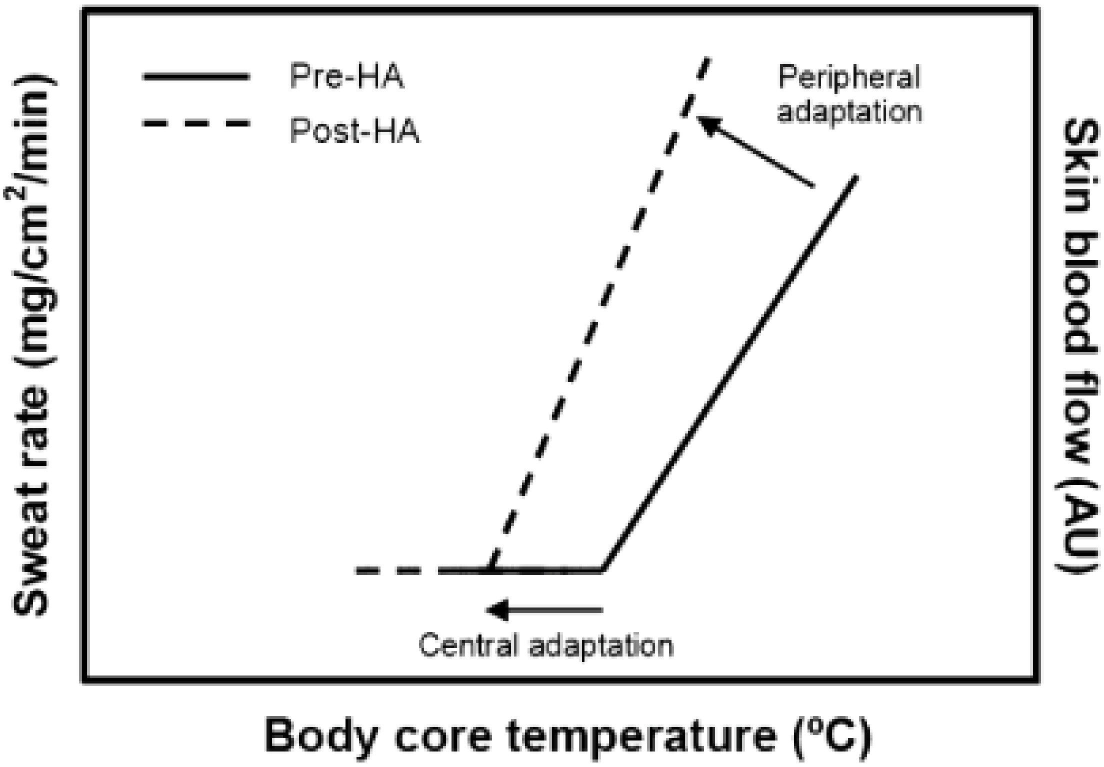


Figure 2.21: Represents the central and peripheral adaptations in sudomotor function post HA. Core temperature at the onset of sweating is decrease (*i.e.,* central adaptation). Increase in sweat rate and sensitivity with a steeper slope (*i.e.,* peripheral adaptation). Figure from Périard *et al.,* (2015).

Cardiovascular adaptation

The cardiovascular adaptations to HA include; hypervolemia and a reduced resting and exercise intensity specific HR (Armstrong & Maresh 1991; Taylor, 2000; Sawka *et al.,* 2011; Taylor 2014a; Périard *et al.,* 2015). Plasma volume (PV) expansion leads to hypervolemia. Plasma volume expansion is an essential adaptation for maintaining cardiovascular stability during heat stress (Taylor, 2000; Taylor 2014a; Périard *et al.,* 2015). In the absence of increased PV, sweating during exercise-heat stress has the potential to reduce stroke volume and increase HR to maintain cardiac output (Taylor, 2000). When PV expands the body has a greater capacity to lose fluids through sweating and still maintain stroke volume and cardiac output (Taylor, 2000). Therefore, post HA, stroke volume is greater and cardiac frequency is lower for a given exercise intensity in the heat (Taylor, 2000). Consequently, at these given intensities, greater blood flow can be directed to the skin for heat dissipation (Taylor, 2000). HA also reduces resting and exercise intensity specific HR, which is referred to as a '*classic adaptation'* to HA (Sawka *et al.,* 2011). These adaptations improve cardiovascular stability and reduce cardiovascular strain (Armstrong & Maresh 1991; Taylor, 2000; Sawka *et al.,* 2011; Taylor 2014a; Périard *et al.,* 2015).

Sudomotor adaptation

The changes in sudomotor function present arguably the most important adaptive responses to HA (Taylor, 2000). This is because sweating provides the greatest physiological capacity to lose excess heat (Tansey & Johnson, 2015). Therefore, increases in sudomotor function allow for a greater maintenance of heat balance. The sudomotor adaptations are; increased sweat rate at a given sub-maximal exercise intensity, increased sweat gland sensitivity relative to core temperature changes, a reduced core temperature at the sweating threshold and increased sodium retention (Taylor, 2000; Shibasaki *et al.,* 2006; Taylor, 2014a; Périard *et al.,* 2015; Tansey & Johnson, 2015; Tyler *et al.,* 2016). Changes in sudomotor function occur centrally and peripherally (Figure 2.21) (Shibasaki *et al.,* 2006; Périard *et al.,* 2015). The central change is a reduction in core temperature at the onset of sweating (*i.e.,* sweating threshold) (Figure 2.21). The peripheral changes are an increase in the size and efficiency of the eccrine sweat glands (Figure 2.21) (Sato *et al.,* 1990). The size of sweat glands are correlated with sweat rate (Sato & Sato, 1983), whereby, larger sweat glands produce a greater amount of sweat (Sato & Sato, 1983; Sato *et al.,* 1990; Shibasaki *et al.,* 2006; Périard *et al.,* 2015). The combination of increased sweat rate and an earlier onset of sweating improves evaporative cooling leading to a reduction in skin temperature and skin blood flow, for a given core temperature (Périard *et al.,* 2015).

Post HA, there is also an increase in electrolyte (*e.g.,* chloride) reabsorption and a reduction in sodium secretion, thus changing the composition of the secreted sweat (*i.e.,* more diluted sweat) (Taylor, 2014a; Périard *et al.,* 2015; Tyler *et al.,* 2016). The increased reabsorption of electrolytes lowers the cutaneous water vapour pressure at a given skin temperature (Taylor, 2014a; Périard *et al.,* 2015; Tyler *et al.,* 2016). Therefore, a more dilute sweat is more readily evaporated due to the greater water vapour gradient between the skin and the ambient air (Taylor, 2014a; Périard *et al.,* 2015; Tyler *et al.,* 2016).

It is noteworthy, that adaptations in sudomotor function are only beneficial when the environment and situation allows for sweat evaporation. For instance, when the environment is very humid, increased sweat production will not be evaporated away from the body, as the air is already saturated with moisture (Kenney *et al.,* 2015). Consequently, heat is not removed via the process of evaporation and there is no reduction in thermal stress, instead the increased fluid loss requires greater fluid intake to retain a fluid balance (Kenney *et al.,* 2015).

Perceptual adaptation

There is evidence to suggest that perception of exercise intensity and how hot the environment feels is also improved post HA (Armstrong & Maresh 1991; Tyler *et al.,* 2016; Willmott *et al.,* 2016). Improvements in RPE are associated with a decrease in cardiovascular (*i.e.,* reduced HR) and thermal strain (*i.e.,* reduced core temperature) (Armstrong & Maresh, 1991). Whereas improvements in thermal sensation are most likely associated with a decrease in skin temperature (Flouris & Schlader, 2015). These improvements in perception have also resulted in participants feeling more comfortable in the hot exercise environments (Sawka *et al.,* 2011; Willmott *et al.,* 2016). Therefore, HA can physiologically adapt people to the heat, resulting in less risk of heat illness whilst also improving their feeling of exertion and comfort in the environment (Sawka *et al.,* 2011; Périard *et al.,* 2015; Tyler *et al.,* 2016).

In summary, HA benefits include: a decrease in resting and exercise core temperature and HR, an early onset of sweating, increase sweat rate and sensitivity, retention of sodium concentration, increase in skin blood flow, reduced skin temperature, increase in plasma volume, improved rate of perceived exertion and thermal sensation (Armstrong & Maresh 1991; Taylor, 2000; Taylor, 2014a; Sawka *et al.,* 2011; Périard *et al.,* 2015). These adaptations result in an increased heat loss capacity and heat tolerance.

2.8.2. Types of heat acclimation

There are four types of heat acclimation; a constant work-rate/ fixed-intensity, self-regulated exercise, passive exposure and isothemic /controlled hyperthermia heat acclimation (Taylor & Cotter, 2006; Périard *et al.,* 2015; Racinais *et al.,* 2015). The constant work rate model is also referred to as the fixed-intensity HA model. The HA exercise intensity is prescribed at the start of the HA programme and remains the same for every HA session (Taylor & Cotter, 2006; Périard *et al.,* 2015; Racinais *et al.,* 2015). Typically, the work rate is based on a percentage $\dot{V}O_{2max}$. Secondly, self-regulated HA models either use a constant subjective measure during HA, whereby, RPE is set (*e.g.,* RPE = 15) and the participants will change their exercise intensity to consistently maintain the set RPE (Neal *et al.,* 2016). Alternatively, the self-regulated model can set the work to rest ratios and the participants control how hard they work (Taylor & Cotter, 2006; Racinais *et al.,* 2012; Racinais *et al.,* 2015). Thirdly, passive HA involves sedentary exposure to a hot environment. Passive HA methods include: sitting in an environmental chamber (Fox *et al.,* 1963a; Racinais *et al.,* 2017), saunas (Scoon e*t al.,* 2007; Stanley *et al.,* 2015) and hot water immersion (HWI) (Zurawlew *et al.,* 2016). Adaptations develop as result of the external heat stress. Lastly, isothermic acclimation, also referred to as controlled hyperthermia, is considered the optimal method for achieving heat adaptations (Taylor, 2014a; Périard *et al.,* 2015; Racinais *et al.,* 2015). Thus there has been considerable research using the method, especially in recent years (Fox *et al.,* 1963b; Fox *et al.,* 1967; Garrett *et al.,* 2011; Garrett *et al.,* 2012; Gibson *et al.,* 2015ab; Mee *et al.,* 2015; Willmott *et al.,* 2016; James *et al.,* 2017). Isothermic heat acclimation uses a set target core temperature which participants maintain throughout heat exposure and HA programme (Daanen *et al.* 2011; Taylor, 2014a; Périard *et al.,* 2015). The core temperature is usually set around 38.5°C and is controlled by manipulating the workload (Daanen *et al.* 2011; Taylor, 2014a; Périard *et al.,* 2015). Therefore, workload is decreased when core temperature >38.5°C and vice versa (Fox *et al.,* 1963b; Gibson *et al.,* 2015a). The time spent with a core temperature >38.5°C is an important factor of the isothermic HA model, as it is considered the driver of adaptation (Fox *et al.,* 1963b; Taylor, 2014a; Gibson *et al.,* 2015a). Studies aim to increase core temperature to 38.5°C within ~30-min of entering the hot environment and maintain core temperature for a further ~60-min, per HA session (Gibson *et al.,* 2015ab; Mee *et al.,* 2015; Neal *et al.,* 2016; Willmott *et al.,* 2016; James *et al.,* 2017).

Heat adaptations have been achieved through all four methods. However, the magnitude of adaptation is dependent on the frequency, intensity, duration and number of heat exposures (Périard *et al.,* 2015). Typically, HA consists of single daily heat exposures of 60-120-min, with a work rate equating to an end core temperature of 38.5-39°C, with a traditional programme lasting 10-14 days (Armstrong & Maresh, 1991; Daanen *et al.,* 2011; Sawka *et al.,* 2011). Furthermore, the population requiring HA should be considered when selecting the type of HA, whereby, passive interventions may be more effective on a sedentary population, due to reduced physiological stress without having to complete exercise (Taylor & Cotter, 2006). Whereas, active acclimation methods, increase the physiological strain compared to passive methods, therefore adaptations could develop more quickly (Taylor & Cotter, 2006).

2.8.3. Optimising heat adaptations

Taylor *et al.,* (2014a) explain the stages in acquiring the optimal physiological adaptations to heat stress (Figure 2.22). Firstly, a strong exercise-heat stress or thermal stimulus (*i.e.,* adaptation impulse) is required to initiate an imbalance in thermal homeostasis. Secondly, if the adaptation impulse is sustained over a sufficient amount of time, then after a latency period (4-days), physiological adaptations will develop. Thereafter, if the adaptation impulse is not increased then adaptations will plateau, leaving an adaptation reserve between acquired adaptation and the genetically determined physiological maximum for adaptation. Once the adaptation impulse is removed (*i.e.,* stop HA) then there will be decay in adaptation, eventually returning to pre-adaptation baseline (Figure 2.22).

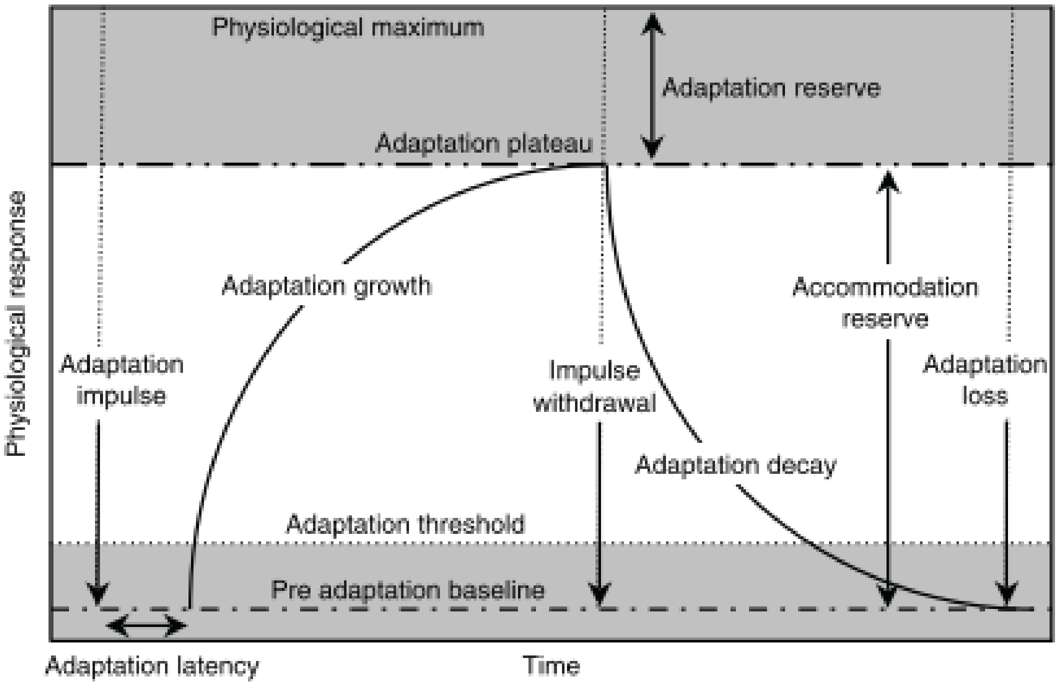


Figure 2.22: Characteristic of physiological adaptation. Figure from Taylor, (2014a).

2.8.4. Time course for adaptation

The time course of the adaptations are dependent upon type of adaptation, inter-individual adaptation variation, previous HA exposure and method of HA (Taylor *et al.,* 2014a; Périard *et al.,* 2015; Daanen *et al.,* 2017; Corbett *et al.,* 2018). However, Armstrong & Maresh (1991), later updated by Périard *et al.,* (2015) present the general time course for physiological adaptations to the heat (Figure 2.23). The first physiological adaptation is a reduction in HR, developing within the first 4-5 days of HA and near optimal adaptation by day 7 (Sawka *et al.,* 2011; Périard *et al.,* 2015). Adaptations in skin and core temperature, plasma volume expansion and thermal perception occur with ~7 days (Armstrong & Maresh, 1991; Sawka *et al.,* 2011; Périard *et al.,* 2015). Changes in sudomotor function require the most stimulus for adaptation and require between 8-14 days of heat exposure to develop (Armstrong & Maresh, 1991; Sawka *et al.,* 2011; Périard *et al.,* 2015). Although near optimal adaptation may require 14 days of heat exposure, the majority of adaptations (75%-80%) can be obtained in the first 4-7 days of HA (Pandolf, 1998).

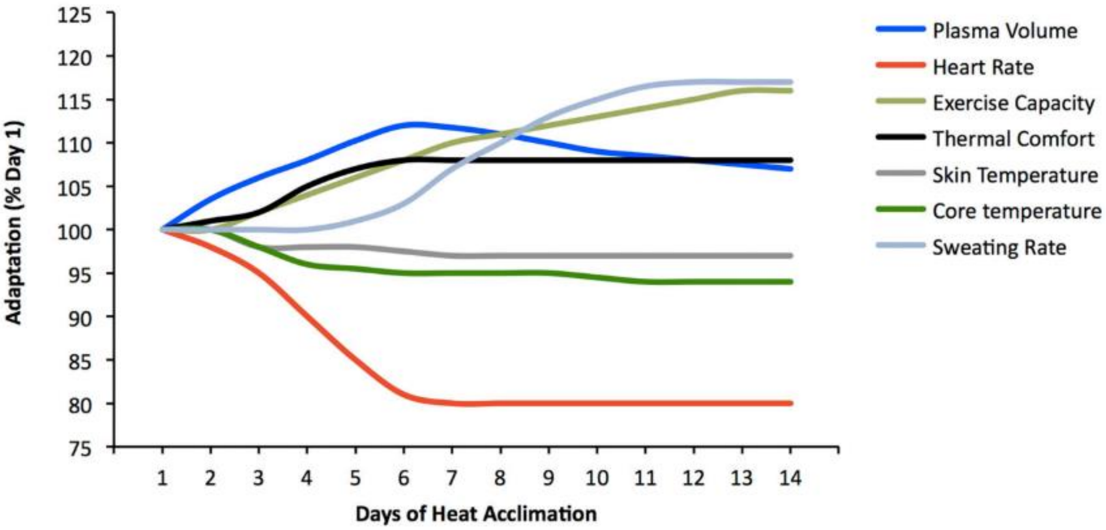


Figure 2.23: Time course of physiological adaptations to heat acclimation. Figure from Périard *et al.,* (2015).

2.8.5. Duration of heat acclimation

Heat acclimation programmes can be defined by the duration (*i.e.,* how many days of HA) or by the acclimation method (*e.g.,* isothermic HA). There are three duration lengths, in which acclimation can be categorised by; short (<7 days), medium (8-14 days) or long (>15 days) (Garrett e*t al.,* 2011; Périard *et al.,* 2015). Traditional acclimation programmes are within the medium time range (10-14 days) and typically use a constant work rate model (Lorenzo *et al,* 2010; Racinais *et al,* 2014). There has been an emphasis in the sport performance research to reduce the number of days required to develop heat adaptations (Garrett *et al.,* 2011; Garrett *et al.,* 2012; Gibson *et al.,* 2015ab; Mee *et al.,* 2015; Neal *et al.,* 2016; Willmott *et al.,* 2016; James *et al.,* 2017).

In the context of heat-related illness prevention for the elderly, short term HA provides the greatest practical intervention, as the MET Office provides a 5-day weather forecast for all weather (MET Office, 2018f). The current heatwave preparation time given to the public is 3 days, the accuracy (± 2°C) of the 3 day MET Office forecasts is ~87% (MET Office, 2018f). The accuracy of the 4-day weather forecast is now as accurate as the next day forecast was 30 years ago (MET Office, 2018f). Therefore, the public can start preparing for hot weather 5-days prior to its arrival and will be fairly certain of how hot and how long the weather will last, 3 to 4-days before the hot weather starts.

2.8.6. Young healthy adults and heat acclimation

Constant work rate

The Lorenzo *et al.,* (2010) study is an example of a constant work rate HA protocol. Participants conducted 10-days HA (40°C, 30% RH), each session consisting of two 45-min bouts of cycling exercise at 50% $\dot{V}O_{2max}$, with 10-min passive rest in between bouts. Findings suggested a significant decrease in core temperature (-0.5°C) and HR (-15 b.min^{-1}). Whilst there were no differences observed in the control group that completed the exercise regime in temperate conditions (13°C, 30% RH). Plasma volume expanded in the HA group (+6.5%) but not in the control group (-4.6%). Other constant work rate studies have also found similar adaptive responses (Nielsen *et al.,* 1993; Cheung & McLellan 1998; Lorenzo & Minson, 2010; Castle *et al.,* 2011; Tyler *et al.,* 2016). Although, adaptations through constant work rate are evident, the physiological strain does not change during the HA programme, therefore, there is less of a stimulus for adaptation from the first HA session to the last. Consequently, the magnitude of adaptation stimulus is decreased compared to protocols that have progressive physiological stimulus (*e.g.,* isothermic HA) (Taylor & Cotter, 2006; Taylor *et al.,* 2014a; Périard *et al.,* 2015; Racinais *et al.,* 2015; Tyler *et al.,* 2016).

Research has also investigated heat adaptation when applying a progressive fixed intensity model by, increasing environmental temperature, intensity and/or duration of exercise, during the HA programme. Thereby increasing the thermal/physical strain during the HA, to potentially increase the magnitude of heat adaptations (Daanen e*t al.,* 2011; Chen *et al.,* 2013). Daanen *et al.* (2011) increased environmental temperature from 35°C, 29% RH for the first 9 days, to 41°C, 33%RH for the last 3 days. The exercise intensity was a constant work rate of 45% $\dot{V}O_{2max}$ for the initial 60-min, thereafter the participants completed incremental exercise starting at 50W and increasing in 3W for 30-min, 6W for the next 15-min and 9W for the last 15-min. On completion of 9 days HA, T_{re} and HR after 60-min was significantly reduced; -0.58°C and -25 b.min^{-1}. This was not further reduced with the additional hotter HA days. However, when participants completed the same test 7 days after the initial 12 days of HA, T_{re} and HR after 60-min was further reduced; -1.22°C and -27 b.min^{-1}(values are change from day 1 of HA. The continued adaptation post 12 days HA could be a finding from the additional hotter HA days. Chen *et al.,* (2013) progressed the fixed intensity model by increasing the duration (+5-min each day from an initial 25-min) and intensity (+5% ventilatory threshold each day from an initial intensity of 10% below ventilatory threshold) of exercise throughout the 5-day HA. There was a significant decrease in HR by 5-10% (core temperature was not obtained). The Daanen *et al.,* (2011) and Chen *et al.,* (2013) studies are examples of how increasing thermal and physical strain during HA can develop phenotypic adaptations to the heat.

Self-regulated

Neal *et al.,* (2016) combined the use of isothermic and self-regulatory models. Participants were instructed to maintain an RPE of 15 until they reached a pre-determined core temperature (38.3°C) before work load was manipulated by the researcher to maintain a T_{re} of 38.5°C. Racinais *et al.,* (2012, 2015) self-regulated model was to have trained athletes complete acclimatisation. The number of days and time spent completing acclimatisation was controlled by the research however, exercise intensity was controlled by the athletes. Both methods developed phenotypic adaptations with changes in T_{re}, HR, PV and sweat rate (not all adaptations in all studies). The limitation of a self-regulated method is standardising the exercise intensity, work load and physiological strain of the participants. This is due to the drive for adaptation being placed on the motivation of the participants to complete high intensity exercise. Therefore, as motivation changes day-to-day the stimulus for adaptation will change accordingly. However, the strength of the method is that it is simple to implement with large groups of people.

Passive

Fox *et al.* (1963a) reported adaptations with passive HA. The HA protocol of this seminal study was for participants to sit in a 43°C, 100% RH environment for between 30-min and 3 hours achieving an oral temperature between 37.3-38.5°C. Heat stress tests were completed before and after HA, whereby participants were immersed in water up to the sternum and the temperature was increased from 34°C to 43°C. The experiment was terminated at an oral temperature of 38.5°C (total exposure time not given). Findings suggested a significant decrease in resting core temperature (-0.19 ± 0.04°C), HR (approximately -8 $b.min^{-1}$, data taken from figure) and an earlier onset of sweating (-0.18 ± 0.03°C) post HA. There was also an increase in skin blood flow post HA; at the forearm (4.5 ± 1.03 $ml.100ml.min^{-1}$) and hand (2.8 ± 1.32 $ml.100ml.min^{-1}$) measurement sites. This early study shows that passive HA can develop phenotypic adaptations to the heat. However, the HA protocol in this study is considerably long (12-14 days). The length of the protocol would render it unsuitable as a method of heat-adaptation in preparation for a heat wave.

Additionally, the use of environmental chambers are not a practical solution for either; passive or active HA, whereas saunas and HWI could be more accessible and therefore a practical alternative for heat wave preparation. Scoon *et al.,* (2007) and Stanley *et al.,* (2015) used sauna bathing as part of a training programme. The exposure time was 30-min in both studies with temperatures ranging from 87-91°C. The studies found improvement in performance (~2%, Scoon *et al.,* 2007) and plasma volume (+17.8%, Stanley *et al.,* 2015). However, both studies were long term heat acclimation (10-13 sauna exposures). Therefore, the effects of short term HA with sauna bathing is unknown and would be required if it were to be considered a practical HA solution.

The use of HWI in the form of baths could also be a practical solution to HA. Recently, Zurawlew *et al.,* (2016) investigated the adaptive effects of constant work rate exercise and passive hot water immersion over 6 consecutive days. The method of HA combined 40-min running exercise at 65% $\dot{V}O_{2max}$ in temperate conditions (18°C) followed by up to 40-min passive HWI (40°C). The HA group were compared against a control group, which only differed in water temperature (34°C) for the immersion section of the study. Findings suggested significant phenotypic adaptations to the heat when completing HWI; resting T_{re} (-0.27°C) and final T_{re} and HR during submaximal exercise in 18°C (-0.28 °C and -7 $b.min^{-1}$) and 33°C (-0.36°C and -6 $b.min^{-1}$), there was no change in T_{re} or HR in the control group. Furthermore, sweat onset, T_{sk} and RPE were also significantly lower during submaximal exercise in 18 °C and 33 °C post HA (data in figure form). This study highlights that combining the physiological stressors of exercise in temperate conditions and the associated stressors of passive HWI leads to phenotypic heat adaptations in the young.

Isothermic acclimation

Isothermic HA studies have found phenotypic adaptations to the heat after 5-days of HA. These included reductions in resting and exercise HR and $T_{re,}$ increases in PV and sweat rate and decreases in T_{sk} (Gibson *et al.,* 2015ab; Mee *et al.,* 2015; Neal *et al.,* 2016; Willmott *et al.,* 2016; James *et al.,* 2017). These studies highlight the strength of the method being a high thermal stimulus throughout the HA programme to obtain the greatest magnitude of adaptations in a short period of time (Taylor & Cotter, 2006; Périard *et al.,* 2015; Racinais *et al.,* 2015; Tyler *et al.,* 2016). Additionally, Gibson *et al.,* (2015b) evaluated the efficacy of an absolute core temperature of 38.5°C by comparing the phenotypic responses of an isothermic model using 38.5°C for 10-days and 38.5°C for 5-days increasing to 39°C for the final 5-days. The results found no differences in the magnitude of phenotypic adaptations between conditions. This highlights that currently the best independent variable for isothermic adaptation is a core temperature of 38.5°C.

2.8.7. Elderly and heat acclimation

In relation to the elderly population the optimal and most palatable HA strategy for facilitating heat adaptation is currently unknown. Both constant and isothermic methods have been investigated with mixed results and various limitations.

Constant work rate

An early study by Pandolf *et al.,* (1988) investigated the age-related differences in HA between middle aged (average age 46 yrs) and young adults (average age 21 yrs). The HA protocol consisted of two 50-min periods of treadmill walking (1.56 $m.min^{-1}$, 5% grade) separated by 10-min rest for 10 consecutive days in a hot (49°C, 20% RH) environment. End exercise T_{re} and HR decreased in both middle aged (-25 $b.min^{-1}$ and -0.5°C) and young (-19 $b.min^{-1}$ and -0.7°C) adults. Sweat onset and sensitivity were also not different between groups. Although, this study highlights that phenotypic adaptation are achievable in middle aged men, it still remains unclear how older people respond to HA.

Armstrong & Kenney (1993) investigated the effects of a 9 day active, HA protocol on a passive heat stress test in a comparative study between young (26 ± 2 yrs) and old (61 ± 1 yrs) males. The passive heat stress test required the participants to sit initially for 30-min in 28°C environment, the subsequent phase was to increase the dry bulb temperature by 2°C increments every 5-min over 60-min (28–46°C). The last 30-min of the test was conducted in a 46°C environment. The HA protocol required the participants to either cycle or walk at 40% $\dot{V}O_{2max}$ in a 45°C, 27% RH environment for 1.5-2 hours. The results indicated that HA was achieved in both groups with a significant decrease in resting T_c and mean body temperature (T_{mb}), post-acclimation. The acclimation effect on the T_c and T_{mb} was evident throughout the post acclimation heat stress test. The results also showed no significant difference between age groups, pre or post acclimation in: T_c, T_{sk} and T_{mb}. This study highlights the ability of older people to physiologically adapt to the heat. However, a caveat to this interpretation is in relation to the age of the older participants in the study (58-67yrs), where not all would be considered at the highest risk of heat illness (Kenney *et al.,* 2014). The heat stress test in the study was passive, therefore there was a greater reliance on skin blood flow in the maintenance of heat balance. There was no difference in T_{sk}, an indicator of skin blood flow, between age groups, this could be because a deterioration in the ability to increase skin blood flow occur at 65 years old and older (Minson *et al.,* 2002). Therefore, in Armstrong & Kenney's (1993) study fitness is likely to be greater determinate of thermoregulation than age due to matched fitness and an age range of 58-67yrs.

Best *et al.,* (2014) used a similar age for their elderly group (50-63 yrs) to investigate the age-related differences in heat adaptations using a constant-work rate model. The HA protocol was cycling at 70% $\dot{V}O_{2max}$ for 60-min for 6-days in 35°C, 40% RH environment. The Best *et al.,* (2014) found that both groups had significant decreases in T_c, HR and T_{sk} post HA. Furthermore, there was no difference in adaptation between groups. Therefore, similar to Armstrong & Kenney (1993) there was no age-related differences in HA adaptations between the young and elderly group.

Inoue *et al.,* (1999) used an older age group for their elderly population which contained a normally fit group ($\dot{V}O_{2max}$ 30±1 $ml.kg^{-1}.min^{-1}$) (67 ± 3 yrs) and highly fit elderly group ($\dot{V}O_{2max}$ 47±3 $ml.kg^{-1}.min^{-1}$) (63 ± 3 yrs). Participants exercised at ~35% $\dot{V}O_{2max}$ for 90-min in a hot (43°C, 30% RH) environment for 8 days. Improvements in performance, T_{re} and percentage of HR maximum was similar across age groups post HA. Therefore, similar to Armstrong & Kenney (1993) and Best *et al.,* (2014) there was no difference in the magnitude of physiological adaptation between young and elderly, irrespective of the elderly aerobic fitness. Inoue *et al.,* (1999) research has furthered the age-related difference in HA due to the elderly group being within the population that are most likely to go to a G.P or A & E for heat-related illness during periods of hot weather (Kenney *et al.,* 2014; Smith *et al.,* 2016). Nevertheless, it is noteworthy that these studies used a percentage of $\dot{V}O_{2max}$ to match the workload between young and elderly participants. As discussed a percentage $\dot{V}O_{2max}$ does not account for biophysical difference between participants (Cramer & Jay, 2014). Therefore, it is likely that during the HA session the young and elderly are working at different metabolic heat productions, consequently the stimulus for adaptation will be different between and within groups.

Isothermic acclimation

As discussed isothermic acclimation is considered the optimal method for achieving heat adaptations in a young healthy population (Taylor, 2014a; Racinais *et al.,* 2015; Périard *et al.,* 2015). Dannan & Herweijer (2014) were the first to complete a comparative isothermic short term heat acclimation with elderly (>75yrs) and young females (20-30yrs). The experimental protocol consisted of two heat strain tests (20-min cycling at 50W in 35°C, 40% RH environment), one completed on day 1 and the other on day 5. Three days of isothermic HA was completed in-between heat stress tests, whereby participants were exposed to a 35°C, 40% RH environment for one hour each day, whilst targeting an exercise intensity of 50W and a gastrointestinal temperature (T_{gi}) of 38-38.5°C. Unfortunately, the results indicated no physiological or perceptual adaptations to the heat, in the elderly or young females, post HA (Table 2.7).

Table 2.7: Physiological and perceptual variables for elderly and young females, pre and post short term heat acclimation. Data from Daanen & Herweijer (2014).

Physiological and perceptual variables	**Elderly**		**Young**	
	Pre HA	**Post HA**	**Pre HA**	**Post HA**
Pre exercise core temperature (°C)	37.1 ± 0.2	37.1 ± 0.3	37.1 ± 0.3	37.1 ± 0.3
Post exercise core temperature (°C)	37.7 ± 0.3	37.6 ± 0.2	37.5 ± 0.2	37.1 ± 0.4
Post exercise heart rate (b.min^{-1})	125 ± 15	124 ± 15	126 ± 19	122 ± 13
Whole body sweat rate (L.h^{-1})	0.09 ± 0.04	0.12 ± 0.03	0.16 ± 0.07	0.16 ± 0.04
Thermal sensation	2.9 ± 0.8	2.9 ± 0.8	2.8 ± 1.1	2.3 ± 0.9
Rating of perceived exertion	15.4 ± 2.3	14.9 ± 2.3	11.8 ± 2.2	12.0 ± 2.4

Abbreviations: HA; heat acclimation.

An absence of adaptation in the Daanen & Herweijer (2014) might be explained by the duration, frequency and intensity of the heat exposures. Firstly, the time spent within a thermally challenging environment could be extended, either in the number of days (*i.e.,* > 3 days) or the duration of each HA session. (*i.e.,* > 1 hour). Secondly, the exercise intensity (50W cycling) was too difficult for the majority of the elderly participants to maintain (exercise intensity was decreased in five of the eight elderly participants). The decrease in exercise intensity and the one-hour exercise heat exposure may have resulted in insufficient cardiovascular and physiological strain to induce heat adaptations. The insufficient strain is evidenced by isothermic HA not being maintained in some participants; four elderly and three young participants were able to reach a T_{gi} >38°C during all 3 acclimation days. This is significant because to develop physiological adaptation thermal strain in the form of an elevated T_c is required to induce physiological changes (Périard *et al.,* 2015).

In summary, across the active and passive elderly HA studies there is evidence to suggest that elderly people have the ability to acclimate to the heat. Thereby, HA programmes could result in heat-alleviating benefits for the elderly population. The challenge is to find the optimal and palatable method of HA that elicits the most adaptations for the elderly in a short period of time in order for them to physiologically endure heatwaves. Therefore, further research into chronic heat-alleviating strategies for the elderly should address previous research limitations, whilst also acknowledging the greater number of considerations that exist when trying to heat adapt this population. These limitations include; the duration of the heat acclimation programme, there is a balance required between too many days that the HA is no longer a feasible heat-related illness prevention strategy for heatwaves and too short that adaptations do not develop. This is because the magnitude of physiological adaptation is largely dependent on the frequency, intensity, duration and number of heat exposures (Périard *et al.,* 2015). Secondly, the age of the elderly participants should be over the age of 65 years, to ensure that age-related comparisons can be made between young and elderly participants and that the HA strategies have the potential to help the most vulnerable age groups to heatwaves. This is because 65 is the age when there is an increase in G.P and A & E visits in relation to heat-related illnesses during heatwaves (Kenney *et al.,* 2014; Smith *et al.,* 2016). Thirdly, investigate participants that represent a greater proportion of the elderly population, in relation to their aerobic fitness. Lastly, maintaining physiological strain throughout HA programme is essential for developing heat adaptations. The HA should target a core temperature of >38.5°C as this has evidence of optimal heat adaptations in younger populations (Gibson *et al.,* 2015b) and is yet to be investigated in an elderly population.

.

2.7. Conclusion

The purpose of this literature review was to highlight the inevitable global and national changes to the climate and growing ageing population. Furthermore, how changes in climate will increase the likelihood of extreme hot weather causing severe heat-related illness in a growing elderly population. The review also explained the age-related differences in thermoregulation, that result in the elderly being at greater susceptibility to heat-related illnesses compared to young adults. It then reviewed current public health advice and policy identifying the strengths and areas for improvement in future public health advice to further prepare and protect the most vulnerable populations to hot weather. Lastly, it considered acute and chronic heat-alleviating strategies for the prevention of heat-related illnesses in young healthy populations and reviewed the limited literature pertaining to the elderly.

The completion of the literature review identified the key research problem as; the prevention of the forecasted increase in heat-related deaths in the vulnerable elderly population. It is evident that the elderly are a population that is growing and living longer they are also seemingly at a disadvantage both behaviourally and physiologically at protecting themselves against the harmful effects of high ambient temperatures. Currently, there is a lack of population specific research-informed advice on how the most vulnerable can maintain safe during periods of hot weather.

There are several studies that can contribute to the overarching aim of the prevention of severe heat-related illness in the elderly. Firstly, research that investigates a valid and reliable tool for the detection of minor heat-related illnesses. By developing a practical tool that can identify the early signs and symptoms of heat-related illnesses the general public can prevent severe heat-related illness by stopping the heat illness continuum. Secondly, how the UK's elderly population response to UK summer environments remains unclear. This research will provide a greater understanding of how best to help the UK's elderly population during the summer. Thirdly, additional research is required into acute cooling interventions for the elderly population. An intervention that is practical and immediately alleviates heat stress would be of benefit to the advice provided in the heatwave plan for England and the elderly population. Lastly, there is a lack of knowledge investigating the adaptive effect of isothermic short term heat acclimation (STHA) in the elderly. If the elderly are able to adapt using STHA then they have the potential to prepare for imminent hot weather prior to a rise in environmental temperature.

2.8. Research study aims and hypotheses

Based on the identified research gaps, this thesis completed the following research studies with the associated hypotheses:

Study one: An investigation into the validity and reliability of a new heat illness susceptibility questionnaire (HIS-Q).

It was hypothesised that the HIS-Q would demonstrate significant construct validity, via the decrease of heat illness symptoms post short term heat acclimation (STHA). Moreover, that the HIS-Q would also demonstrate strong reliability during a repeated measures laboratory protocol consisting of exercise heat stress.

Study two: An investigation into elderly peoples' physiological and perceptual responses to exercise at different intensities that simulated activities of daily living, across UK summer climatic conditions.

It was hypothesised that the elderly would have increases in physiological and thermal strain with an increase in exercise intensity and heat stress. Additionally, that the elderly would feel warmer and more uncomfortable with increases in exercise intensity and heat stress.

Study three: An investigation into elderly peoples' physiological and perceptual responses to physical and perceptual cooling during exercise simulating moderate activities of daily living for the elderly in the hottest UK summer conditions.

It was hypothesised that elderly peoples' physiological and perceptual strain would decrease when drinking refrigerated water periodically throughout rest and exercise. Also that L-menthol would decrease perceptual strain, whilst not effecting physiological strain.

Study four: An investigation into the differences in phenotypic adaptations to isothermic STHA, between the elderly and young. Additionally, it assessed the differences in phenotypic adaptations between a novel STHA protocol and isothermic STHA within the elderly.

It was hypothesised that the elderly and young would have similar magnitude of adaptation to the isothermic STHA protocol. Furthermore, that the novel STHA would elicit some adaptive response to the heat, albeit not to the same extent as the isothermic STHA method.

2.9. Theoretical framework

A theoretical framework was produced prior to the completion of the elderly studies. Figure 2.24 represents the theory that as exercise intensity (represented on the y axis as metabolic rate) and summer environmental temperature (represented on the x axis as environmental temperature) increases so does the risk of heat illness susceptibility in the elderly population. The black arrows on the figure represent how the acute (cooling) and chronic (heat acclimation) interventions will positively impact heat illness prevention by reducing the levels of heat illness susceptibility risk. The purple arrows represent the possible negative effects of L-menthol on heat illness susceptibility risk due to making the elderly feel cooler but not positively effecting heat balance.

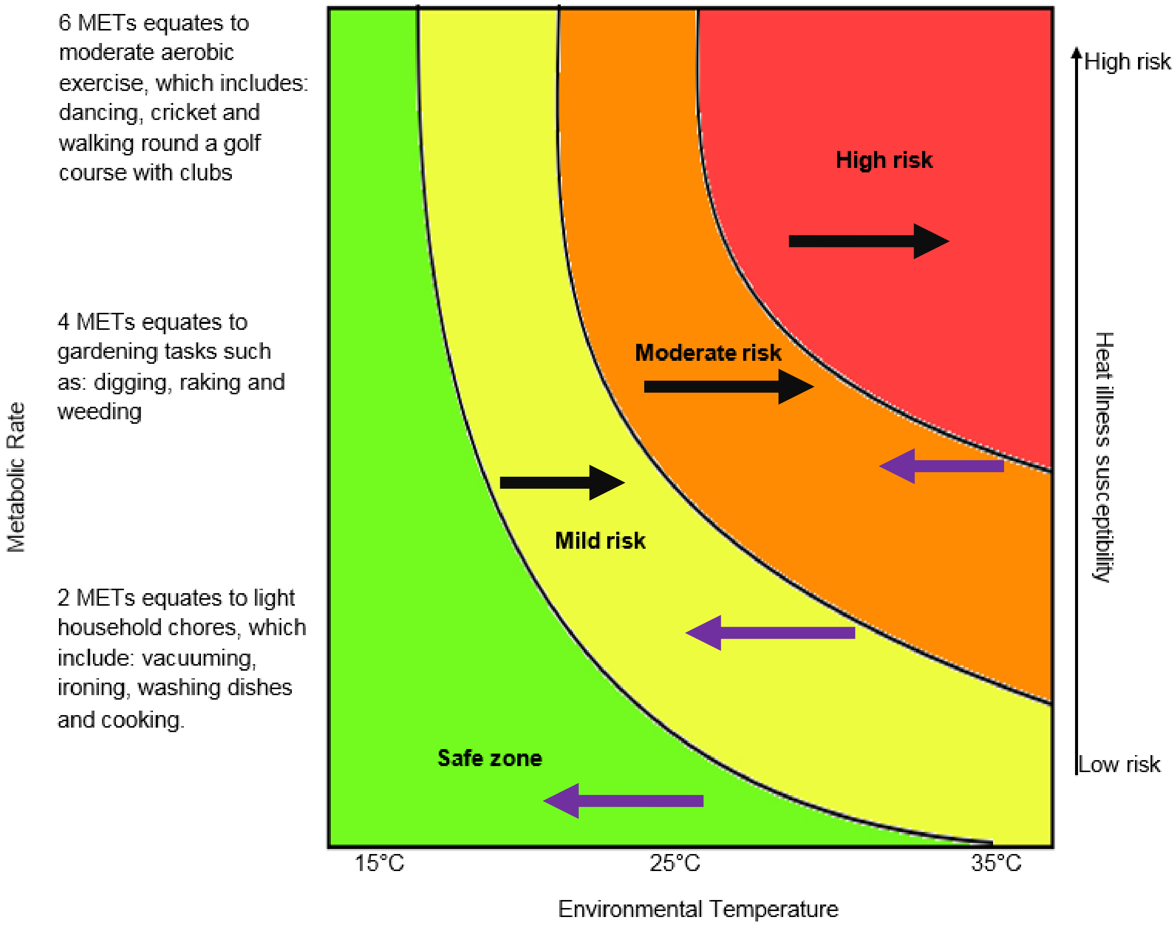


Figure 2.24: Represents the theoretical framework of elderly peoples' heat illness risk during UK summer climatic conditions. Black arrows represent the positive shift in heat illness risk when using physical cooling or heat acclimation interventions. Theoretically the interventions move the quadrants to the right, which increases the size of the safe zone and decreases the size of the high risk zone. Purple arrows represent the negative shift in heat illness risk when using perceptual cooling. Theoretically perceptual cooling move the quadrants to the left, which decreases the size of the safe zone and increases the size of the high risk zone.

Chapter 3 General methods

Chapter 3 outlines the general methods used in the experimental chapters within this thesis. Where experiments use different methods, they are explained fully within the corresponding experimental chapter.

3.1. Health and safety procedures

The experiments completed as part of this thesis received ethical approval from the University of Brighton's Tier 2 Research Ethics Committee and were conducted in accordance with the principles of the revised Declaration of Helsinki (World Health Organisation, 2013). All procedures were carried out in line with the university's standard operating and laboratory risk assessment guidelines.

To ensure participant safety, there were always at least two experimenters during experimental work; one inside the environmental chamber and the other outside. Additionally, at least one of the experimenters was first aid trained.

Control of Substances Hazardous to Health (COSHH) forms were completed for the cleaning solutions used in this thesis. Due to the use of menthol in study 3 (Chapter 6, p139) a further COSHH form was completed for the safety of its oral use with participants (Appendix J, p264).

Cleaning procedures for testing included; disinfecting (Bioguard, UK) the treadmill and cycle ergometers prior to and after experimental testing. Further, the mouth pieces and falconia tubing (Baxter Woodhouse & Taylor Ltd, UK) used for expired air collection were submerged in disinfectant (Virkon, 1% Antec Int., UK) for 15-min before being rinsed under cold water and then dried overnight before their subsequent re-use. HR monitors (Polar Electro, RS800, Finland), were rinsed under warm water and sprayed with disinfectant (Bioguard, UK) and were dried overnight. Skin thermistors were cleaned with an alcohol wipe prior to their subsequent re-use. Biohazard waste procedures included immediately disposing of rectal thermistors and sharp objects within a marked biohazard waste bin and a sharps container.

During experimental testing, exercise was terminated at a $T_{re} \geq 39.7°C$ and at $\geq 39.0°C$, if participants were ≤ 40 yrs or ≥ 60 yrs (Drinkwater & Horvath, 1979). Other termination criteria included volitional exhaustion, the participant could no longer maintain the prescribed exercise intensity or participants were showing signs of serious heat illness including; disorientation, nausea and/or vomiting. Post heat exposure, the participants remained within the laboratory until T_{re} was within 0.5°C of pre-exercise values and that they showed no signs of distress. Participants were offered ice lollies, electric fans and cool water, on completion of a post-exercise nude body mass (NBM) measurement, to facilitate the cooling process (Shirreffs *et al.,* 1996).

3.2. Participants

The participants in this thesis were a combination of physically active males and females aged between 18-85 yrs. The decision to include both males and females in the study was to increase the real world applicability of the research outcomes. The purpose of the thesis was to decrease the risk of heat illness within the elderly population, via practical heat alleviating strategies. It was the aim for policy makers such as Public Health England to use the evidence based advice to inform the elderly population on how to alleviate heat strain during periods of hot weather. Therefore, by including both males and females increases the applicability of the research to the general elderly population. Furthermore, the recruitment of healthy elderly people for environmental research is challenging and by allowing both sexes in the research studies increases the statically power of the research. Additionally, the elderly females in the study were postmenopausal, consequently the menstrual cycle was a variable that did not need to be controlled. There is also recent evidence that whole-body heat loss is not effect by the menstrual cycle, in young women, supporting the inclusion of young women to increase statistical power in study 1 (Notley *et al.,* 2018a).

Prior to the commencement of the study, all participants were informed of the purpose, demands, risks and benefits of completing experimental testing. It was explained that they could withdraw from participation, without the need to provide a reason and their written inform consent and medical histories were collected (Appendices K and L, p266-267). Further to these measures, the ethics committee required participants in study 2 (Chapter 5, p124) to obtain a general practitioner (G.P) signature in approval of their participation; all G.P's were given participant information sheets to inform their decision (Appendix M, p268). Following the guidance from the university's Tier 2 Ethics Committee we did not seek G.P signatures for the subsequent studies of this thesis involving elderly participants.

Experiment exclusion criteria for all participants were; serious injury in the 6 months prior to testing that could hinder participation, history of heat illness, cardiovascular and/or respiratory problems, known to have anaphylactic shock symptoms to needles, probes or other medical type of equipment and/ or been in a hot climate as close as one week prior to testing. Additionally, participants ≥ 60 yrs could not participate if an abnormality was detected on their pre-experimental testing, resting electro-cardiogram (ECG) (MEDCARD

12 lead ECG, Medisoft, Belgium) analysis. Furthermore, a list of current medication was collated from the elderly participants and were reviewed to ensure safe participation and avoidance of changes in thermoregulation due to the medication. Therefore, if a potential participant was on medications such as diuretics, beta-blockers and anti-depressants they could not take part in the study.

One exception to the exclusion criterion was approved by the Tier 2 Ethics Committee. A participant in study 4 (Chapter 7, p167) had a pacemaker, therefore making them ineligible to participate due to a history of cardiovascular problems. However, their exceptional level of fitness, evidenced by their completion of multiple ultra-marathon events including; the Marathon Des Sables (250km Sahara Desert race), meant that the ethics committee considered them safe to participate under the experimental exercise conditions.

3.3. Experimental procedures

3.3.1. Experimental environment

Preliminary and experimental trials were completed in a controlled environmental chamber with an available range of -20 to +50°C and 20-95% relative humidity (RH) (TISS, UK). The set temperatures for study 1a and 1b (Chapter 4, p108) were; 45°C, 20% RH and 40°C, 40% RH. The targeted environmental conditions for the experimental studies 2-4 (Chapter 5-7, p124, p139 and p167) were 15°C, 25°C and 35°C all at 50% RH. These conditions simulate the range of environmental conditions likely to be experienced during British summer time (MET Office, 2018b). Within the environmental chamber, conditions were thermostatically controlled (WatFlow control system, TISS, UK), as well as being continuously monitored throughout the trial using a heat stress meter (HT30, Extech Instruments, USA). Environmental conditions were recorded every 5-min during trials from the heat stress meter to accurately report the environment experienced by the participants.

3.3.2. Elderly participants preliminary visit

Preliminary visits were used to familiarise elderly participants with the equipment, facilities, questionnaires and scales. It allowed participants to ask any questions regarding the experimental testing and gave the experimenter the opportunity to ask the participant to complete a preliminary medical questionnaire. If at the end of the visit the participant still wanted to take part in the study, then testing dates were arranged. Participants in study 2 (Chapter 5, p124) were also given a medical note and a participant information sheet for their G.P to sign and could only begin testing once it was signed (Appendix M, p268). No exercise testing was completed on the preliminary visit.

3.3.3. Pre-experimental participant preparations

In preparation for experimental testing, participants were asked to refrain from; drinking alcohol for 24 hours, caffeine for 12 hours and strenuous exercise for 24 hours; prior to all trials (Stapleton *et al.,* 2014c). Participants were also asked to arrive to the laboratories using the same mode of transport to control for subtleties in resting metabolic rate (Haugen *et al.,* 2003) and at the same time of day to control for circadian rhythm (Kräuchi & Wirz-Justice, 1994). Furthermore, participants were instructed to drink 500ml of water 2 hours prior to testing to ensure euhydration, confirmed with a pre-experimental urine sample assessed for hydration status (Sawka *et al.,* 2007) (Section 3.4.1). If euhydration was not achieved, then the participants were asked to drink 500ml of water and provide another urine sample for analysis after 30 minutes. Experimental testing was not started until the participant was adequately hydrated. Participants completed; the graded exercise test, the simulated activities of daily living test and six-minute walking test, in athletic shorts, t-shirts and trainers. Participants were able to remove their t-shirts during heat acclimation sessions.

3.3.4. Baseline measures

All participants had to sign informed consent and pass the medical questionnaire before baseline measures were completed. On arrival at the laboratories, participants provided a urine sample for hydration analysis (Section 3.4.1) and completed anthropometric assessment (Section 3.4.2). Elderly participants then completed a 10-min supine 12-lead ECG to detect for heart abnormalities by a qualified technician with blood pressure taken on completion (Section 3.4.5). If a heart abnormality was detected or the participant was hypertensive (systolic >150mmHg) then they could not complete exercise testing and were referred to their G.P. No participants were excluded from the study based on that criterion.

Prior to all experimental testing participants recorded their NBM (Section 3.4.2), inserted a rectal probe (Section 3.4.3) and were fitted with a HR monitor (Section 3.4.5). Additionally, skin thermistors were placed (Section 3.4.4) in preparation for the simulated activities of daily living exercise protocol (Section 3.3.6). To obtain baseline HR, T_{re} and T_{sk}, 5-min seated rest in normothermic conditions was applied before experimental testing.

3.3.5. Graded exercise test

Following the baseline measures, a preliminary graded exercise test (GXT) was completed within environmental testing conditions, in studies 2-4 (Chapters 5-7, p124, p139 and p167). The purpose of the GXT was to determine the individual power outputs equating to the experimental METs and $\dot{H}_{prod}$. The GXT-commenced following a 30-min rest period to allow habituation to the environment. During this time, on minute 19, a 45-s gas sample was collected using open-circuit spirometry. Indirect calorimetry from the gaseous analysis provided the individual 1 MET resting value (Section 3.4.7). Thereafter, the GXT was completed on a recumbent cycle ergometer (Cardiostrong, BC50, Germany) and consisted of 7 continuous, 3-min, incremental (15W) stages, from an initial power of 25W (Figure 3.1). Expired air samples were collected in the last minute of each stage for ~45-s and indirect calorimetry was used to determine subsequent power outputs required to achieve experimental MET and $\dot{H}_{prod}$ exercise intensities (Section 3.4.7, Figures 3.2 and 3.3 and Table 3.1). The participants'; HR, T_{re} and RPE were taken at the end of each stage.

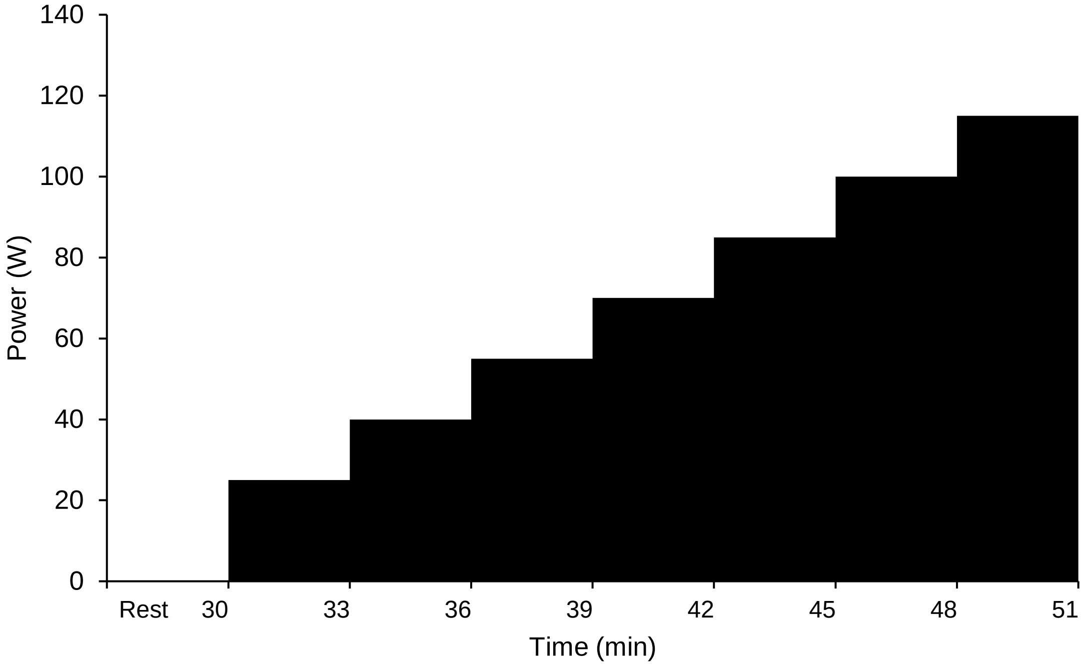


Figure 3.1: Submaximal graded exercise test (GXT) completed on recumbent bike in studies 2-4 (Chapter 5-7, p124, p139 and p167).

Figure 3.2 and 3.3 is data from one participant's GXT. The equation of the line in figure 3.2 was used to calculate the power output required for the simulated activities of daily living testing in the subsequent trials. The same method was used to calculate power at a set $\dot{H}_{prod}$ (Figure 3.3). Table 3.1 is a worked example of calculating power at 6 METs and 3.5 $W.kg^{-1}$ $\dot{H}_{prod}$ using the equation for figures 3.2 and 3.3.

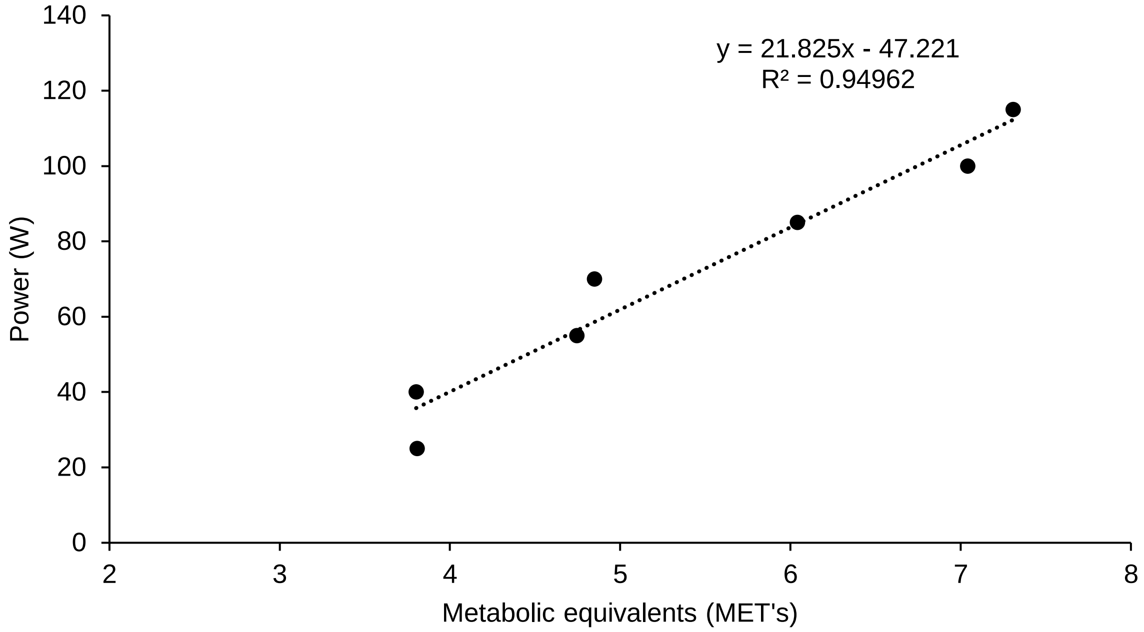


Figure 3.2: Graded exercise test with an older participant. Metabolic equivalents (MET's) *vs.* power (W).

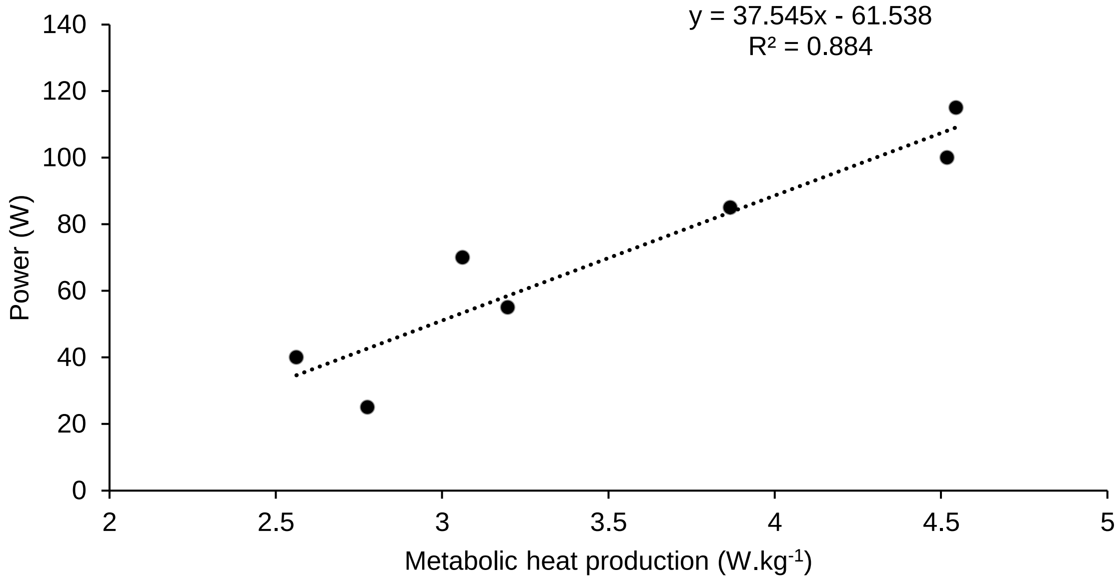


Figure 3.3: Graded exercise test with an older participant. Metabolic heat production (W.kg^{-1}) *vs.* power (W).

Table 3.1: Worked example of calculating power outputs for 6 METs and 3.5 W.kg^{-1} $\dot{H}_{prod.}$

6 METs	**3.5 W.kg^{-1} $\dot{H}_{prod}$**
y = 21.825x - 47.221	y = 37.545x - 61.538
y = (21.825*6) - 47.221	y = (37.545*3.5) - 61.538
y = 83W	y = 71W

3.3.6. Simulated activities of daily living equivalents

In studies 2-4 (Chapters 5-7, p124, p139 and p167) participants completed the same experimental protocol to assess physiological and perceptual responses within different environments and at different MET values that simulated activities of daily living. Experimental trials consisted of 30-min seated rest (40-min in Study 3, Chapter 6, p139) followed by 30-min of recumbent cycling exercise at the corresponding MET intensity for the individual study.

Participants were fitted with a HR monitor and four skin thermistors (Eltek Ltd, UK) attached in accordance with Ramanathan (1964) (Section 3.4.4) for the assessment of mean skin temperature (T_{sk}). Cuddy *et al's.,* (2014) equation for core-to-skin gradient was calculated (Equation 1, Appendix N, p269) and WBSR was determined from NBM measurement pre-post exercise (Section 3.4.6).

Throughout testing, HR, T_{re} and T_{sk} were recorded every 5-min. Thermal sensation (TS), thermal comfort (TC) and RPE were recorded at 10-min intervals (Section 3.5). 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 ~ 45-s, to monitor and calculate MET's and $\dot{H}_{prod}$ (Servomex 4100 Xentra gas analyser, UK) (Section 3.4.7).

3.3.7. Six-minute walk test

As a test of functional capacity a six-minute walk test (6MWT) was used in studies 3 and 4 (Chapters 6 and 7, p139 and p167). The aim of the test was for participants to walk as far as possible in 6 minutes on a hard, flat surface without running or jogging (Enright, 2003). The 6MWTs were completed on a treadmill (Woodway Pro, Germany) within experimental conditions. Kervio *et al.*, (2003) investigated the reliability of the 6MWT in health elderly adults and found a 3.3% coefficient of variation in the distance covered between the 2nd and 3rd 6MWT, after an initial familiarisation trial. Similarly, all participants completed a familiarisation of the 6MWT, post completion of the GXT. The recorded 6MWTs were completed after the simulated activities of daily living testing.

A set of standardised instructions were given to the participants before every 6MWT, these were:

"The aim of this test is to walk as far as possible for 6 minutes. I will let you know as each minute goes past, and then at 6 minutes I will ask you to stop where you are. 6 minutes is a long time to walk, so you will be exerting yourself. You are permitted to slow down, to stop, and to rest as necessary, but please resume walking as soon as you are able. Remember that the objective is to walk as far as possible for 6 minutes, but don't run or jog (Crapo et al., 2002). To go faster point up and the experimenter that you can see through the window will increase the speed, to slow down, point down and the experimenter will slow down the treadmill".

The treadmill was operated from outside of the environmental chamber by an experimenter. When the participant had indicated their readiness to start, the experimenter increased the treadmill speed to 3km.h^{-1}, participants then subsequently pointed up to indicate they wanted the speed to be increase by 0.2km.h^{-1} and pointed down if they required the speed to be reduced by 0.2km.h^{-1}. Participants nodded their head to indicate the speed was at a comfortable pace. HR, T_{re}, TS, TC, RPE, distance covered in km and end speed in km.hr^{-1} were recorded at the end of the 6MWT (Photo 3.1). Figure 3.4 represents a schematic overview of the experimental protocol.

Photo 3.1: Participant completing the six-minute walk test.

Measurements	**Baseline**	**30-min rest**	**30-min recumbent cycling at specified intensity**	**6MWT**	**Post exercise**
Hydration: U_{osmo} and USG	↑				
NMB	↑				↑
HR, T_{re} and T_{sk}	↑	↑ Every 5-min	↑ Every 5-min	↑ At the end of the 6MWT	↑
RPE, TS and TC	↑	↑ Every 10-min	↑ Every 10-min	↑ At the end of the 6MWT	

Figure 3.4: Schematic of the experimental protocol.

Abbreviations: U_{osmo}; osmolality, USG; urine specific gravity, NMB; nude body mass, HR; heart rate, T_{re}; rectal temperature, T_{sk}; skin temperature, RPE; rating of perceived exertion, TS; thermal sensation, TC; thermal comfort.

3.4. Physiological measures

3.4.1. Hydration

On arrival at the Welkin laboratories, participants provided a urine sample. Euhydration was determined when urine specific gravity (USG) was <1.020 and urine osmolality <700 mOsm.kg^{-1} (Sawka *et al.,* 2007).

Urine specific gravity was measured using a refractometer (Specific Gravity Refractometer Model 32, Atago; USA). The refractometer was calibrated prior to each test using distilled water (USG = 1.000). Approximately 2ml of the urine sample was placed onto the glass surface reader and the plastic cover closed. The refractometer was then held towards the light and the experimenter recorded the value displayed on the scale within the eye piece.

Urine osmolality was measured using a handheld osmometer (Osmocheck™ Pocket, Vitech Scientific Ltd, UK.). The osmometer was calibrated prior to each measurement using distilled water (Osmolality = 0). Approximately 2ml of the urine sample was placed in the well and the start button was pressed. The result was displayed to within ± 10 mOsmol.kg^{-1} H_2O. The measuring well was immediately cleaned with disinfectant after assessment.

Participants that arrived and did not test as euhydrated underwent rehydration prior to testing. Rehydration required participants to drink 500ml of water and provide another urine sample for analysis. Rehydration was only required in study 4 (Chapter 7, p167), three young males and three elderly males required additional hydration on at least one heat acclimation session. Rehydration typically took between 15-30-min.

To assess the test-retest reliability of the refractometer and the osmometer, a urine sample was taken from ten elderly adults (69 ± 3 yrs). Each sample was assessed for USG and osmolality in duplicate. Between analyses the osmometer and refractometer were calibrated with distilled water (Table 3.2).

Table 3.2: Reliability of refractometer and osmometer. Mean ± SD.

	Urine specific gravity		**Urine osmolality (mOsm.kg^1)**	
	1	**2**	**1**	**2**
Mean ± SD	1.012 ± 0.005	1.011 ± 0.005	440 ± 175	440 ± 178
TEM	0.0004		7.50	
CV%	0.04		1.66	
95% LoA	0.0002		0.0	
Upper/Lower	0.001/-0.001		20.7/-20.7	
r	0.99		0.99	
p	<0.01		<0.01	

Abbreviations: TEM; Typical error of measurement, CV; coefficient of variation, LoA; limits of agreement, *r*; Pearson's correlation, *p*; significance of *r*.

3.4.2. Anthropometry

Anthropometric data was collected prior to experimental testing, height was measured by a stadiometer (Detecto, USA) to the nearest 0.5cm and NBM was measured to 0.01kg using digital scales (Adam, GFK 150, USA). In study 1 (Chapter 4, p108), body fat percentage (BF%) was measured via air displacement plethysmography (BODPOD, Life Measurement, USA). The BODPOD was used in study 1 (Chapter 4, p108) because it was part of a larger study, in which the researchers were investigating pre-to-post body mass changes, post different cooling interventions, that were completed after the replicated heating element of the trials. In the subsequent studies, the sum of four skin folds; bicep, triceps, subscapular and supra-iliac using skin fold callipers (Harpenden, UK) were used for participant demographics (Durnin and Womersley, 1974) (Equations 2-5, Appendix N, p269).

Intra-rater reliability of skin fold measurements were taken on ten elderly individuals (70 ± 4 yrs). The same experimenter took the skin fold of the biceps, triceps, subscapular and Iliac crest, then repeated the process in triplicate. The skin fold measurements were subsequently used to calculate body density and estimate body fat percentage (Equations 2-6, Appendix N, p269). The average of the three measurements was recorded and the process was repeated 2-3 days later (Table 3.3).

Table 3.3: Intra-rater reliability of skin fold measurements in elderly individuals. Mean ± SD.

	Biceps (mm)	**Triceps (mm)**	**Subscapular (mm)**	**Iliac crest (mm)**	**Total skin folds (mm)**
Day 1	5.7 ± 2.0	12.3 ± 5.4	12.2 ± 3.2	10.2 ± 3.6	40.3 ± 10.6
Day 2	6.2 ± 2.2	12.4 ± 4.4	12.5 ± 3.6	11.2 ± 4.0	42.3 ± 10.6
TEM	1.00	1.10	1.00	1.60	2.50
CV%	17.50	8.80	7.80	15.30	6.00
95% LoA	-0.48	-0.17	-0.30	-1.04	-1.99
Upper	2.40	2.83	2.36	3.50	4.84
Lower	-3.36	-3.18	-2.96	-5.58	-8.82
r	0.76	0.97	0.93	0.82	0.95
p	<0.01	<0.01	<0.01	<0.01	<0.01

Abbreviations: TEM; Typical error of measurement, CV; coefficient of variation, LoA; limits of agreement, *r*; Pearson’s correlation, *p*; significance of *r*.

3.4.3. Core temperature

Rectal temperature

Rectal temperature (T_{re}) was measured as an estimation of core temperature. A disposal probe (Henley, UK) that was attached to a data logger (Squirrel 1000 series, Eltek Ltd., UK) was used to measure T_{re}. The manufacturer stated accuracy and reliability are ±0.05°C and ±0.01°C, between environmental condition 0-70°C. The probe was self-inserted by the participant to a depth of 10cm past the anal sphincter with a zinc oxide tape bung to ensure the correct depth was achieved and maintained. During all experimental testing within the environmental chamber, T_{re} was monitored throughout and recorded every 5-min.

The inter-day reliability of T_{re} was taken from twenty-seven elderly individuals (71 ± 4 yrs) and was determined by the 30-min T_{re} resting measurements in the 2 MET and 4 MET trials in study 2 (Chapter 5, p124) (Table 3.4).

Table 3.4: Inter-day reliability of rectal temperature. Mean ± SD.

	Rectal temperature (°C)	
	1	**2**
Mean ± SD	37.15 ± 0.30	37.15 ± 0.33
TEM	0.18	
CV%	0.48	
95% LoA	-0.0007	
Upper/Lower	0.50/-0.50	
r	0.68	
p	<0.01	

Abbreviations: TEM; Typical error of measurement, CV; coefficient of variation, LoA; limits of agreement, *r*; Pearson's correlation, *p*; significance of *r*.

3.4.4. Skin temperature

Skin thermistors (Eltek Ltd, UK); attached to the right side of the body to the; midpoint of the right pectoralis major (T_{chest}), midpoint of the triceps brachii lateral head (T_{arm}), right rectus femoris ($T_{upper\ leg}$) and right gastrocnemius lateral head ($T_{lower\ leg}$) and connected to a data logger (Squirrel 1000 series, Eltek Ltd., UK) were used to measure skin temperature every 5-min throughout the experiments. The four skin temperatures were then used to calculate mean skin temperature from Ramanathan (1964) equation (Equation 7, Appendix N, p269).

The reliability of the skin thermistors was determined by recording the temperature of four separate thermistor within a temperature controlled water bath (24°C) (TBS1, Digitron, UK). The 24°C water temperature was selected as the water bath maintained temperature consistently when an approximate room temperature was selected. The skin thermistors were suspended in the water and given 10-min to stabilise. Thereafter, temperature was recorded every min for two consecutive 10-min periods (Table 3.5).

Table 3.5: Reliability of skin thermistors. Mean ± SD.

	Skin thermistor 1 (°C)	**Skin thermistor 2 (°C)**	**Skin thermistor 3 (°C)**	**Skin thermistor 4 (°C)**
1	24.05 ± 0.02	23.95 ± 0.03	23.95 ± 0.02	23.85 ± 0.02
2	24.05 ± 0.02	23.95 ± 0.02	23.95 ± 0.02	23.85 ± 0.02
TEM	0.02	0.02	0.02	0.02
CV%	0.07	0.08	0.09	0.07
95% LoA	0	0.01	-0.01	0
Upper/Lower	0.05/-0.05	0.06/-0.05	0.05/-0.07	0.05/-0.05
r	-0.11	0.36	-0.22	-0.11
p	0.76	0.59	0.55	0.76

Abbreviations: TEM; Typical error of measurement, CV; coefficient of variation, LoA; limits of agreement, *r*; Pearson's correlation, *p*; significance of *r*.

3.4.5. Cardiovascular measures

Heart rate

Heart rate (HR) was measured throughout all experimental trials and recorded every 5-min using short-range telemetry (Polar Electro, RS800, Finland).

Electro-cardiogram (ECG)

The elderly participants had a resting 12 lead ECG completed by the experimenter, who is a qualified ECG technician, prior to exercise testing (Photos 3.2 and 3.3). The ECG electrodes required contact with the skin to obtain a signal on the ECG monitor. Therefore, male participants completed ECG analysis shirtless and chest hair was shaved if necessary. Female participants completed ECG's in their bra and electrodes were placed underneath the fabric when necessary. Once the electrodes were in place the participants lay supine on a massage table and the ECG recording was started. It was essential that participants remained still throughout the ECG recording because movement of the wires presented significant interference with the reading. The experimenter analysed the live ECG recording and was assessing for cardiovascular abnormalities such as; ST depression or elevation, continuous ectopic beats and right bundle branch block. ECG recordings were taken over 10-min.

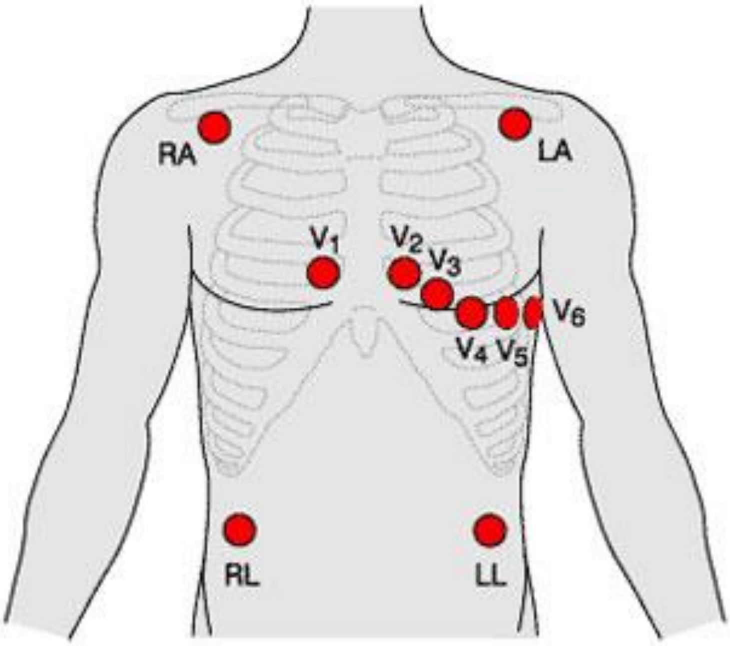


Photo 3.2: Diagram of the electrode placement for a 12 lead electrocardiogram.

Photo 3.3: ECG analysis on an elderly participant.

Blood pressure (BP)

Automatic blood pressure (BP) (Omron, M4, Japan) was taken at the end of the 10-min rest whilst the participant was still in the supine position. The BP cuff was secured around the upper left arm to a tightness in which one finger could be placed under the cuff, ensuring contact with the skin and the brachial artery lined up with the pressure inflator. The start button was then pressed and the pressure in the cuff inflated to 220 mmHG and then deflated. The reading was given on the digital display within a couple of minutes. An average of two readings were taken and participants required a systolic BP <150 mmHg to participate in the study.

3.4.6. Whole body sweat rate

An estimation of whole body sweat rate (L.hr^{-1}) was determined from the difference between a pre-and-post exercise towel dried NBM measurement, accurate to 0.01kg (Equation 8, Appendix N, p269).

3.4.7. Respiratory gaseous analysis

Respiratory gaseous analysis was completed via indirect calorimetry using Douglas bags. Douglas bags were selected for use with all participants due to the reliability, ease and comfort of use. Unlike online systems the Douglas bags can be easily removed between samples and does not cover the majority of the face, which can become uncomfortable in the heat during an experimental trial. The experimental testing within this thesis had sustained periods without the need for respiratory gaseous analysis as the participants were completing steady state exercise and the gaseous was retrospectively analysed to ensure accurate exercise intensities.

Prior to respiratory gaseous analysis the gas analyser (Servomex International Ltd., UK) was calibrated by the experimenter. The calibration was completed against nitrogen (N) and a mixture of known gases comprising of oxygen (O_2) and carbon dioxide (CO_2) (Brin oxygen company [BOC], UK). The calibration samples were firstly zeroed against 100% N prior to being calibrated against 80% N, 15% O_2 and 5% CO_2, before finally being calibrated against 80% N, 18% O_2 and 2% CO_2. The completion of the calibration process prior to analysis ensures that the measurements were reliable across experimental samples.

To measure an expired air sample, participants wore a nose-clip and inserted a mouthpiece connected to a 2-way valve (University of Brighton). The valve was connected to a Douglas bag via falconia tubing. Expired air during the GXT and the simulated activities of daily living was collected using open-circuit spirometry for ~45-s after the mouthpiece had been in for a ~30-s, timed on a stop clock. One litre of the expired air was analysed for O_2 and CO_2

content. Thereafter, the entirety of the gas was evacuated from the Douglas bag assessing for gas temperature and volume using a vacuum pump and a dry gas meter (Harvard, UK).

Using the Oxygen Uptake software package (University of Brighton), volumes of oxygen uptake ($\dot{V}O_2$ L.min^{-1}), carbon dioxide production ($\dot{V}CO_2$ L.min^{-1}), expired ventilation ($\dot{V}_E$) and respiratory exchange ratio (RER) ($\dot{V}CO_2$ L.min^{-1}/ $\dot{V}O_2$ L.min^{-1}) were then calculated. These values were subsequently used to calculate metabolic energy expenditure (M) (Equation 2.2) and individual relative $\dot{H}_{prod}$ and exercise MET values (worked example and equations 9-11, Appendix N, p269).

The inter-day reliability of calculating $\dot{H}_{prod}$ and MET via Douglas bags is displayed in table 3.6. The data presented is nine older participants (69 ± 3 yrs) that completed two trials at an exercise intensity of 3.5 W.kg^{-1} $\dot{H}_{prod}$ / 6 METs within 35°C, 50% RH.

Table 3.6: Reliability of calculating exercise intensities during exercise using Douglas bags.

	$\dot{H}_{prod}$ (W.kg^{-1})		**METs**	
	1	**2**	**1**	**2**
Mean ± SD	3.79 ± 0.41	3.64 ± 0.46	5.40 ± 1.49	5.68 ± 1.51
TEM	0.15		0.35	
CV%	4.0		6.3	
95% LoA	-0.14		0.28	
Upper/Lower	0.28/-0.55		1.79/-0.68	
r	0.88		0.95	
p	<0.001		0.002	

Abbreviations: TEM; Typical error of measurement, CV; coefficient of variation, LoA; limits of agreement, *r*; Pearson's correlation, *p*; significance of *r*.

3.4.8. Haematological measures

In study 4 (Chapter 7, p167), capillary blood samples were taken from the fingertip at rest pre and post HA to analyse plasma volume changes. All blood samples were taken by the experimenter who was trained in taking blood samples and was Hepatitis B vaccinated. Participants could specifically opt out of having their blood taken but still participate in the study.

Participants placed their hands under warm running water to maximise skin blood flow to the finger tips and arterialise the blood sample before towel drying their hands. They were then asked to take a seat and rest for 5-min before the fingertip was cleaned with an alcohol wipe and left to air dry for a few seconds. Once dry, a single use lancet (Accu-Chek Safe-T-Pro Plus, Roche Diagnostics ltd., UK) was used to puncture the skin of the fingertip. The first drop of blood was wiped with a tissue and disposed of (in a biohazard waste bin) to prevent the collection of damaged blood cells. Blood was then collected for haematocrit (Hct) and haemoglobin (Hb) analyses.

Haematocrit

Blood for Hct analysis was collected in 75µl heparinised tubes (Hawksley & Sons Ltd., UK) in duplicate. Immediately following the collection, each tube was filled with clay at the opposite end. The blood samples were then placed into the centrifuge (Haematospin 1300, Hawksley & Sons Ltd, UK), with the clay end facing outward. The lid of the centrifuge was magnetically closed and the samples were spun at 5000 revolutions per min (rpm) for two and half minutes. The process of spinning the blood separated the red blood cells (RBC) from the blood plasma. To calculate the ratio between RBC and blood plasma the tubes were placed on a micro haematocrit reader (Hawksley & Sons Ltd, UK). The mean of the two samples was taken for Hct % and used in the change in plasma volume (∆PV) equation (Equation 3.12).

Haemoglobin

Blood to determine haemoglobin concentration [Hb] was collected immediately after Hct and from the same puncture wound. The blood was collected in 10 µl cuvettes (Hb201, HemoCue, Ltd., Sweden) in duplicate and analysed in a calibrated B-Hemoglobin photometer (HemoCue, Ltd., Sweden). Hb concentration was displayed on the digital screen within a few seconds. The mean of the two measures (Hct and [Hb]) were used within the ∆PV equation from Dill & Costill (1974) that was set up in an excel spreadsheet (Equation 12, Appendix N, p269). The reliability of the Hct and [Hb] are displayed in table 3.7.

Table 3.7: Reliability of haematological measures. Means ± SD.

	Hct (%)		[Hb]	
	1	**2**	**1**	**2**
Mean ± SD	41 ± 2	42 ± 3	14.0 ± 0.8	14.5 ± 1.2
TEM	1.82		0.63	
CV%	4.34		4.36	
95% LoA	-1.57		-0.09	
Upper/Lower	3.47/-6.61		1.16/-2.28	
r	0.67		0.71	
p	0.10		0.07	

Abbreviations: Hct; haematocrit, Hb; haemoglobin, TEM; Typical error of measurement, CV; coefficient of variation, LoA; limits of agreement, *r*; Pearson's correlation, *p*; significance of *r*.

3.4.9. Skin blood flow

In study 4 (Chapter 7, p167), forearm skin blood flow (SkBF) was measured using laser Doppler (moorVMS-LDF2, Moor instruments, UK). The manufacturer stated accuracy and reliability of the flux measurement are ± 10% and ± 3%, between environmental conditions of 0-45°C and 0-80% RH. The manufacturer guidelines for completing skin probe (VP1T, Moor instruments, UK) calibration was once a month. As the HA study was completed in 3-week cycles, calibration was completed prior to each new HA cycle. Calibration was completed in accordance with manufacturer's guidelines. Firstly, the skin probe was connected to the laser Doppler monitor through one of the front ports. The probe was then suspended in the manufacturer's probe flux standard for 2-min before entering the calibration mode on the laser Doppler monitor. The calibration was then completed automatically and the probe was wiped clean with an alcohol wipe prior to its use on the participant.

Participants rested their forearms on a table with their palms facing up, at approximately chest height. The placement of the laser Doppler probe was the upper left forearm avoiding prominent venous areas. The probe was placed within a probe holder (PH1-V2, Moor instruments, England) and attached to the forearm with an adhesive disc. To ensure accurate replacement for subsequent SkBF measurements, a black pen mark was drawn around the probe holder for visible replacement. The participant rested as still as possible for 30-min. Blood pressure was taken at minute 20, to calculate mean arterial pressure (MAP) (Equation 13, Appendix N, p269). Mean flux was taken over the last 5-min of the resting period. Mean flux and MAP were subsequently used in the equation for cutaneous vascular conductance (CVC) (Equation 14, Appendix N, p269) as an estimation of SkBF.

The inter-day reliability of CVC in nine elderly (68 ± 4yrs) participants was completed during two 30-min rest period within 35°C, 50% RH (Table 3.8).

Table 3.8: Inter-day reliability of cutaneous vascular conductance. Mean ± SD.

	cutaneous vascular conductance	
	1	**2**
Mean ± SD	0.56 ± 0.28	0.56 ± 0.29
TEM	0.10	
CV%	18.24	
95% LoA	0.002	
Upper/Lower	0.28/-0.28	
r	0.87	
p	0.002	

Abbreviations: TEM; Typical error of measurement, CV; coefficient of variation, LoA; limits of agreement, *r*; Pearson's correlation, *p*; significance of *r*.

3.5. Perceptual measures

Participant were asked how hard they felt the exercise was using Borg’s scale (Borg, 1982) for rating of perceived exertion (RPE). Also, during rest and exercise participants were asked how comfortable they were based on the environment (Guéritée & Tipton, 2015) using a thermal comfort (TC) scale and how cold or hot they perceived the environment using a thermal sensation (TS) scale (Young, *et al.*, 1987). In study 3 (Chapter 6, p139), due to giving water in the intervention trial, participants were also asked how thirsty they felt (Table 3.9). To minimise inter-individual differences in scale interpretation, a set of standardised instructions were given to the participants to anchor the points on the scales. For using RPE the instructions were; ‘*6 means no exertion at all and 20 means the most maximal exertion*’ (Borg, 1982). Furthermore, it is also standard practice to familiarise participants with perceptual scales prior to testing (Flouris & Cheung 2009; Schlader *et al.,* 2009). Therefore, in studies 1-4 (Chapters 4-7, p108, p124, p139 and p167), all the perceptual scales were presented to the participants during the pre-experimental visit, to ensure scale understanding.

Table 3.9: Perceptual scales: Left to right; rating of perceived exertion (RPE), thermal comfort (TC), thermal sensation (TS) and thirst sensation (ThS).

RPE	Thermal Comfort	Thermal Sensation	Thirst Sensation
		8.0 unbearably hot	
20 maximal exertion	6	7.5	9 very, very thirsty
19 very, very hard	very uncomfortable	7.0 very hot	8
18	5	6.5	7 very thirsty
17 very hard	uncomfortable	6.0 hot	6
16	4	5.5	5 thirsty
15 hard	just uncomfortable	5.0 warm	4
14	3	4.5	3 slightly thirsty
13 somewhat hard	just comfortable	4.0 neutral	2
12	2	3.5	1 not thirsty
11 fairly light	comfortable	3.0 cool	
10	1	2.5	
9 very light	very comfortable	2.0 cold	
8		1.5	
7 very, very light		1.0 very cold	
6 resting		0.5	
		0.0 unbearably cold	

3.6. Statistical analyses

Prior to participant recruitment, a G*Power (version 3.1) power analysis was conducted to determine sample size. This was completed in accordance with established guidelines for *a priori* determination (Farrokhyar *et al.,* 2013). Sample sizes were determined from the main dependent variable (T_{re}), and α (0.05) and β (0.8) levels were set to ensure sufficient statistical power then participants were recruited.

All data was analysed using a standard statistical package (SPSS version 22.0) and reported as means and standard deviations (SD). Statistical significance was accepted at the level of $p \leq 0.05$.

Throughout this thesis there are three main types of data analysed; ordinal, interval and ratio. Ordinal data is defined as having two or more categories that have an order to them. One example of ordinal data is finishing paces in a race, first and second, by nature first is better than second, but how much better is unknown with ordinal data. Interval data is continuous and each increase in interval data represent an equal increase, for example temperature data. Interval data may have an assigned zero point but it is not a true zero point. Whereas, ratio data which is similar to interval data, has the addition of a true and meaningful zero point, for example heart rate data (Vincent and Weir, 1994; Field, 2017).

In this thesis, perceptual data (*e.g.,* RPE, TS and TC) are types of ordinal data. Some of the physiological variables (*e.g.,* T_{re} and T_{sk}) in this thesis are types of interval data, whereas other types of physiological data (*e.g.,* HR and BP) are ratio data. All data was tested for normality and sphericity to test they were parametric before completing parametric analysis. Data normality was assessed using the Shapiro–Wilk's test for skewness and kurtosis. The data was deemed normally distributed if Shapiro-Wilks was not significant ($p > 0.05$) and the values for skewness and kurtosis were within -1.96 and +1.96 (Field, 2017). Sphericity of the data was assumed when Mauchly's test of sphericity was not significant ($p > 0.05$). Due to Mauchly's test being non-significant it was then assumed that there was equal variance within the differences between the conditions. When Mauchly's test was violated ($p < 0.05$) then the Greenhouse-Geisser adjustment was used (Field, 2017). If data was deemed parametric then paired sample t-tests were used to determine the statistical difference between pre and post-tests when the same participants were used. Cohen's *d* was the effect size used in accordance with Lakens (2013) to assess the size of the effect within-groups when a t-test had been used for determining statistical significance. Cohen's *d* was interpreted as; small (0.2), moderate (0.5) and large (0.8) in accordance with Cohen (1998) (Equation 15, Appendix N, p269).

One-way and two-way repeated measures and two-way mixed methods (between and within participant conditions) Analysis of variance (ANOVA's) were used to determine the statistical difference between group means. ANOVA makes multiple comparisons, leading to a familywise error rate (Field, 2017). To reduce the effects of a familywise error rate a post-hoc analysis, using a Bonferroni correction, was completed. Bonferroni is a conservative adjustment of the *p* value to reduce the risk of making a type I error (Field, 2017). Partial eta squared (ηp^2) was the effect size used in accordance with Lakens (2013) to assess the size of the effect within- and between- groups when an ANOVA had been used for determining statistical significance (Equation 16, Appendix N, p269).

The perceptual scale data within this thesis represents ordinal data. The data is ordinal because the participant chooses a value that best represents how they are feeling at the time of the question, for example the thermal comfort scale ranges from very comfortable (1) to very uncomfortable (6), moving up in whole integers. Due to ordinal data using discrete values to represent a point on a scale, some researchers choose to present ordinal data as medians and interquartile ranges rather than means and standard deviations (SD). The reason for adopting this approach is because the mean of ordinal data has the potential to produce a value that is not represented in the ordinal data, for example 4.7 on a whole integer scale does not exist on the thermal comfort scale. Non-parametric analyses techniques do not require the data to follow a particular distribution either, working by using the rank order of observations rather than the measurements themselves (Vincent and Weir, 1994; Field, 2017).

Another approach to the analysis of perceptual data is for the ordinal data to be analysed using more classic, parametric statistical analyses techniques (*e.g.,* t-tests and ANOVAs) (Flouris & Cheung, 2009; Daanen & Herweijer, 2014; Kenny *et al.,* 2016; Schlader *et al.,* 2017). Current practice by world leading environmental physiology researchers is to present their ordinal data as means and SD and use this alternative approach (Flouris & Cheung, 2009; Daanen & Herweijer, 2014; Kenny *et al.,* 2016; Schlader *et al.,* 2017). There does not appear to be a clear boundary between when data that is presented as scores or observations rather than measurements is analysed using parametric as opposed to non-parametric techniques. In this thesis, pre-to-post ordinal data was analysed using a Wilcoxon signed rank test with non-parametric effect size *r* (Equation 17, Appendix N, p269). However, when the study design had three or more groups or comparisons then ordinal data was analysed using an ANOVA. This is common practice in the environmental physiology literature (Flouris & Cheung, 2009; Daanen & Herweijer, 2014; Kenny *et al.,* 2016; Schlader *et al.,* 2017) and is in accordance with Field, (2017) for two-way repeated measure ANOVA designs.

One limitation of parametric statistical analyses is that ANOVA does not consider the ranking of ordinal data (Field, 2017; Frost, 2019). Furthermore, non-parametric analysis allows the experimenter to analyse the median rather than the mean, which in some data sets it a better indication of central tendency (Field, 2017, Frost, 2019). However, despite its limitations, there are still advantages of using parametric analysis on non-parametric data. It does not require the data to have the same variability, which is hard to satisfy within non-parametric analysis (Frost, 2019). Further, parametric statistical analyses is more conservative and may increase the risk of a type II error (i.e. a false negative), but it reduces the risk of a type I error (*i.e.,* a false positive) (Frost, 2019). Therefore, if a significant effect is observed using parametric statistical analysis it is more likely to reflect a true effect from an intervention (Frost, 2019).

3.6.1. Reliability statistics

A combination of absolute and relative reliability statistics were used in this thesis to determine reliability within the individual variables. This provides a more robust approach to determining reliability than using a single measure of reliability (Atkinson & Nevill, 1998). The measurements of reliability included; typical error of measurement, coefficient of variation, Pearson's correlation, intraclass correlation coefficient and limits of agreement (Bland & Altman, 1999; Hopkins, 2000; Atkinson, 2003). The equations to calculate those reliability measurements are in appendix N (Equations 18-23, p269).

3.6.2. Meaningful change

Heat acclimation was completed in studies 1a and 4 (Chapters 4 and 7, p108 and p167). To determine meaningful changes, from pre-to-post HA, in physiological and perceptual variables, predefined analytical limits of meaningful changed were used. The predefined analytical limits were; ΔT_{re} >0.20°C, ΔHR >5 b.min^{-1} ΔWBSR >0.2L.h^{-1}, ΔPV >5% and >Δ1 in perceptual scales (RPE, TS and TC) in accordance with Willmott *et al.,* (2016).

Chapter 4 The validity and reliability of a new questionnaire for the detection of heat illness susceptibility

4.1. Abstract

Aim: The aims of this investigation were to produce a new heat illness susceptibility-questionnaire (HIS-Q) and subsequently assess the HIS-Q's validity (study 1a); using ten sessions of isothermic heat acclimation (HA), completed over 12 days, and reliability (study 1b); using a repeated heat stress test (HST).

Methods: To assess validity twenty male participants (mean ± SD; age; 24 ± 7 yrs, height; 179 ± 6 cm, body mass; 76.15 ± 9.51 kg and peak oxygen consumption [$\dot{V}O_{2peak}$]; 49.8 ± 6.1 ml.kg^{-1}.min^{-1}) completed one preliminary trial to determine cycling $\dot{V}O_{2peak}$, followed by ten-sessions of HA. The HIS-Q was completed following HA sessions 1 and 10. To assess reliability, twelve (11 males and 1 female: mean ± SD; age; 21 ± 2 yrs, height; 180 ± 8 cm, body mass; 75.19 ± 8.38 and $\dot{V}O_{2peak}$; 47.6 ± 8.1 ml.kg^{-1}.min^{-1}) participants completed one preliminary and three experimental trials. Exercise intensity for the experimental trials were prescribed using a metabolic heat production ($\dot{H}_{prod}$) model. A graded exercise test on a treadmill in a hot environment (40°C and 40% RH), was used to determine an individual running speed of 9 W.kg^{-1} $\dot{H}_{prod}$. During each experimental trial, the HIS-Q was completed pre-exercise and at a rectal temperature (T_{re}) of 39.5°C, or at volitional exhaustion.

Results: Construct validity indicated a significant decrease in individual HIS-Q scores between session 1 and 10 of HA ($T = 8.00$, $p < 0.01$, $r = -0.49$). In the reliability study, the peak HIS-Q scores were; HST1: 5 ± 3, HST2: 4 ± 3, HST3: 3 ± 2. The intra-class correlation coefficients (ICC), mean bias and limits of agreement (LoA) were: HST1 and HST2; ICC = 0.67, mean bias (LoA) = 1.25 (-4.17, 6.67); HST1 and HST3; ICC = 0.55, mean bias (LoA) = 1 (-4.29, 6.29); HST2 and HST3; ICC = 0.67, mean bias (LoA) = -0.25 (-4.99, 4.49).

Conclusion: Data suggests that the HIS-Q has the potential to be a sensitive tool for assessing susceptibility to heat illness, as demonstrated by a decrease in HIS-Q score post HA. Furthermore, the HIS-Q showed moderate reliability during repeated short–duration heat stress tests. The HIS-Q warrants further experimental investigation, during field-based and prolonged exercise-heat stress to further assess reliability.

4.2. Introduction

Athletes, various occupations and the elderly are at increased risk of heat-related mortality when competing, working and living in high environmental temperatures (Cheung *et al.,* 2000). Fatalities may result when people develop either classic or exertional heat stroke (EHS). Classic heat stroke affects vulnerable populations who have an attenuated ability to dissipate heat gained from the environment (Bouchama & Knochel, 2002; Flynn *et al.,* 2005). Whereas, EHS develops during strenuous physical activity with or without heat stress and therefore, is more likely to impact younger, physically active individuals (Heled *et al.,* 2004; Jay & Brotherhood, 2016). Classic and EHS are diagnosed when a patient exhibits signs of neurological dysfunction and a rectal temperature (T_{re}) ≥ 40°C (Bouchama & Knochel, 2002; Nadir, *et al.,* 2016). Currently, ~2000 people in the UK die per year of a heat-related illness (HRI) and epidemiological evidence suggests a fivefold increase by 2080 (Hajat *et al.,* 2014). However, heat-related mortality is preventable with the correct behavioural strategies, including but not limited to; seeking shade, decreasing exercise intensity and removing excess clothing (Bouchama & Knochel, 2002; Reid *et al.,* 2009; Schlader *et al.,* 2010; Flouris, 2011). A caveat to this is that behavioral strategies are implemented when a person feels uncomfortable within their environment (Flouris, 2011; Schlader, 2014; Flouris & Schlader, 2015). Therefore, if people do not interpret the environment as uncomfortable and potentially harmful to health, they are unlikely to implement behavioural strategies to prevent HRI (Flouris, 2011; Schlader, 2014; Flouris & Schlader, 2015).

Heat illnesses occur along a continuum, with minor HRI (*e.g.,* heat rash and cramps) developing into more severe HRI (*e.g.,* heat exhaustion or heat stroke), if untreated (Coris *et al.,* 2004; Heled *et al.*, 2004; Luber & McGeehin, 2008). A valid and reliable tool for the detection of HRI could increase the awareness of mild signs and symptoms, providing individuals such as; athletes, firefighters and the elderly, with the knowledge to implement behavioural strategies to prevent the development of life-threatening conditions. Coris *et al.,* (2006) developed the heat illness symptoms index (HISI) comprising of ten points and thirteen heat illness symptoms, to quantify mild and moderate HRI symptoms in athletes. To the author's knowledge the HISI is the only attempt to quantify individual symptoms of heat illness with the application of an ascending severity scale. Validity analysis of HISI scores found significant but weak correlations with; sweat loss ($r = 0.21$, $p < 0.01$), heat index ($r = 0.13$, $p < 0.01$) and RPE ($r = 0.16$, $p < 0.01$). However, despite Coris *et al.,* (2006) advances in severe HRI detection, there are limitations to the HISI. Firstly, the index has too many symptoms as evidenced by the removal of *stopping sweating* and *swelling* from the index due to poor correlation to total HISI scores; $r = 0.17$ and $r = 0.26$. Surprisingly, Coris *et al.,* (2006) did not correlate HISI scores to $T_{re,}$ a marker of heat strain, but acknowledged this as a limitation. Lastly, the structure of the HISI can result in ambiguity in how individuals should categorise the severity of their symptoms, due to no explanation of the difference between a mild, moderate or severe symptom. Consequently, this relies on the subjectivity of the individual to a greater extent, which is likely to differ between individuals. The structure could be further improved with the separation of heat illness signs and symptoms. Symptoms of mild heat illness are and can be self-reported, however, when an individual is suffering from confusion, as is common in heat stroke, they cannot self-diagnose this sign, therefore, requiring an observer to report on their HRI signs.

At present, there is no valid and reliable tool for assessing an individual's risk of developing a severe HRI via the reporting of HRI signs and symptoms. A heat illness susceptibility questionnaire (HIS-Q) would provide value to HRI prevention by increasing public awareness of minor signs and symptoms, consequently preventing severe HRI from developing. Although there is no tool for the assessment of HRI, there are reliable and valid tools for the assessment of illness severity within other environmental extreme conditions. These include; the Cold Injury Severity Scale, for cold injuries (Ruijs *et al.* 2006) and the Lake Louise questionnaire (LLQ) for aute mountain sickness (ASM) (Roach *et al.,* 1993). To ensure the LLQ was a valid tool for the evaluation of AMS, it was validated concurrently against a physician's assessment of AMS signs and symptoms (Savourey *et al.*, 1995). Construct validity is the form of validity that evaluates a measure against an expected outcome (Currell & Jeukendrup, 2008). For the evaluation of heat illness, heat acclimation (HA) can be used as a form of construct validity as the acquisition of physiological adaptations (*e.g.,*. decreases in resting and exercise HR and $T_{re,}$ and increases in sweat rate, skin blood flow and plasma volume expansion [Sawka *et al.,* 2011]), reduces the risk of HRI (Armstrong & Maresh, 1991; Minett *et al.,* 2016). Furthermore, a strong correlation between peak T_{re} and peak HIS-Q scores is another measure of construct validity as it is reasonable to suggest that a higher T_{re} results in a higher HIS-Q score. Multiple repeated exercise trials can assess reliability of a measure across separate experimental days (Wragg *et al.,* 2000). The use of intra-class correlation coefficient (ICC) and Bland-Altman's limits of agreement (LoA) allow for interpretation of measurement reliability (Currell & Jeukendrup, 2008).

The aims of this study were twofold; to produce a new HIS-Q that incorporated both signs and symptoms of HRI. Secondly, to conduct initial validity and reliability assessments within controlled, acute exercise-heat stress conditions. The primary hypothesis was that the HIS-Q would exhibit strong construct validity via a decrease in individual HIS-Q scores following the acquisition of heat adaptations during HA. Additionally, that peak HIS-Q scores would be strongly correlated with peak $T_{re.}$ Lastly, it was hypothesised that the HIS-Q would display moderate to excellent inter-day reliability. This was quantified by ICC values greater than

0.5. Furthermore, ICC values between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.9 are indicative of, moderate, good, and excellent reliability in accordance with by Koo & Li (2016). With additional reliability quantified by values within the LoA.

4.3. Methods

4.3.1. Development of the HIS-Q

The first developmental stage of the HIS-Q was to establish the most relevant minor HRI symptoms. The HIS-Q was constructed through literature review (Coris *et al.,* 2004; Howe & Boden, 2007; Luber & McGeehin, 2008; Hunt *et al.,* 2013), the reported frequency of symptoms in Coris *et al.,* (2006) and Relf *et al.,* (2017) studies, and input from medical professionals with extensive experience with heat stroke patients (Webborn *et al.,* 2010; Gomm *et al.,* 2016). The minor HRI symptoms formed Part 1 of the HIS-Q, in which the participant self-assessed the severity of their own HRI symptoms (Appendix O, p276). HRI signs formed Part 2 of the questionnaire and were reported by an observer, due to the chance of a participant being unable to self-report signs as a consequence of potential confusion and disorientation (Appendix O, p276). The two parts of the questionnaire were structured differently; Part 1 was based on the style of the LLQ (Roach *et al.,* 1993) while Part 2 drew from the assessment for concussion (Maddocks *et al.,* 1995). Part 1 allowed the participant to select a number associated with the most accurate description of the severity of how each symptom was impacting upon their health, the scale for each symptom ranged between 0-3, with 0 equating to; *do not have symptom* to 3; *the symptom is severely impacting upon my health* (Figure 4.1). Part 2 asked simple questions to the participants to establish if they were suffering from confusion, a neurological sign of severe HRI (Figure 4.1) (Nadir *et al.,* 2016). Once the structure and wording of each section had been drafted, the HIS-Q went through a rigorous pilot work process to assess layman's understanding during a six person focus group, terminological understanding between American and English and given to the heat illness medical professionals for their refinement.

On completion of this development stage, the HIS-Q comprised two parts; Part 1 as a self-report of six HRI symptoms, with a possible score of 18 (*i.e.,* maximum value of 3 from each question), while Part 2 was an observer's report on the participant's HRI signs, with a possible score of 6 (Figure 4.1). Therefore, a maximum HIS-Q score of 24 was able to be reported. Additionally, if available, the observer was able to record the participant's core temperature (specifying the method which was used; rectal, tympanic, oral, etc.) to facilitate clinical assessment of heat stroke (Appendix O, p276).

4.3.2. Study 1a and 1b

The experimental protocols for study 1a and 1b, were approved by the University's ethics committee and conducted in accordance with the principles of the revised Declaration of Helsinki (World Health Organisation, 2013) and the University of Brighton's health and safety procedures (Section 3.1). Prior to testing, participants provided informed, written consent and a medical questionnaire (Section 3.2). In preparation for testing, participants followed the pre-experimental preparation guidelines (Section 3.3.3). During preliminary testing in both studies, hydration (Section 3.4.1), anthropometric (Section 3.4.2) and baseline measures (Section 3.3.4) were collected prior to exercise assessment.

4.3.3. Study 1a

Participants

Twenty physically active male participants (mean ± SD; age 24 ± 7 years, height 179 ± 6 cm, body mass 76.15 ± 9.51 kg and peak oxygen consumption [$\dot{V}O_{2peak}$] 49.8 ± 6.1 ml.kg^{-1}.min^{-1}) volunteered for study 1a.

Preliminary trial

Participants completed one preliminary trial and ten 60-min sessions of HA. The preliminary trial was a $\dot{V}O_{2peak}$ test on a cycle ergometer (SRM, high performance model, Jülich, Germany) within temperate conditions (22°C, 40% RH) and was used for descriptive statistics.

Isothermic heat acclimation

Heat acclimation consisted of cycling exercise (Monark 620 Ergomedic, Varberg, Sweden) in hot dry conditions (45°C, 20% RH). Participants cycled at 2.3 W.kg^{-1} for the initial 15-min at 80 rpm, which was in line with prescription guidelines for HA (Gibson *et al.,* 2016) and recent HA studies from our laboratories (Gibson *et al.,* 2015 ab; Mee *et al.,* 2015; Willmott *et al.,* 2016; James *et al.,* 2017). Power output was then adjusted by removing mass off the cycle ergometer load-pan every 15-min, in relation to the participant's change in T_{re} (ΔT_{re}) and RPE, as has been the practice in other studies (Patterson *et al.,* 2004; Gibson *et al.,* 2015ab; Garrett *et al.,* 2011). The aim of each HA session was to achieve and maintain T_{re} at or above 38.5°C (Taylor, 2014a, Périard *et al.,* 2015; Racinais *et al.,* 2015). During the experimental trials; T_{re} and HR were recorded every 5-min and thermal sensation (TS) (Young *et al.,* 1987), rating of perceived eversion (RPE) (Borg, 1982) and thermal comfort (TC) (modified Gagge *et al.,* 1967) were recorded every 10-min. Additionally, to estimate whole body sweat rate (WBSR) a pre and post nude body mass measurement was taken (Section 3.4.6). The HIS-Q was recorded at rest then following session 1 and 10 of HA.

4.3.4. Study 1b

Participants

Twelve (11 males and 1 female) physically active participants (mean ± SD; age 21 ± 2 years, height 180 ± 8 cm, body mass 75.19 ± 8.38 kg and $\dot{V}O_{2peak}$ 47.6 ± 8.1 $ml.kg^{-1}.min^{-1}$) volunteered for study two.

Preliminary trial

Participants completed one preliminary trial and three main trials. The preliminary trial was a submaximal graded exercise test (GXT) on a motorised treadmill (Woodway, ELG2, Germany), in 40°C, 40% RH within an environmental chamber (TISS, UK). The GXT consisted of six, 3-min, incremental (+0.8 $km.h^{-1}$) stages, starting at 6 $km.h^{-1}$ (Bird & Davison, 1997) at 1% incline (Jones & Doust, 1996). Respiratory gas was collected at the end of each stage for the determination of individual exercise intensity for the main trials, using a metabolic heat production ($\dot{H}_{prod}$) model. Individual running speeds equating to 9 $W.kg^{-1}$ $\dot{H}_{prod}$(determined through pilot work) were used for the main trials (Section 3.4.7). Following the sixth stage, participants rested in temperate conditions for 15-min prior to completing a $\dot{V}O_{2peak}$ test. Participants re-entered the chamber and performed 1-min incremental stages (+1 $km.h^{-1}$) from an initial speed of 8 $km.h^{-1}$ until volitional exhaustion. Expired gas was collected for ~45-s of each stage (Section 3.4.7). $\dot{V}O_{2peak}$ was determined as the highest $\dot{V}O_2$ averaged over 10-s it was not maximal as not all criteria were met (*e.g.,* plateau in $\dot{V}O_2$) (Bird & Davison, 1997) (Figure 4.1).

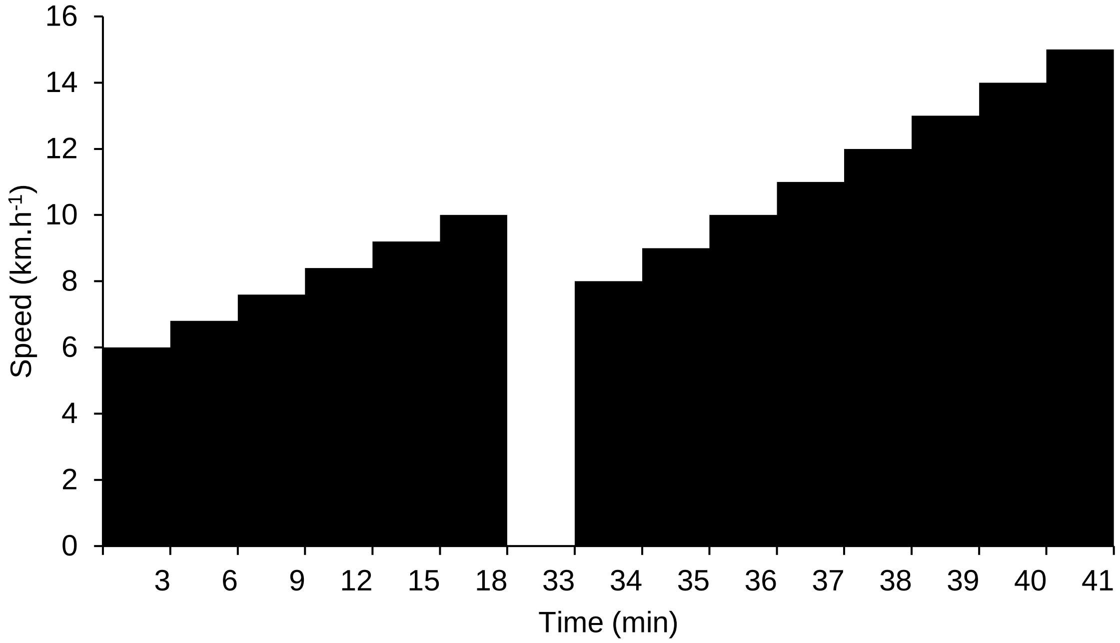


Figure 4.1: Schematic of the graded exercise test and $\dot{V}O_{2peak}$ assessment. Design from Bird & Davison (1997).

Heat stress test

On completion of the hydration assessment (Section 3.4.1), participants completed the baseline measures (Section 3.3.4), with the addition of skin thermistors (Section 3.4.4).

After a 20-min stabilisation period, resting measurements were recorded and the participant entered the chamber (40°C, 40% RH), whilst wearing an upper body sauna suit (Everlast, London, UK) to restrict heat dissipation and increase the rate of change in T_{re} for the initial 15-min of the heat stress test (HST). During the experimental trials; T_{re}, HR, RPE, T_{sk} and TS were recorded every 5-min. Expired gas was collected for ~45-s at minutes 4, 14 and 24, to ensure participants were exercising at 9 $W.kg^{-1}$ of $\dot{H}_{prod}$. The HIS-Q was recorded at rest and at the end of exercise; either at a T_{re} of 39.5°C or volitional exhaustion. Participants completed a total of 3 HSTs, each separated by 7 days to assess the inter-day reliability of the HIS-Q.

4.4. Statistical analyses

All data are presented as mean ± SD and were assessed for normality and sphericity prior to further statistical analyses (Section 3.6). When the assumption of sphericity was violated the Greenhouse-Geisser adjustment was used. In study 1a, differences in pre-exercise resting measures, peak values and individual HIS-Q scores were analysed using a paired samples t-test when data was parametric and via a Wilcoxon signed rank test when data was non-parametric. Effect sizes are presented as Cohen's *d* values for parametric data and *r* values for non-parametric data, values > 0.5 are considered as moderate effects and > 0.8 as large effects (Cohen, 1988; Field, 2017). Spearman's rho correlations were conducted between HIS-Q and various variables (T_{re}, RPE and TS) as a construct validity measure. Additionally, to determine meaningful adaptation from the HA protocol predefined analytical limits were used; $\Delta T_{re} > 0.2°C$, $\Delta HR > 5$ b.min^{-1}, ∆WBSR > 200ml, >∆1 in perceptual scales (RPE, TS and TC) (Willmott *et al.,* 2016).

In study 1b, differences in pre-exercise resting and peak measures were assessed using a one-way repeated measures ANOVA when data was parametric (*e.g.,* HR) and via a Friedman's test when data was non-parametric (*e.g.,* TS). Effect sizes were estimated using η_p^2 within statistical ANOVA analysis, to analyse the magnitude and trends of the intervention (Nakagawa & Cuthill, 2007). Bland-Altman's LoA and ICC with 95% confidence intervals (CI) were calculated as inter-day reliability analysis for the HIS-Q (Atkinson & Nevil, 1998). Reliability was classified as; moderate, good and excellent, when ICC values were between 0.5 and 0.75, 0.75 and 0.9, and > 0.9 (Koo & Li, 2016). Bland-Altman plots were produced using Microsoft Excel (2013), all other statistical analysis was conducted using a standard statistical package (IBM SPSS Version 22.0). Data is reported as mean ± SD and statistical significance was accepted at the level of $p < 0.05$.

4.5. Results

4.5.1. Study 1a

The isothermic heat acclimation developed phenotypic adaptations with significant reductions in; resting T_{re} ($t = 6.41$, $p < 0.01$, $d = 1.44$), resting HR ($t = 11.23$, $p < 0.01$, $d = 2.51$) and peak RPE ($T < 0.01$, $p < 0.01$, $r = -0.57$). Likewise, WBSR increased ($t = -6.27$, $p < 0.01$, $d = 1.41$) and TS ($T < 0.01$, $p < 0.01$, $r = -0.60$) and TC improved following HA ($T < 0.01$, $p < 0.01$, $r = -0.55$). There was no observed difference in peak T_{re} ($t = 1.44$, $p = 0.17$, $d = 0.32$), however peak HR reduced ($t = 2.89$, $p < 0.01$, $d = 0.65$) (Table 4.1).

Table 4.1: Mean ± SD physiological and perceptual measurements for session 1 and 10 of HA.

	Session 1	**Session 10**	**∆1-10**
Resting T_{re} (°C)	37.10 ± 0.25	36.81 ± 0.26	-0.28 ± 0.20*#
Peak T_{re} (°C)	38.49 ± 0.28	38.42 ± 0.28	-0.07 ± 0.21
Resting HR (b.min^{-1})	69 ± 8	60 ± 8	-10 ± 4*#
Peak HR (b.min^{-1})	165 ± 13	159 ± 12	-6 ± 9*#
WBSR (ml)	1086 ± 428	1521 ± 426	435 ± 310*#
Peak RPE	15 ± 1	14 ± 2	-1 ± 1*#
Peak TS	6.9 ± 0.4	6.1 ± 0.5	-1.0 ± 0.5*#
Peak TC	4 ± 1	2 ± 1	-1 ± 1*#

Abbreviations: T_{re}; rectal temperature, HR; heart rate, WBSR; whole body sweat rate, RPE; rating of perceived exertion, TS; thermal sensation, TC; thermal comfort, ∆; indicates change. * denotes a significant difference ($p < 0.05$) from session 1 to session 10. # denotes a meaningful adaptation from session 1 to session 10.

There was a significant decrease in individual HIS-Q score from pre (3 ± 2) to post (1± 1) HA ($T = 8.00$, $p = 0.02$, $r = -0.49$) (Figure 4.2). Fourteen out of the twenty participants had a decrease in HIS-Q score, five participants had no change in HIS-Q score and one person had an increase in symptoms, following HA (Figure 4.2).

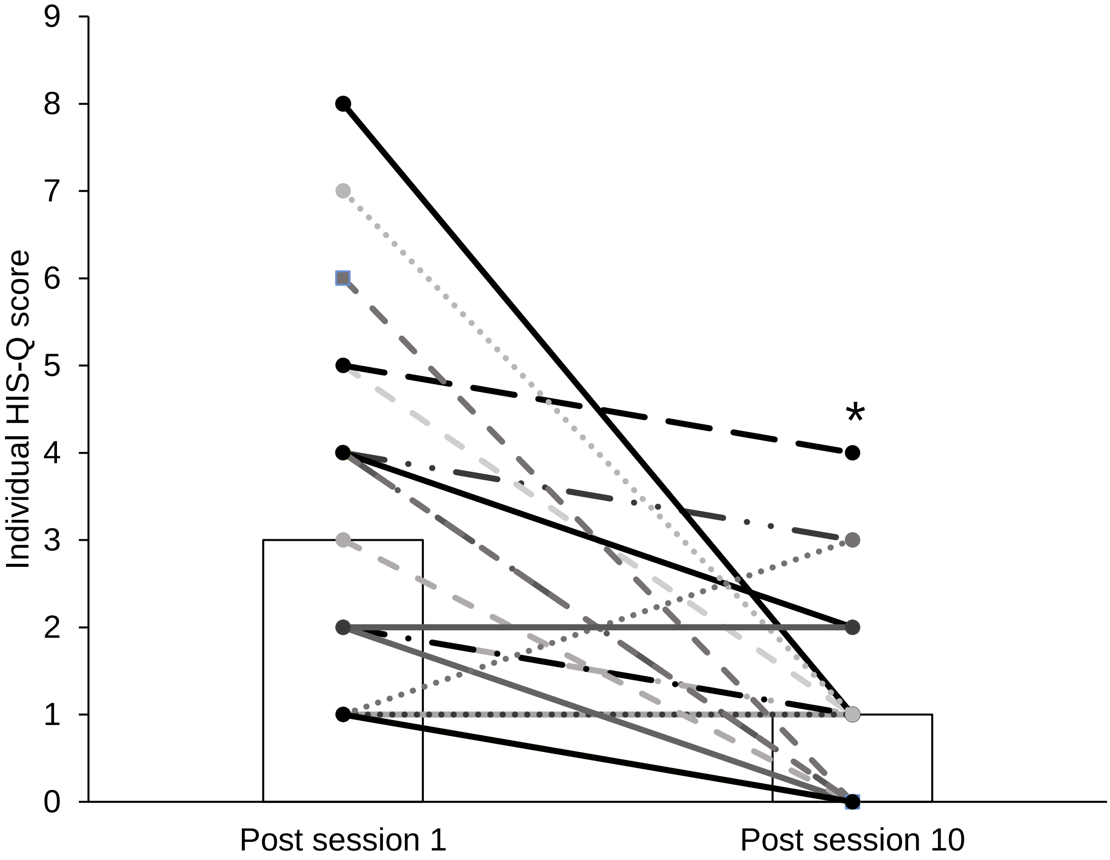


Figure 4.2: Individual HIS-Q score (out of a total 24) post session 1 and 10 of heat acclimation. Bars represent the mean and the lines and markers represent the individual participant data points. * denotes a significant decrease ($p < 0.05$) in individual HIS-Q score.

4.5.2. Study 1b

There was no observed difference in resting physiological variables between HSTs for T_{re} ($F_{(2,22)} = 0.06$, $p = 0.94$, $\eta_p^2 = 0.01$), HR ($F_{(1.334,14.673)} = 0.54$, $p = 0.55$, $\eta_p^2 = 0.05$) or T_{sk} ($F_{(2,22)} = 0.37$, $p = 0.70$, $\eta_p^2 = 0.03$). Therefore, participants arrived to each HST in a similar physiological status. Likewise, there were no observed differences for; exercise duration ($F_{(2,22)} = 0.13$, $p = 0.29$, $\eta_p^2 = 0.11$), peak HIS-Q ($\chi^2(2) = 1.63$, $p = 0.44$), peak T_{re} ($F_{(1.307,14.378)} = 0.01$, $p = 0.96$, $\eta_p^2 < 0.01$), peak T_{sk} ($F_{(2,22)} = 0.71$, $p = 0.50$, $\eta_p^2 = 0.06$), peak HR ($F_{(2,22)} = 0.71$, $p = 0.50$, $\eta_p^2 = 0.06$), peak TS ($\chi^2(2) = 2.46$, $p = 0.29$) and peak RPE ($\chi^2(2) = 0.21$, $p = 0.90$) (Table 4.2).

Table 4.2: Mean ± SD for exercise duration time and peak physiological and perceptual measures during the heat stress tests.

	HST 1	**HST 2**	**HST 3**
Exercise duration (min)	33.6 ± 9.9	35.4 ± 9.1	33.5 ± 7.6
HIS-Q	5 ± 3	4 ± 2	3 ± 2
T_{re} (°C)	39.31 ± 0.30	39.31 ± 0.25	39.31 ± 0.33
T_{sk} (°C)	37.98 ± 0.69	37.76 ± 0.77	37.91 ± 0.70
HR (b.min^{-1})	182 ± 16	184 ± 13	187 ± 18
TS	7.5 ± 0.5	7.5 ± 1.0	7.5 ± 0.5
RPE	17 ± 2	17 ± 2	17 ± 2

Abbreviations: HST; heat stress test, HIS-Q; heat illness susceptibility questionnaire, T_{re}; rectal temperature, T_{sk}; mean skin temperature, HR; heart rate, TS; thermal sensation, RPE; rating of perceived exertion.

There was no correlation between peak T_{re} and peak HIS-Q scores ($r = 0.05$, $p = 0.79$). Similarly, change in T_{re} (ΔT_{re}) and ΔHIS-Q were not correlated ($r = 0.04$, $p = 0.83$). However, there was a significant, moderate correlation between peak RPE and peak HIS-Q ($r = 0.63$, $p < 0.01$, $y = 0.9402x - 12.3336$) and between peak TS and peak HIS-Q ($r = 0.46$, $p < 0.01$, $y = 1.3175x - 5.9018$).

Bland-Altman analysis of reliability reported good LoA between HSTs for peak HIS-Q scores, as all but one value were within the 95% LoA (Figure 4.3). The mean bias and (LoA) were: HST 1 and HST 2; 1.25 (-4.17, 6.67); HST 1 and HST 3; 1 (-4.29, 6.29); HST2 and HST3; -0.25 (-4.99, 4.49). It is noteworthy, that the 95% LoA could be considered too greater range from the mean bias line (Figure 4.3). In accordance with Koo & Li (2016) the ICC's showed moderate correlations (*i.e.,* ICC between 0.5 - 0.75) between the HSTs for peak HIS-Q scores (ICC (95% CI)); HST 1 and 2 (ICC = 0.67 (-0.29, 0.90)); HST 1 and 3 (ICC = 0.55 (-0.44, 0.87)); and HST 2 and 3 (ICC = 0.67 (-0.21, 0.91)).

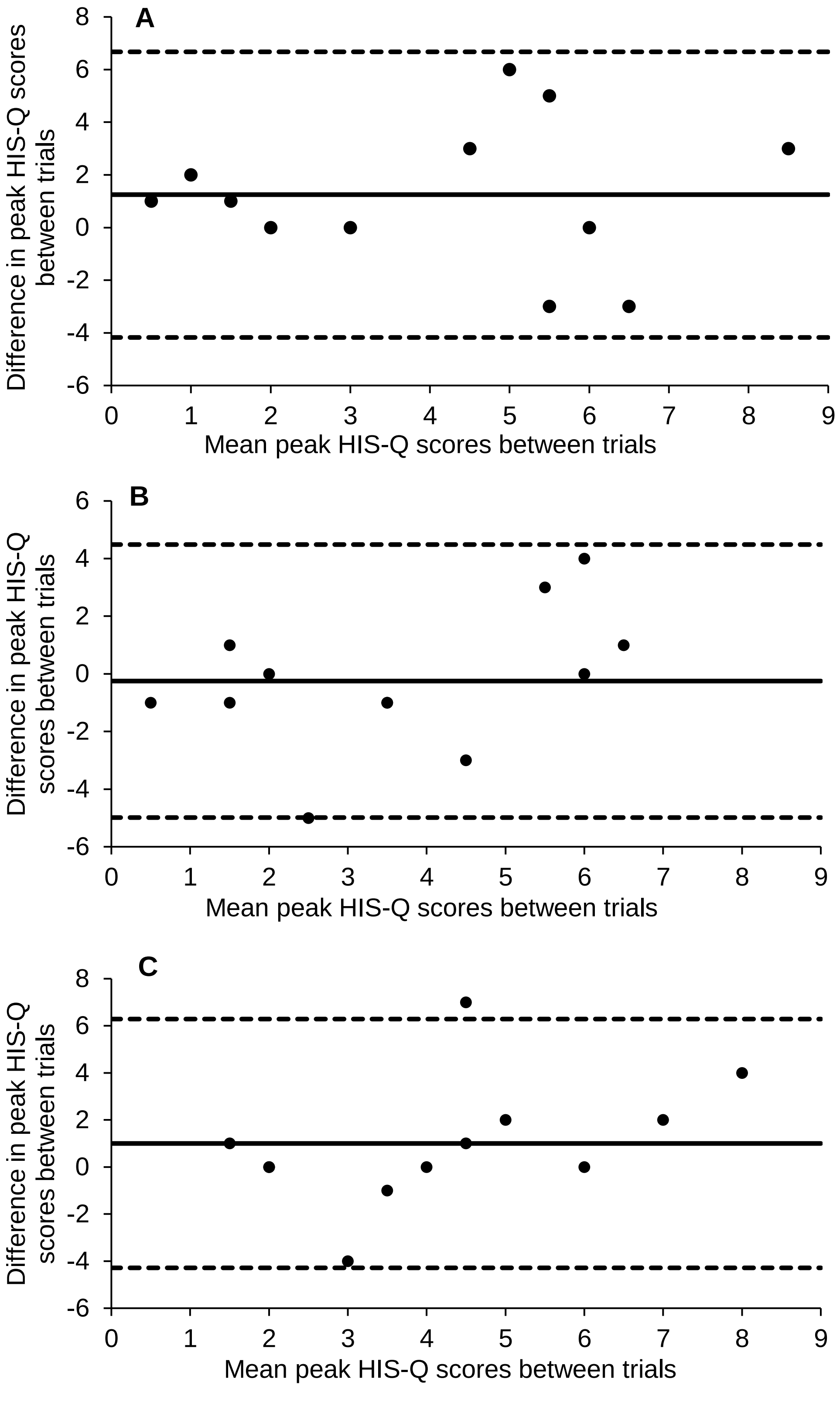


Figure 4.3: Bland- Altman plots with mean bias (solid line) and 95% LoA (dotted line) for heat stress test 1 and 2 (A), heat stress test 1 and 3 (B) and heat stress test 2 and 3 (C).

4.6. Discussion

The aim of this study was to investigate the validity and reliability of a new tool for assessing an individual's risk of developing a severe heat illness via the reporting of heat illness symptoms and signs. The HIS-Q was a sensitive tool to quantify the changes in heat illness susceptibility following HA. Furthermore, the HIS-Q demonstrated moderate reliability, as defined by ICC values and LoA values, during multiple repeated short-duration heat stress tests.

4.6.1. Validity

Two assessments of construct validity were completed, HA and a correlation analysis between peak T_{re} and peak HIS-Q scores. To the authors' knowledge this is the first study to use HA as a method of construct validity for a new questionnaire. Heat acclimation was chosen to assess the validity of the HIS-Q because those individuals who are not heat acclimatised are at greater risk of suffering a severe heat illness (Armstrong & Maresh 1991; Gosling *et al.,* 2008; Kovats & Ebi, 2006; Minett *et al.,* 2016). Therefore, it is reasonable to hypothesise that once an individual is acclimated to the heat their HIS-Q scores would decrease. The data indicated meaningful phenotypic adaptations during the 10 sessions of HA, as determined by the predetermined analytical limits; $\Delta T_{re} > 0.2°C$, $\Delta HR > -5$ b.min^{-1} $\Delta WBSR > 200ml$ and $>\Delta 1$ in perceptual scales (RPE, TS and TC) (Willmott *et al.,* 2016) (Table 4.1). These adaptations decrease the risk of heat illness (Minett *et al.,* 2016). Peak T_{re} on session 10 of HA was not significantly different to session 1, highlighting continued physiological strain across the HA protocol. Nevertheless, the heat adaptations acquired were strongly represented in the significant decrease in individual HIS-Q score (Figure 4.2).

When assessing the individual differences in HIS-Q scores alongside heat adaptations, there is no clear differences between the fourteen participants that presented decreased HIS-Q scores post HA and those that did not. All participants developed a meaningful decrease in resting HR, >5 b.min^{-1}. Fifteen of the participants had a meaningful decrease in resting $T_{re,}$ >0.2°C, of the five participants that did not have a decrease, two of them had no decrease in HIS-Q score and the other three did. Similarly, all but one participant had a meaningful increase in WBSR, >200ml and that participant had a decrease in HIS-Q score. Therefore, there does not seem to be one singular physiological parameter that directly effects HIS-Q score. Interestingly, three of the four participants that had no change in individual HIS-Q score and the one participant that had an increase in HIS-Q score, post HA, all had a meaningful decrease in RPE, TS and TC, a decrease of 1 in the respective scales. Consequently, it is more likely to be a combination of physiological and perceptual differences that lead to a decrease in heat illness symptoms (*i.e.,* HIS-Q score).

No correlation was present between peak T_{re} and peak HIS-Q. Currently, this is a limitation to the HIS-Q, due to a T_{re} > 40°C being one of the diagnostic signs of severe heat illness (Nadir *et al.,* 2016), it is reasonable to suggest that a higher T_{re} would result in a large magnitude of heat illness symptoms and an increase in severity of those symptoms being reported. The absence of a correlation could be explained by the design of the HST, due to exercise ceasing when the participant terminated the test or when they reached a T_{re} of 39.5°C, therefore the range in T_{re} was minimal, possibly explaining the lack of correlation between peak T_{re} and peak HIS-Q. Furthermore, validity could be improved with a minimum duration of heat exposure. Prolonged hyperthermia increases the risk of severe heat illness (Armstrong *et al.,* 2007; Sawka *et al.,* 2011). For example, when athletes start a marathon, they are typically euhydrated, however, during the prolonged exercise they can become dehydrated (Sawka *et al.,* 2007; Sawka *et al.,* 2011). Dehydration leads to a greater rise in core temperature and risk of heat illness (Sawka *et al.,* 2007; Sawka *et al.,* 2011). Therefore, over prolonged exercise, signs and symptoms of heat illness have more time to develop. Consequently, correlations between peak T_{re} and peak HIS-Q could be improved if taken after a sustained period of hyperthermia rather than immediately after a rapid increase in T_{re}.

Despite the lack of correlation between peak T_{re} and peak HIS-Q, there were moderate and significant correlations between peak HIS-Q and peak RPE and between peak HIS-Q and peak TS. The correlation between peak RPE and peak HIS-Q ($r = 0.63$, $p < 0.01$) was stronger than the correlation found by Coris *et al.,* (2006) between the HISI and RPE ($r = 0.16$, $p < 0.01$). The increased strength in relationship between RPE and HIS-Q in the present study may be explained by the set $\dot{H}_{prod}$ protocol compared to the intermittent exercise nature of American football practice used in the Coris *et al.,* (2006) study. Rating of perceived exertion has been found to correlate with dehydration (Carter & Gisolfi, 1989), which is a risk factor of HRI. Therefore, a stronger relationship between HIS-Q and RPE may be a measure of improving upon the work of Coris *et al.,* (2006) in successfully identifying risk susceptibility to heat illnesses.

4.6.2. Reliability

Designing a multiple trial test-retest reliability study for a subjective variable that has identical conditions is challenging. This is because even when all the conditions are the same, the participant may interpret heat illness symptoms differently between tests. Furthermore, despite implementing a heat exposure free week between testing, there could be an element of familiarity to the test conditions, possibly leading to variability within HIS-Q scores. This is evident within this study, because the differences in HIS-Q values between

HSTs were in symptoms such as fatigue and nausea which may be more dependent on the participant's inter-day interpretation of the exercise intensity rather than a true symptom of heat illness.

The current study found that only one point was outside the LoA in the Bland-Altman analysis (Figure 4.4). However, the 95% LoA could be considered too greater range for a scale that has a maximum score of 24, with the smallest range being; -4.99, 4.49. Conversely, the ICC values support the HIS-Q's reliability with values > 0.5 indicating moderate reliability (Koo & Li, 2016). Further, reliability research with the HIS-Q with increased exercise duration and intensity is warranted. Heat illnesses and associated high T_{re} are frequently observed in athletes competing in endurance events lasting >2-hours under constant exposure to high environmental temperature (Cheuvront & Haymes, 2001; El Helou *et al.,* 2012). The duration of exercise-heat stress in study 1b was ~30-min and although heat strain was high, as demonstrated by HR >180 $b.min^{-1}$ and T_{re} = 39.5°C, it may not be long enough to experience the whole spectrum of heat illness symptoms. Implementing a minimum heat exposure time prior to completing the HIS-Q could see greater HIS-Q scores, and is supported by the LLQ that requires participants to be exposed to a change in altitude for several hours before its completion (Roach *et al.,* 1993). It is noteworthy, that to accurately evaluate the reliability of the HIS-Q, a person would need to get a repeated bout of heat related illness and then compare HIS-Q scores, however, this is not ethically possible within a laboratory setting.

It is important to highlight that Coris *et al.,* (2006) did not report data on controlled test-retest reliability, therefore, an assessment of inter-day reliability of the HISI through control measures was not possible to compare against.

4.6.3. General discussion on HIS-Q

Across study 1a and 1b there were no reported results for Part 2 of the HIS-Q. This observation is unsurprising as it may be explained by an insufficient level of hyperthermia experienced, as demonstrated by a maximum T_{re} of 39.5°C. The main outcome measure for Part 2 of the HIS-Q is neurological dysfunction, which typically develops when core temperature is above 40°C. Due to ethical guidelines the maximum T_{re} for termination of exercise was 39.5°C, therefore the observer was unlikely to witness neurological dysfunction in the participants. Future research that evaluates the HIS-Q should complete observations during field-based events, where higher levels of physiological strain (*i.e.,* T_{re} > 40°C) are experienced. Triathlons, marathons and ultra-marathon events in hot environments often have participants who present with high T_{re} and suffer from acute heat illnesses; including exertional heat stroke (Cheuvront & Haymes, 2001; Gosling *et al.,* 2008; El Helou *et al.,* 2012; Gomm *et al.,* 2016). Therefore, due to the greater severity of HRI, the athletes are likely to report higher HIS-Q scores, with the addition of HRI signs being reported in Part 2 of the HIS-Q. Further, in competition scenarios there are qualified medical professionals that would be able to diagnose the severity of heat illness at the point of administering the HIS-Q, further increasing its validity.

It is noteworthy that the HIS-Q used in studies 1a and 1b is the first version of a new questionnaire for the prevention of severe heat illness, and other environmental questionnaires have gone through many iterations before becoming the '*gold standard'* measure for the determination of their respective environmental illnesses. For example, the development of a questionnaire for AMS had multiple prior versions (Sampson *et al.,* 1980; Sampson *et al.,* 1983; Wright *et al.,* 1985) before the LLQ became the '*gold standard'* (Roach *et al.,* 1993). Furthermore, the LLQ has a subsequent version to improve validity for children (Southard *et al.,* 2007), recognising population differences in interpretation of symptoms. Therefore, whilst the limitations across the studies are recognised, this is a platform which future research can learn and improve from, in the aim to produce a valid and reliable HIS-Q that prevents severe HRI from developing.

4.7. Conclusion

Data suggests the HIS-Q is a valid tool for assessing changes in heat illness susceptibility following HA which elicits physiological and perceptual changes to cope with heat stress. This level of construct validity suggests that the HIS-Q is a sensitive tool for determining heat sensitivity. Furthermore, the HIS-Q indicated moderate reliability within acute heat stress conditions. The HIS-Q warrant further investigation within field-based events and prolonged exercise-heat stress to promote greater physiological strain across markers that may underpin progression to HRI.

Chapter 5 Physiological and perceptual responses in the elderly to simulated daily living activities in UK summer climatic conditions

5.1. Abstract

Aim: 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.

Methods: Twenty-eight participants (17 males, 10 females and 1 transgender female: mean ± SD; age; 71 ± 4 yrs, height; 169 ± 10 cm, body mass; 76.92 ± 0.23, body fat percentage; 23 ± 4 %) were randomly assigned into three experimental groups based on environmental conditions; 15°C, 25°C or 35°C, 50% RH. 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 recumbent cycling.

Results: No change was observed in the perception of thermal comfort between the 6 METs in 25°C trial compared to the 6 METs in 35°C (*just uncomfortable*) and a non-significant ($p > 0.05$) increase in RPE was observed (14 ± 2 *vs.* 15 ± 2). In contrast, physiological strain markers did significantly increase across the same conditions, including change in T_{re} during exercise (0.27 ± 0.17°C *vs.* 0.64 ± 0.18°C) and peak T_{sk} (32.94 ± 1.15°C *vs.* 36.11 ± 0.44°C).

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

5.2. 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 (Hajat *et al.*, 2014; Kenney *et al.*, 2014; Smith *et al.*, 2016). 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 (Hajat *et al.*, 2014). Furthermore, extreme heatwaves such as the 2003 European heatwave resulted in ~70,000 deaths (Robine *et al.,* 2008; Åström *et al.,* 2011). With some counties experiencing up to 92% excess mortality within the elderly population (Conti *et al.,* 2005). Elderly people also comprise the majority of the emergency and G.P visits during heatwaves for heat-related illnesses (Hajat *et al.*, 2014; Kenney *et al.*, 2014; Smith *et al.*, 2016). 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 (WHO, 2011; PHE, 2015). The information provided encourages people to; increase fluid intake, seek shade, take cool showers and reduce physical activity (WHO, 2011; PHE, 2015). Metabolic heat production ($\dot{H}_{prod}$) is decreased with decreased physical activity, consequently less excess heat dissipation is required to maintain a thermal equilibrium (Sawka & Young, 2000). 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; Change4Life (NHS, 2009) and One You, which includes the Couch to 5K campaign (PHE, 2016). 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 (Anderson & Kenney, 1987; Inoue *et al.,* 1999ab; Larose *et al.,* 2013ab; Stapleton *et al.,* 2014bc; Stapleton *et al.,* 2015). 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 (Kenney *et al.,* 2014). 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 *et al.,* (2014b, 2015) 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. However, the exercise intensities used by Larose *et al.,* (2013ab) and Stapleton *et al.,* (2014b, 2015) are at a set $\dot{H}_{prod}$ and do not replicate activities of daily living for the elderly. Furthermore, the extreme environments > 35°C and < 20 % 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 (MET Office, 2018b). The RH in the UK is variable, during average summers RH ranges from ~60-80% (MET Office, 2018d), however, during periods of hot weather RH is between 20-60% (Burt, 2004; Shanklin & Colwell, 2005).

Additionally, there is a dearth of knowledge pertaining to how the elderly perceptual perceive hot climatic conditions. This is surprising due to changes in behavioural thermoregulation (*i.e.,* '*first line of defence'* for maintaining heat balance), requiring people to be uncomfortable enough within their environment (Schlader *et al.,* 2010; Flouris, 2011; Schlader, 2014; Flouris & Schlader, 2015). In young adults, thermal discomfort is predominately driven by increases in skin temperature, during rest and exercise (Schlader *et al.,* 2010; Flouris, 2011; Schlader, 2014; Flouris & Schlader, 2015). Similar, behavioural thermoregulation research with elderly people during rest and exercise is scarce, with Taylor *et al.,* (1995) reporting greater change in core temperature before implementing behavioural changes in the elderly compared to the young. As core temperature is a slower responding physiological measurement compared to skin temperature there may be a decreased perceptual awareness of the elderly during periods of hot weather. Consequently, the physiological and perceptual responses to activities of daily living of elderly people in UK summer environments warrants investigation.

The elderly population could benefit from advice on how to maintain healthy and active lifestyles during periods of hot weather to promote 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.

5.2. Methods

5.2.1. Participants

28 (17 males; 10 females; 1 transgender female) habitually active participants volunteered for the study and were divided into three experimental groups; 15°C, 25°C or 35°C. Participants were placed into groups by the experimenter to match, for; stature, body mass, body fat percentage and age (Table 5.1). The experimental protocol was approved by the University's ethics committee and conducted in accordance with the principles of the revised Declaration of Helsinki (World Health Organisation, 2013) and the University of Brighton's health and safety procedures (Section 3.1).

Prior to testing, participants provided informed, written consent and a medical questionnaire (Section 3.2). Additionally, the participants' G.P's were informed of their patient's participation and gave their written consent for their patient to participate (Section 3.3.2). In preparation for testing, participants followed the pre-experimental preparation guidelines (Section 3.3.3).

Table 5.1: Mean ± SD participant characteristics.

	15°C	**25°C**	**35°C**
Gender (M/F/TF)	5/4/0	6/3/0	6/3/1
Age (yrs)	70 ± 3	70 ± 2	72 ± 5
Stature (cm)	166 ± 11	172 ± 9	170 ± 9
NBM (kg)	74.89 ± 14.68	79.43 ± 17.46	76.48 ± 12.34
BSA (m^2)	1.83 ± 0.23	1.91 ± 0.25	1.88 ± 0.19
Body fat (%)	24 ± 4	22± 3	23 ± 4

Abbreviations: M; males, F; females, TF; transgender females, NBM; nude body mass, BSA; body surface area.

5.2.2. Preliminary trial

During preliminary testing, hydration (Section 3.4.1) anthropometric (Section 3.4.2) and baseline measures (Section 3.3.4) were collected, followed by a GXT within their predetermined environment (Section 3.3.5). The purpose of the GXT was to determine the participants' power output at 2, 4 and 6 metabolic equivalents (METs) (Section 3.3.5). Metabolic equivalents were used as an easy way to quantify energy expenditure of activities of daily living, 2, 4 and 6 METs values equate to; washing-up, gardening and brisk walking (Jetté *et al.,* 1990; Ainsworth *et al.,* 2011). Expired air was collected using open-circuit spirometry for ~45-s 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 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 (Kwan *et al.,* 2004; Ainsworth *et al.,* 2011). 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 (Jetté *et al.,* 1990). At the end of each stage; HR, T_{re} RPE were recorded.

5.2.3. Experimental testing

Prior to experimental testing, hydration (Section 3.4.1) and baseline measures (Section 3.3.4) were collected. During the main trials the participants completed the simulated activities of daily living protocol (Section 3.3.6) at randomly selected intensity of; 2, 4 or 6 METs within the participant's assigned environmental condition. Throughout testing physiological measurements; HR, T_{re} and T_{sk} were recorded every 5-min. Perceptual measures; TS, TC, and RPE were recorded every 10-min. To estimate WBSR, a pre and post NBM measurement was taken (Section 3.4.6.). All exercise trials were completed 7 days apart to allow for participant recovery.

5.2.4. Statistical analyses

All data are presented as mean ± SD and were assessed for normality and sphericity prior to further statistical analyses (Section 3.6). When the assumption of sphericity was violated the Greenhouse-Geisser adjustment was used (Section 3.6). One-way ANOVAs 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 (Nakagawa and Cuthill, 2007). Data were analysed using SPSS (Version 22.0, SPSS Inc., Chicago, Illinois, USA) with significance set at $p < 0.05$.

5.3. Results

5.3.1. Baseline measures and exercise intensity

There were no observed differences (p >0.05) between the environmental groups for participant characteristics (Table 5.1). Similarly, participant commenced all experimental trials in a similar physiological state as there were no within or between–participant differences for baseline; T_{re} ($F_{(4,48)} = 1.9$, $p = 0.127$, $\eta_p^2 = 0.14$), HR ($F_{(4,50)} = 1.4$, $p = 0.239$, $\eta_p^2 = 0.10$) and T_{sk} ($F_{(4,50)} = 1.3$, $p = 0.294$, $\eta_p^2 = 0.09$).

By research design there were no observed differences for exercise condition between environmental conditions for METs ($F_{(2,81)} = 0.2$, $p = 0.860$, $\eta^2 = 0.004$), or for $\dot{H}_{prod}$ ($F_{(2,81)} = 1.5$, $p = 0.240$, $\eta^2 = 0.04$) (Table 5.2). Furthermore, there were no observed differences for peak RPE ($F_{(2,25)} = 0.1$, $p = 0.905$, $\eta_p^2 = 0.01$) and peak HR ($F_{(2, 50)} = 1.9$, $p = 0.165$, $\eta_p^2 = 0.07$) for environmental condition. However, as expected, there were observed differences for peak RPE ($F_{(2,24)} = 65.0$, $p < 0.001$, $\eta_p^2 = 0.72$) and peak HR ($F_{(1.313, 32.832)} = 108.0$, $p < 0.001$, $\eta_p^2 = 0.81$) for exercise condition. Post-hoc analyses identified a significant difference between all exercise conditions for peak RPE (Table 5.2) and peak HR (Table 5.3). These results indicate no increase in RPE and HR when environmental temperature is increased (*e.g.,* similar RPE and HR in 15°C trial compared to 25°C, when exercising at the same intensity), however there was a significant increase in RPE and HR when exercise intensity was increased (*e.g.,* higher RPE and HR in 4 MET trial compared to 2 MET trial).

5.3.2. Perceptual response

There were observed differences for peak TS ($F_{(1.620, 40.499)} = 45.0$, $p < 0.001$, $\eta_p^2 = 0.64$) and peak TC ($F_{(2,50)} = 13.1$, $p < 0.001$, $\eta_p^2 = 0.35$) for exercise condition (Figure 5.1). Furthermore, there was an observed difference for peak TS ($F_{(2, 25)} = 18.570$, $p < 0.001$, $\eta_p^2 = 0.69$) for environmental condition (Figure 5.1). Interestingly, there was no observed differences for peak TC ($F_{(2,25)} = 2.587$, $p = 0.095$, $\eta_p^2 = 0.17$) for environmental conditions, highlighted by TC at 6 METs, 25°C compared to 35°C being exactly the same (TC = 3 *just uncomfortable*). Post-hoc analyses identified differences between all exercise intensities for peak TS and peak TC (Figure 5.1 and Table 5.2). Additionally, peak TS demonstrated a difference between environmental conditions (Figure 5.1). There was no observed interaction between environmental and exercise conditions for peak TS ($F_{(3.240,40.499)} = 1.8$, $p = 0.150$, $\eta_p^2 = 0.13$).

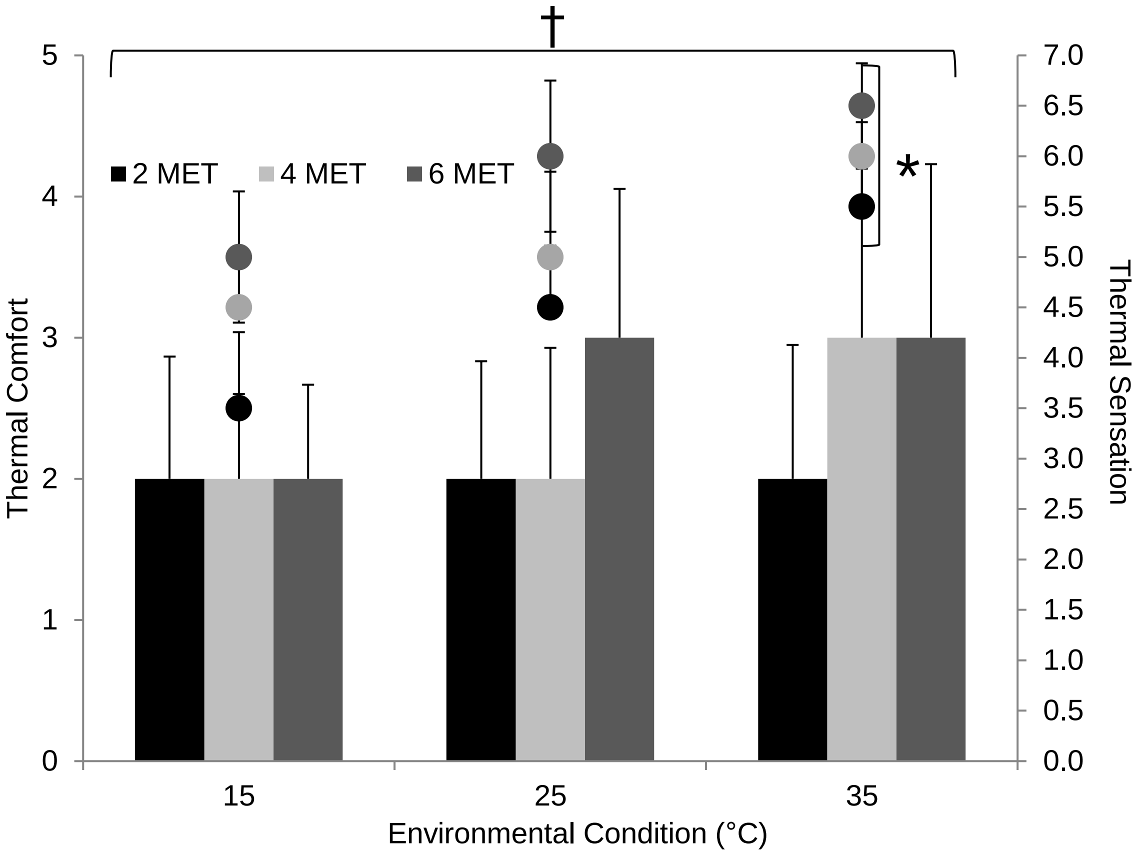


Figure 5.1: Mean ± SD for thermal comfort (bar chart) and thermal sensation (circles) across environmental conditions and exercise intensity. The black bars and circles represent the exercise intensity of 2 METs, light grey bars and circles represent the exercise intensity of 4 METs and dark grey bars and circles represent the exercise intensity of 6 METs. *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 5.2: Mean ± SD of the exercise intensity, peak perceptual responses and absolute difference across exercise conditions within environmental conditions.

Variable	Group	2 MET	4 MET	6 MET	Δ2-4 MET	Δ4-6 MET	Δ2-6 MET
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. *denotes a significant difference ($p < 0.05$) between the exercise conditions. § denotes a significant difference between 15-25°C. # denotes a significant difference between 25-35°C. † denotes a significant difference between 15-35°C.

5.3.3. Physiological responses

There were observed differences for change in rest to end exercise T_{re} (ΔT_{re}) ($F_{(1.507,\ 36.161)} = 121.0$, $p < 0.001$, $\eta_p^2 = 0.70$) and peak T_{re} ($F_{(4,48)} = 43.7$, $p < 0.001$, $\eta_p^2 = 0.65$) for exercise conditions (Table 5.3). Therefore, there was a greater change ΔT_{re} and in peak rectal temperature when exercise intensity was increased and environmental stress remained the same. Post-hoc analyses identified a significant difference between all exercise conditions for ΔT_{re} and peak T_{re} (Table 5.3).

Likewise, there were observed differences for ΔT_{re} ($F_{(2,\ 24)} = 28.2$, $p < 0.001$, $\eta_p^2 = 0.83$), however, no differences for peak T_{re} ($F_{(2,\ 24)} = 1.7$, $p = 0.201$, $\eta_p^2 = 0.13$) for environmental condition. Therefore, the change in exercise rectal temperature was greater with increasing environmental stress when exercise intensity was the same. However, peak rectal temperature was similar with increasing environmental stress, when exercise intensity was the same. Post-hoc analyses identified a significant difference between 15-35°C and 25-35°C for ΔT_{re} (Figure 5.2). There were no observed interactions for ΔT_{re} ($F_{(3.013,\ 36.161)} = 1.9$, $p = 0.141$, $\eta_p^2 = 0.14$) between exercise and environmental conditions.

There were observed differences for ΔT_{sk} ($F_{(2,50)} = 5.7$, $p = 0.006$, $\eta_p^2 = 0.19$) and peak T_{skin} ($F_{(4,50)} = 12.3$, $p < 0.001$, $\eta_p^2 = 0.33$) for exercise condition (Table 5.3). Likewise, observed differences for ΔT_{sk} ($F_{(2,\ 25)} = 10.1$, $p = 0.01$, $\eta_p^2 = 0.45$) and peak T_{sk} ($F_{(2,\ 25)} = 189.2$, $p < 0.001$, $\eta_p^2 = 0.94$) for environmental condition. Post-hoc analyses identified a difference between 2-6 METs for ΔT_{sk} and a difference, between 2-4 METs and 2-6 METs for peak T_{sk} (Table 5.3). Furthermore, there were differences present between environmental conditions for peak T_{sk} and ΔT_{sk} between 15-35°C and 25-35°C (Figure 5.2). There were no observed interactions for ΔT_{sk} ($F_{(4,50)} = 0.3$, $p = 0.244$, $\eta_p^2 = 0.02$) nor peak T_{sk} ($F_{(4,50)} = 0.5$, $p = 0.244$, $\eta_p^2 = 0.10$) between exercise and environmental conditions.

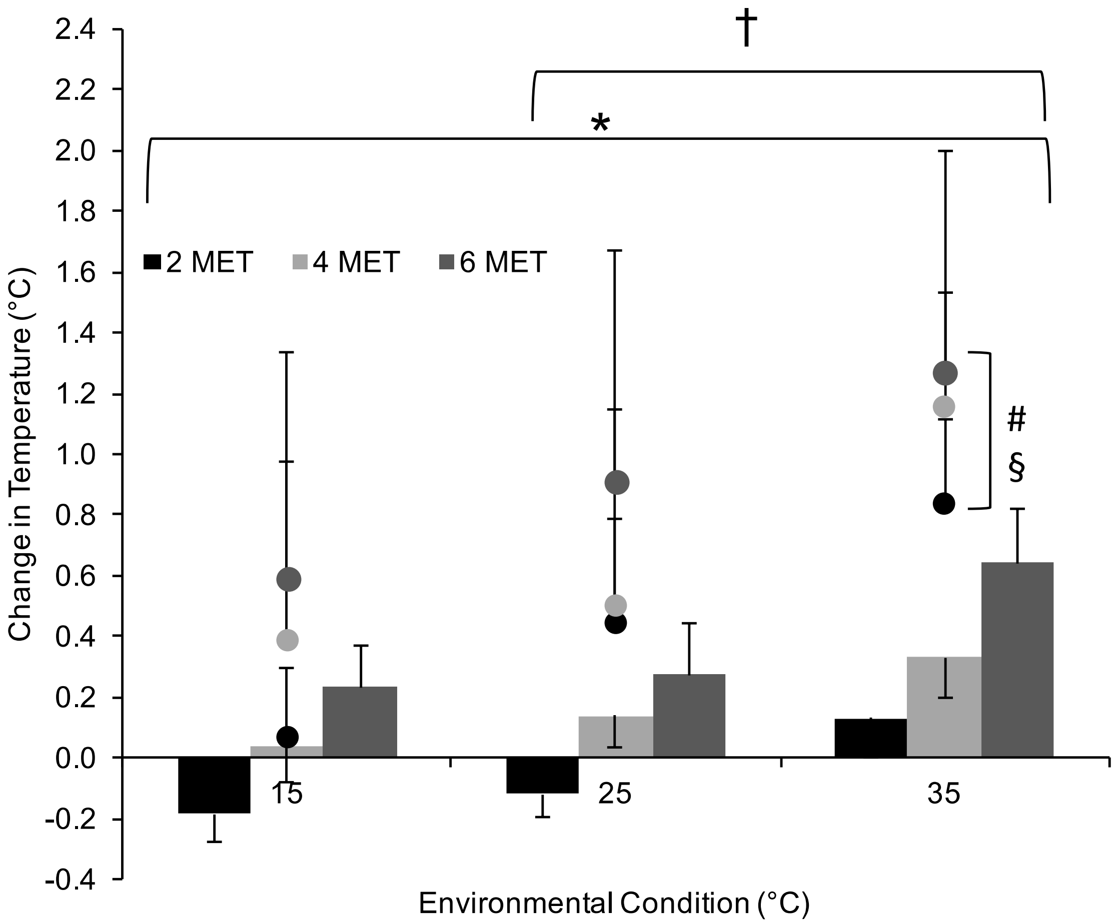


Figure 5.2: Mean ± SD for ΔT_{re} (bar chart) and ΔT_{sk} (circles), across environmental and exercise conditions. The black bars and circles represent the exercise intensity of 2 METs, light grey bars and circles represent the exercise intensity of 4 METs and dark grey bars and circles represent the exercise intensity of 6 METs. *denotes a significant difference ($p < 0.05$) in ΔT_{re} and ΔT_{sk} 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 exercise conditions. § denotes a significant difference ($p < 0.05$) in ΔT_{sk} between 2-6 METs.

Likewise, core-to-skin gradient demonstrated a difference between environmental conditions ($F_{(2,24)}$ = 254.3, p < 0.001 , η_p^2 = 0.96) (Table 5.3). Whereas, there was no difference observed between exercise conditions ($F_{(2, 48)}$ = 1.9, P = 0.165, η_p^2 = 0.07). (Table 5.3). Post-hoc analyses identified a significant difference between all environmental conditions (Figure 5.3).

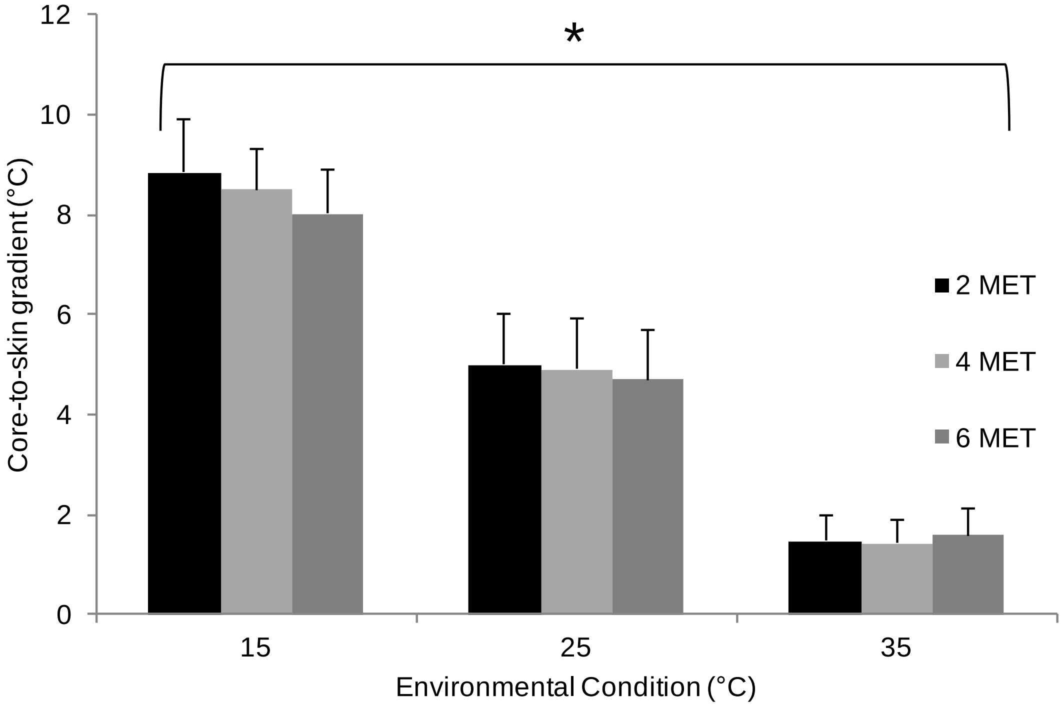


Figure 5.3: Mean ± SD of end exercise core-to-skin gradient, across environmental conditions and exercise intensity. The black bars represent the exercise intensity of 2 METs, light grey bars represent the exercise intensity of 4 METs and dark grey bars represent the exercise intensity of 6 METs* denotes a significant difference (p < 0.001) for environmental condition.

There were observed differences for WBSR for exercise ($F_{(1.579,39.477)}$ = 10.3, p = 0.001, η_p^2 = 0.29) and environmental conditions ($F_{(2, 25)}$ = 8.5 , p = 0.02 , η_p^2 = 0.40). Post-hoc analyses identified a difference between 2-6 METs and 4-6 METs (Table 5.3). Furthermore, there was a difference between 15-35°C (Table 5.3). There was no interaction observed ($F_{(3.158,39.477)}$ = 1.8, p = 0.143, η_p^2 = 0.13) for WBSR between environmental and exercise conditions.

Table 5.3: Mean ± SD of the physiological responses and absolute difference across exercise conditions within environmental conditions.

Variable	Group	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_{sk} (°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_{sk} 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 *
Core-to-skin 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 ($b.min^{-1}$)	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_{sk}; skin temperature, WBSR; whole body sweat rate, HR; heart rate. *denotes a significant difference ($p < 0.05$) between the exercise conditions. § denotes a significant difference between 15-25°C. # denotes a significant difference between 25-35°C. † denotes a significant difference between 15-35°C.

5.4. Discussion

This study is the first to investigate the physiological and perceptual responses 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}, $T_{sk,}$ 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 intensity) 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}. This is surprising because T_{sk}, a modulator of TC which is a driver of thermoregulatory behaviour (Schlader *et al.,* 2010; Flouris & Schalder, 2015) and T_{re} is a marker of heat illness (Bouchama & Knochel, 2002; Coris *et al.,* 2004; Nadir *et al.,* 2016). In this study, physiological strain markers increased, but peak TC remained 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 (Schlader *et al.,* 2010). The potential implications of an attenuated response to environmental discomfort is an increased risk of heat illness due to a continued increase in physiological strain markers (*e.g.,* T_{re} and T_{sk}) without a concomitant behavioural response. Heat illnesses occurs along a continuum, therefore minor heat illnesses (*e.g.,* heat rash) can develop into a severe heat illness (*e.g.,* heat stroke), if left untreated (Coris *et al.,* 2004). Consequently, if an elderly person does not feel uncomfortable enough to minimise heat illness risk, there is the potential for insidious onset of heat stroke. In addition to no changes in TC, RPE, which is a modulator of thermoregulatory behaviour during exercise (Flouris & Schalder, 2015), had a non-significant increase from 25°C, 6 METs (14 ± 2) to (15 ± 2) at 35°C, 6 METs.

Previously, Larose *et al.,* (2014) 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). This suggests that the elderly may display a decreased perception of heat and consequently delayed or modified behavioural thermoregulatory responses compared to their younger counterparts, increasing the risk of heat illness. The current work supports this by observing a blunted perceptual response leading to a potential attenuated behavioural thermoregulatory response. The elderly participants remained '*just uncomfortable'* (TC = 3) and were 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 to minimise inter-individual differences (Section 3.5). In brief, a set of standardised instructions were 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*' (Borg, 1982). Furthermore, participants were familiarised with perceptual scales 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 change in rectal temperature 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 rectal temperature of 37.70 ± 0.41°C, which is not considered hyperthermic (Taylor, 2006). Furthermore, all other exercise and environmental conditions demonstrated lower end T_{re} and ΔT_{re} compared to 6 MET 35°C trial (Table 5.3). Therefore, it can be concluded that it is safe for habitually active elderly people 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_{sk} and increase an individual's risk of developing a heat illness. This is demonstrated by Stapleton *et al.,* (2015), where intermittent exercise and recovery stages provoked a change in oesophageal temperature 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 oesophageal temperature (0.68°C) is similar to the present study (ΔT_{re} of 0.64°C). However, the overall change in oesophageal temperature was 1.15°C with a total heat exposure time of 165-min (Stapleton *et al.,* 2015). Stapleton *et al.,* (2015) highlight the accumulation of heat during repeated bouts of exercise that would likely to be experienced during periods of hot weather. Furthermore, Notley *et al.,* (2018b) found that when older (59 ± 4 yrs) people completed two consecutive days of work (~7.5 hours of intermittent moderate exercise; 9 x 30-min walking at 3 mph, 2% grade) in the heat (38°C, 34% RH) that heat storage was 31% greater on day two compared to day one. Therefore, in a sustained period of hot weather, the elderly may have a greater heat storage accumulation over the duration of the hot weather, when completing the same daily activities.

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 (Flynn *et al.,* 2005; Hajat *et al.,* 2007; Hajat *et al.,* 2014). 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.

5.5. 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 brisk walking/dancing) in high ambient temperatures (35°C) without a concurrent perceptual recognition. Therefore, the elderly have a 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 driver for thermoregulatory behaviour and therefore should use caution when exercising in hot ambient temperatures.

Chapter 6 The elderly's physiological and perceptual responses to physical and perceptual cooling during simulated activities of daily living in UK summer climatic conditions

6.1. Abstract

Aim: The aim of this investigation was to assess the elderly's physiological and perceptual responses to cooling through cold water ingestion (COLD) and to an L-menthol mouth rinse (MENT) during simulated activities of daily living in UK summer climatic conditions.

Methods: Ten participants (7 males and 3 females: mean ± SD; age 69 ± 3 yrs, height 168 ± 10 cm, body mass 68.88 ± 13.72 kg, body fat percentage 28 ± 4 %) completed 3 experimental trials; control (CON), COLD and MENT. A preliminary incremental cycling test was used to calculate individual exercise intensities equating to 6 METs / 3.5 $W.kg^{-1}$ $\dot{H}_{prod}$. Experimental trials consisted of 40-min rest followed by 30-min of cycling exercise at the prescribed exercise intensity and a six-minute walk test (6MWT), within a 35°C, 50% RH environment. HR and T_{re} were recorded every 5-min; TS and TC every 10-min and experimental interventions, cold water (4°C) ingestion (4x300ml during rest and 3x100ml during exercise, total of 1.5L) or menthol (5ml mouth swill for 5-s, with a menthol concentration of 0.01%), were administered every 10-min.

Results: Peak T_{re} was significantly ($p < 0.05$) lower in COLD trial compared to CON (-0.34 ± 0.16°C) and MENT (-0.36 ± 0.20°C). There was also a trend for end exercise HR to decrease in the COLD trial compared to CON (-7 ± 9 $b.min^{-1}$) and MENT (-6 ± 7 $b.min^{-1}$). There was no difference in end exercise TS (CON; 6.1 ± 0.4, COLD; 6.0 ± 0.4, MENT; 6.4 ± 0.6) and TC (CON; 4 ± 1, COLD; 4 ± 1, MENT; 4 ± 1) between trials. The participants walked significantly further during the COLD 6MWT compared to CON (+0.04 ± 0.04 km) and MENT (+0.04 ± 0.03 km). There was also a trend for reduced physiological strain in the COLD 6MWT compared to CON (T_{re}; -0.21 ± 0.24°C, HR; -7 ± 8 $b.min^{-1}$, $p < 0.05$) and MENT (T_{re}; -0.23 ± 0.24°C, HR; -4 ± 7 $b.min^{-1}$).

Conclusion: These findings suggest that the elderly can reduce their physiological strain (T_{re} and HR) during activities of daily living and a 6MWT, in hot UK climatic conditions, when they drink cold water. Furthermore, in agreement with study 2 (Chapter 5, p124), the elderly's perception (TS and TC) of the hot environment did not differ compared to CON at the end of exercise with cold water ingestion or with the menthol mouth rinse. Surprisingly, menthol provided no benefit in perception of the heat and as expected had no functional gains. Due to no change in perception, the elderly could still be at risk of heat illness because they do not feel hot and uncomfortable enough to implement physiological strain reducing strategies such as cold water ingestion (4°C). Therefore, education of when to implement these strategies without perceptual cues is warranted.

6.2. Introduction

The elderly population are the most likely to develop heat-related illnesses including; heat-related mortality, during periods of hot weather (Conti *et al.*, 2005; Kenney *et al.*, 2014; Smith *et al.*, 2016; Mora *et al.*, 2017). This is evidenced by over 65's representing the largest proportion of G.P and hospital visits for heat-related illnesses and the greatest percentage of heat-related deaths during heatwaves (Conti *et al.,* 2005; Kenney *et al.,* 2014; Smith *et al.,* 2016). The number of heat- related illnesses and deaths in the elderly population are predicted to increase over the next century (Hajat *et al.,* 2014; Arbuthnott & Hajat, 2017). This is a consequence of a growing elderly population and increasing warmer climate (Hajat *et al.,* 2014; Arbuthnott & Hajat, 2017). Therefore, strategies to prevent minor and severe heat-related illnesses in the vulnerable elderly group are required.

The risk of severe heat illness is reduced in young populations through implementing acute and chronic heat-alleviating strategies (Armstrong & Maresh, 1991; Gosling *et al.,* 2008; Lee *et al.,* 2008; Bongers *et al.,* 2014; Minett *et al.,* 2016; Ruddock *et al.,* 2017). However, there is a dearth of knowledge pertaining to the effects of acute and chronic heat-alleviating strategies for the elderly population. Within acute heat-alleviation the research is limited to the effects of electrical fan use with the elderly (Jay *et al.,* 2014; Gagnon & Crandall, 2017). This is surprising because, the literature has investigated many acute practical cooling strategies to reduce physiological strain within athletic and occupational populations (Brearley & Walker, 2015; James *et al.,* 2015; Ruddock *et al.,* 2017; Stevens *et al.,* 2017). Consequently, it is yet to be determined whether the findings from acute practical cooling strategies in young healthy populations can be transferred to attenuate the risk of heat illness in an elderly population.

Prevention of heat illness in the elderly requires an intervention with cooling modalities pre or during (*i.e.,* per-cooling) activity, in line with existing research (Bongers *et al.,* 2014; Brearley & Walker, 2015; Tyler *et al.,* 2015; Ruddock *et al.,* 2017). External, internal and mixed methods cooling have been used to reduce physiological strain and improve performance, both as a method of pre and per-cooling (Duffield *et al.,* 2011; Lee *et al.,* 2013; James *et al.,* 2015; Stevens *et al.,* 2017). External methods include cooling vest, cooling garments, cooling packs, cold water immersion (local and whole body) and cold towel application (Tyler *et al.,* 2010; Duffield *et al.,* 2011; Ross *et al.,* 2013; Faulkner *et al.,* 2015). Bongers *et al.,* (2014) reviewed pre and per-cooling techniques, finding external pre-cooling may reduce peak core temperature between -0.1 and -0.4°C, depending on the cooling technique. External per-cooling had peak core temperature changes between +0.2 and -0.3°C, and a maximum HR decrease of 5 b.min^{-1}, depending on the cooling technique. It is noteworthy that the cooling interventions have a different application route and duration prior to and during exercise heat exposure. Therefore, comparison between methods is limited due to the differences in the volume and processes of heat dissipation.

Cooling interventions that use a combination of multiple external cooling methods, are known as mixed methods external cooling. James *et al.*, (2015) used a mixed methods external cooling approach consisting of cold towels, forearm immersion, ice vest and cooling shorts and unsurprisingly found a significant decrease in skin temperature during and immediately after the cooling phase compared to control (immediately after cooling; -6.64 ± 1.46°C *vs* -0.40 ± 0.39°C). Furthermore, Bongers *et al.,* (2014) reported a -0.3°C in core temperature and -3 b.min^{-1} in HR post pre-cooling with mixed methods external cooling. External and mixed methods external cooling strategies have the desired effect of reducing physiological strain. However, wearing an ice vest/ other cooling garments, could be viewed as impractical, due to the cost, weight, storage, feasibility, accessibility and discomfort of wearing a cold garment on the body for a long period of time (Ross *et al.,* 2013; Tyler *et al.,* 2015; Ruddock *et al.,* 2017). These factors decrease the likelihood of elderly people implementing them as a practical cooling method during activities of daily living. The data from Bongers *et al.,* (2014) should be interpreted with some caution as they include their own data within the literature review and therefore there is the potential for author bias within their conclusions.

Internal cooling presents the most practical acute cooling strategy and includes ice slurry and cold fluid ingestion (Ross *et al.,* 2013; Tyler *et al.,* 2015; Ruddock *et al.,* 2017). Although ice slurry research has seen reductions in physiological strain, there are reports of ice slurry leading to gastrointestinal distress in participants (Ross *et al.,* 2013; Stevens *et al.,* 2015). Conversely, cold fluid ingestion has minimal gastrointestinal discomfort. Mündel *et al.*, (2006) found that refrigerated water (4°C) reduced end exercise T_{re} (-0.25°C) and lowered HR by 5 b.min^{-1}, compared to 19°C water control. Likewise, Lee *et al.,* (2008) found that water (4°C) given periodically during rest and exercise (every 10-min), reduced end rest T_{re} (-0.5 ± 0.1°C) and HR (-8 b.min^{-1}) compared to the 37°C water control. Furthermore, T_{re} was significantly lower in the cold-water trial compared to control from 10-min into rest until 45-min into exercise and HR was reduced from 25-min into rest until 35-min into exercise. Consequently, cold fluid ingestion could provide the most practical and comfortable intervention to attenuate the rise in markers of heat illness in the elderly.

Perceptual cooling as well as physical cooling has been investigated in athletic populations. The application of L-menthol elicits a cooling sensation, which in a hot environment is interpreted as a greater feeling of comfort, leading to improvements in performance (Gillis *et al.,* 2010; Steven & Best, 2017). There is some evidence of L-menthol mouth rinse improving time trial and time to exhaustion performance; by 3-9% (Steven & Best, 2017;

Stevens *et al.,* 2015; Best *et al.,* 2018; Jeffries *et al.,* 2018). However, due to L-menthol being a perceptual cooling method, core temperature, a marker of heat illness, can be elevated in comparison to control groups (Gillis *et al.,* 2010; Lee *et al.,* 2012; Gillis *et al.,* 2016). A behavioural thermoregulatory change to the athlete can explain this response, whereby they do not feel uncomfortable enough to perceive the need to slow down. Therefore, they have the capacity to increase the amount of work completed, leading to an accumulation of metabolic heat production and an elevation in core temperature. Schlader *et al.,* (2011) demonstrates this by a significant increase in absolute work done and an increase, albeit not significant, change in exercise core temperature in menthol (MENT) compared to control (CON) trials, during cycling exercise with an RPE clamp of 16: MENT; 228.7 ± 23.7 kJ and 0.97 ± 0.13°C, CON; 187.4 ±16.7 kJ and 0.74 ± 0.06°C.

L-menthol is an active substance within some commercially available cooling products. However, to the researcher's knowledge there is no research investigating the effects of L-menthol on function or heat perception in an elderly population. The potential consequence of these products may be to worsen behavioural thermoregulation in an elderly population, by delaying the life-saving thermoregulatory behaviours such as; seeking shade, taking extra layers of clothing off and opening windows. These thermoregulatory behaviours attenuate heat illness risk, therefore if the elderly do not feel uncomfortable enough to implement them, they are unknowingly putting themselves at greater risk of heat illness. Study 2 (Chapter 5, p124), has suggested that the elderly have a reduced perceptual awareness of increasing environmental temperature. The use of L-menthol could exacerbate this reduced awareness further by eliciting a cooling sensation that makes the elderly feel greater comfort in hot environments.

Currently there is limited research informed advice on how the elderly should cope during periods of hot weather. Therefore, a research-informed acute intervention that is practical, easy to implement and reduces physiological strain could reduce heat illness risk in the population that is at most risk of heat-related mortality. Furthermore, research-informed evidence of the physiological and perceptual implications of L-menthol use within an elderly population is required to support or refute its use during periods of hot weather. This investigation aimed to assess the elderly's physiological and perceptual responses to cooling through cold water ingestion (COLD) and L-menthol mouth rinse (MENT) during simulated activities of daily living in UK summer climatic conditions. The study had two hypotheses; firstly, that COLD would reduce physiological strain in comparison to CON and MENT interventions. Secondly, that MENT would have a perceptual cooling effect compared to CON, whilst having no effect on reducing physiological strain.

6.3. Methods

6.3.1. Participants

Ten (7 males and 3 females) habitually active participants (mean ± SD; age 69 ± 3 yrs, height 168 ± 10 cm, body mass 68.88 ± 13.72 kg, body fat percentage 28 ± 4 %) volunteered for the study. The experimental protocol was approved by the University's ethics committee and conducted in accordance with the principles of the revised Declaration of Helsinki (WHO, 2013) and the University of Brighton's health and safety procedures (Section 3.1).

Prior to testing, participants provided informed, written consent and a medical questionnaire (Section 3.2). In preparation for testing, participants followed the pre-experimental preparation guidelines (Section 3.3.3).

6.3.2. Preliminary trial

During preliminary testing, hydration (Section 3.4.1) anthropometric (Section 3.4.2) and baseline measures (Section 3.3.4) were collected, followed by a GXT within 35°C 50% RH (Section 3.3.5) (Figure 6.1). Respiratory gas was collected at the end of each stage to calculate individual resting 1 MET values and exercise intensities equating to 6 METs and $3.5 W.kg^{-1}$ $\dot{H}_{prod}$ (Section 3.4.7) to be used in the main trials. On completion of the GXT, participants completed a familiarisation of the six-minute walk test (6MWT) (Section 3.3.7).

6.3.3. Main trials

The three main trials were completed in a semi-randomised order via a Latin square design and included; control (CON), cold water ingestion (COLD) and L-menthol mouth rinse (MENT). The Latin square design allowed for each trial to be completed in the various orders equally (*e.g.,* CON, COLD, MENT or COLD, MENT, CON or MENT, CON, COLD etc.) to eliminate any bias of trial order. The experimental protocol consisted of the completion of the simulated activities of daily living protocol (Section 3.3.6) followed by the 6MWT (Section 3.3.7). Experimental testing was completed within a 35°C, 50% RH environment. Throughout testing physiological measurements; heart rate (HR), rectal temperature (T_{re}) and skin temperature (T_{sk}) were recorded every 5-min. Perceptual measures; thermal sensation (TS), thermal comfort (TC), thirst sensation (ThS) and rating of perceived exertion (RPE) were recorded every 10-min. To estimate whole body sweat rate (WBSR) a pre and post nude body mass measurement was taken (Section 3.4.6). All exercise trials were completed 7 days apart to allow for participant recovery (Figure 6.1).

The COLD intervention required the participants to drink 300ml of water (4°C) within 2-min (every 10-min) during rest and 100ml of water (4°C) consumed within a minute (every 10-min) during exercise (Lee *et al.,* 2008). The 4°C temperature was achieved by placing water in a Thermos flask and placing in a refrigerator (~4°C) overnight for morning testing. The water temperature was checked prior to; testing and consumption, using a thermometer (Fisher Scientific, Fisherbrand, red spirit filled partial immersion, UK). The MENT intervention was a 5-s, 25ml L-menthol solution (0.01% concentration) mouth swill, which was expectorated into a bucket (Mündel *et al.,* 2010). The L-menthol solution was prepared ~60-min prior to the participant entering the climatic chamber, by adding 100ml boiling water to 0.01g of menthol crystals. To ensure the crystals remained dissolved in the solution, the temperature was maintained ~37°C and was monitored throughout testing using a thermometer. Throughout the COLD and MENT trials, interventions were administered every 10-min, whilst the CON trial did not have any intervention.

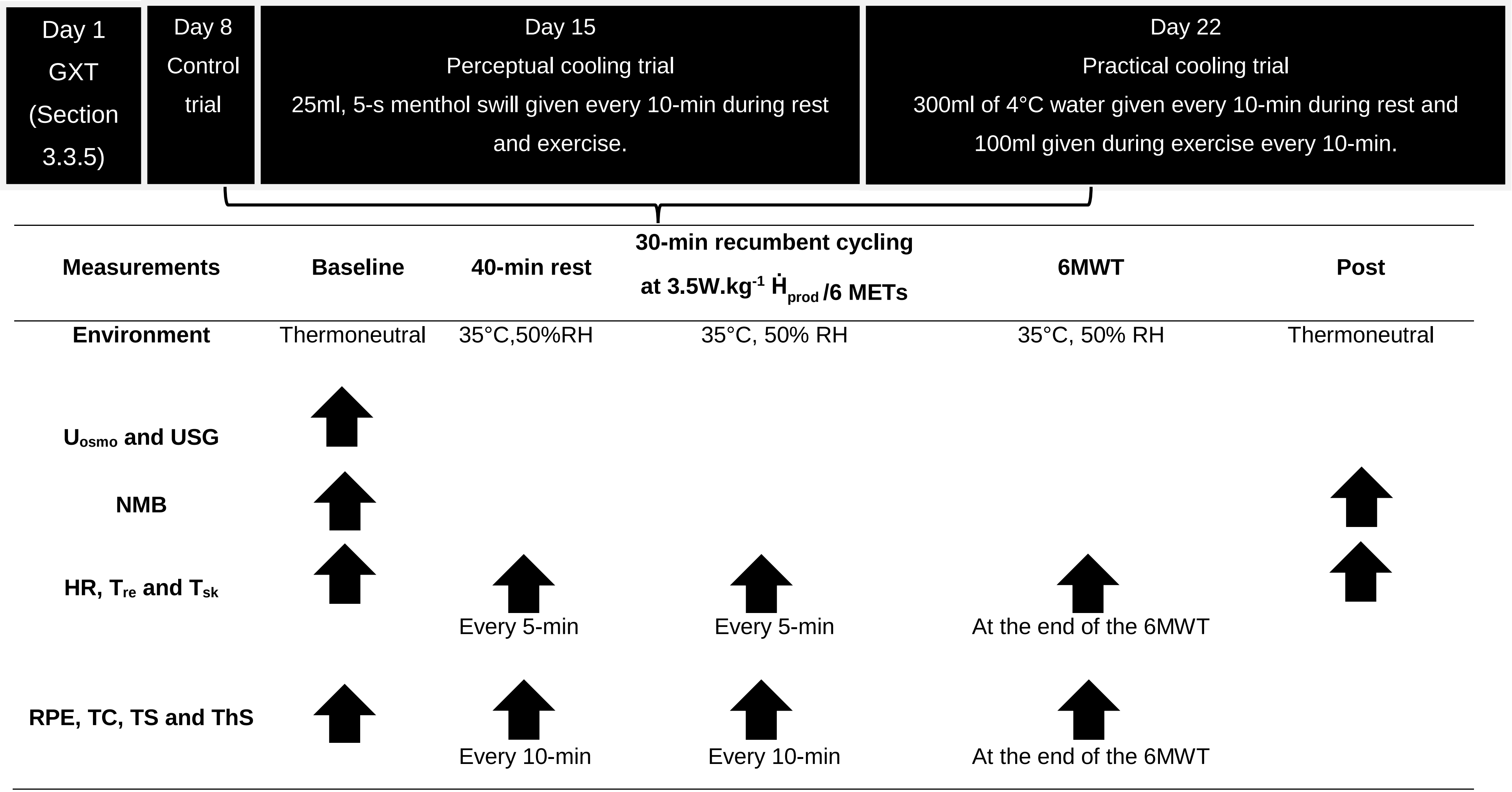


Figure 6.1: Day 8, 15 and 22 completed in a random order. Each trial completed the protocol in the specified environmental conditions. Abbreviations: GXT; graded exercise test, 6MWT; six-minute walk test, U_{osmo}; urine osmolarity, USG; urine specific gravity, NBM; nude body mass, HR; heart rate, T_{re}; rectal temperature, T_{sk}; skin temperature, RPE; rating of perceived exertion, TC; thermal comfort, TS; thermal sensation, ThS; thirst sensation.

6.3.4. Statistical analyses

All data are presented as mean ± SD and were assessed for normality and sphericity prior to further statistical analyses (Section 3.6). When the assumption of sphericity was violated the Greenhouse-Geisser adjustment was used (Section 3.6). One-way ANOVAs for baseline and peak measurement comparison were completed when data was parametric and Friedman's test when data was non-parametric. Two-way repeated measures ANOVAs (time*intervention) were used to analyse time effects between interventions. Follow up Bonferroni-corrected post-hoc comparisons were completed if interaction and main effects were observed in parametric data and Wilcoxon signed rank test when data was non-parametric. Effect sizes were estimated using η_p^2 within statistical ANOVA analysis, to analyse the magnitude and trends of the intervention (Nakagawa and Cuthill, 2007). Effect sizes for t-tests and Wilcoxon ranked test were categorised as; small 0.2, moderate 0.5 and large 0.8 and are presented as *d* and *r* (Cohen, 1998; Field, 2017). Data were analysed using SPSS (Version 22.0, SPSS Inc., Chicago, Illinois, USA) with significance set at $p < 0.05$.

6.4. Results

6.4.1. Baseline measures and exercise intensity

Environmental conditions were not different ($p > 0.05$) between interventions for; temperature, relative humidity and WBGT. Additionally, participants arrived euhydrated for all trials; $U_{osmo} < 700$ mOsm.kg^{-1} and USG < 1.020 and by research design there were no observed differences in the exercise intensity completed for METs and $\dot{H}_{prod}$. Likewise, there were no differences in physiological and perceptual measurements at baseline between interventions for; HR, T_{re}, T_{sk}, RPE, TS, TC and ThS (Table 6.1).

Table 6.1: Environmental conditions, exercise intensity and baseline physiological and perceptual data across interventions. Mean ± SD.

Variable	CON	COLD	MENT	*p [η_p^2]*
Environmental temperature (°C)	35.6 ± 0.3	35.7 ± 0.3	35.5 ± 0.4	0.32 [0.12]
Environmental RH (%)	52.1 ± 1.2	51.1 ± 1.8	52.3 ± 1.8	0.29 [0.13]
WBGT (°C)	29.9 ± 0.5	30.0 ± 0.3	30.0 ± 0.4	0.90 [0.01]
U_{osmo} (mOsm.kg^{-1})	391 ± 189	369 ± 202	369 ± 208	0.94 [0.01]
USG	1.011 ± 0.006	1.010 ± 0.006	1.010 ± 0.006	0.89 [0.01]
METs	6.2 ± 3.0	5.9 ± 2.8	5.7 ± 1.8	0.56 [0.05]
$\dot{H}_{prod}$ (W.kg^{-1})	3.7 ± 0.5	3.7 ± 0.5	3.6 ± 0.5	0.94 [0.01]
HR (b.min^{-1})	67 ± 8	68 ± 8	66 ± 7	0.51 [0.07]
T_{re} (°C)	37.15 ± 0.35	37.18 ± 0.33	37.00 ± 0.30	0.10 [0.23]
T_{sk} (°C)	32.03 ± 0.79	32.14 ± 0.67	32.26 ± 1.03	0.81 [0.27]
RPE	6 ± 0	6 ± 0	6 ± 0	0.37
TC	1 ± 1	2 ± 1	1 ± 1	0.58
TS	4.1 ± 0.4	4.0 ± 0.4	4.1 ± 0.2	0.85
ThS	1 ± 0	1 ± 0	1 ± 0	0.78

Abbreviations: CON; control, COLD; cold water ingestion, MENT; L-menthol mouth rinse, RH; relative humidity, WBGT; wet globe temperature, U_{osmo}; urine osmolarity, USG; urine specific gravity, METs; metabolic equivalents, $\dot{H}_{prod}$; metabolic heat production, HR; heart rate, T_{re}; rectal temperature, T_{sk}; skin temperature, RPE; rating of perceived exertion, TC; thermal comfort, TS; thermal sensation. ThS; thirst sensation.

6.4.2. Physiological responses

To assess any time effect of the interventions, physiological data was analysed at the time point when interventions were given, every 10-min during rest and exercise. There was a significant interaction between time and intervention on T_{re} ($F_{(2.331,\ 20.977)} = 19.26$, $p < 0.001$, $\eta_p^2 = 0.68$). Follow up analysis identified the time points and interventions that were significantly different from one another (Figure 6.2). Likewise, change in T_{re} from baseline to end exercise and peak T_{re} had significant main effects of intervention ($F_{(2,18)} = 25.04$, $p < 0.001$, $\eta_p^2 = 0.74$ and $F_{(2,18)} = 24.98$, $p < 0.001$, $\eta_p^2 = 0.74$) (Table 6.2). These results show a decrease in T_{re} when drinking cold water from 20-min into rest until the end of exercise.

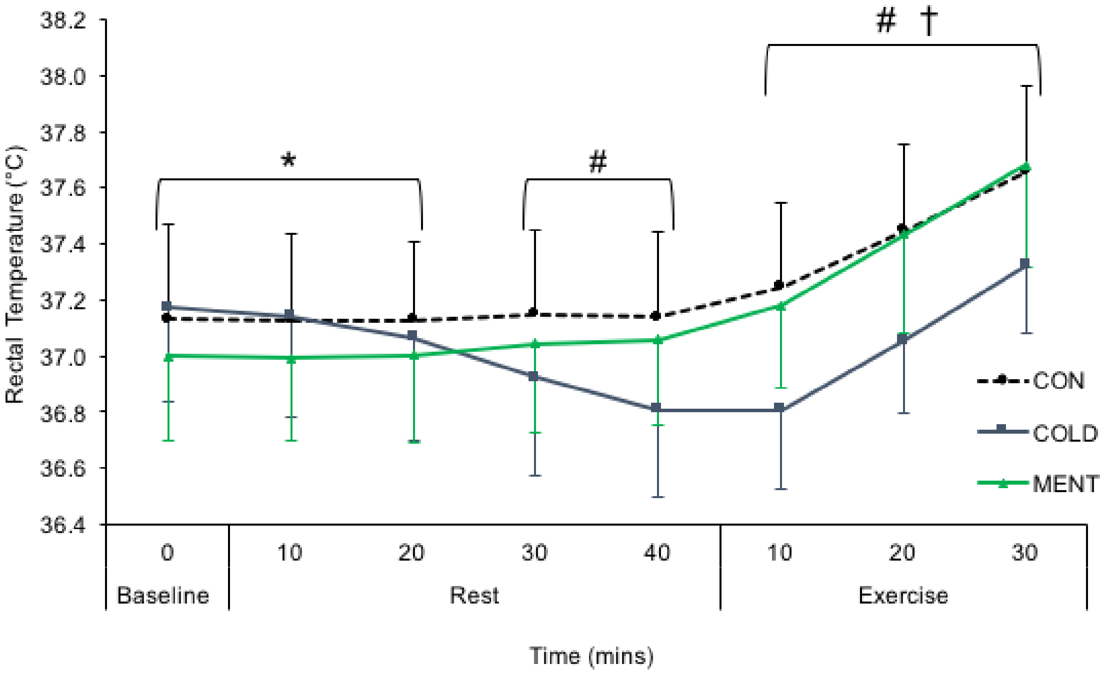


Figure 6.2: Mean ± SD for T_{re} across time and interventions; CON (black circles), COLD (blue squares) and MENT (green triangles). *denotes a significant difference ($p < 0.05$) between CON and MENT. # denotes a significant difference ($p < 0.05$) between CON and COLD. † denotes a significant difference ($p < 0.05$) between COLD and MENT.

There was a significant interaction between time and intervention on HR ($F_{(3.897, 35.609)} = 4.67$, $p < 0.01$, $\eta_p^2 = 0.34$). Follow up analysis identified the time points when HR was significantly lower by drinking cold water compared to swilling menthol, as end rest HR and at minute 20 during exercise (Figure 6.3). Likewise, peak HR had a significant main effect of intervention ($F_{(2,18)} = 5.34$, $p = 0.02$, $\eta_p^2 = 0.37$). However, pairwise comparison only identified a trend ($p < 0.1$) of a reduced HR in COLD compared to CON and MENT (Table 6.2).

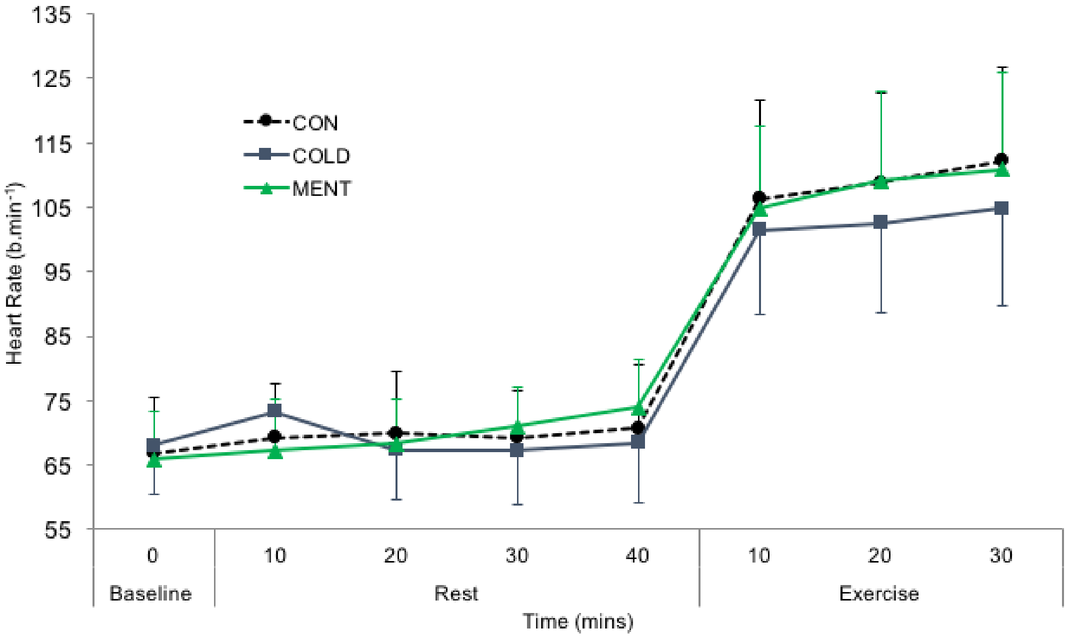


Figure 6.3: Mean ± SD for HR across time and interventions; CON (black circles), COLD (blue squares) and MENT (green triangles). *denotes a significant difference ($p < 0.05$) between COLD and MENT.

Skin temperature was not different between trials, across time ($F_{(3.061, 22.490)} = 0.73$, $p = 0.54$, $\eta_p^2 = 0.85$), or at peak ($F_{(2,18)} = 1.07$, $p = 0.36$, $\eta_p^2 = 0.11$) (Table 6.2). However, due to the decrease in peak T_{re} in the COLD intervention there was a significant main effect of peak core-to-skin gradient between interventions ($F_{(2,18)} = 6.23$, $p = 0.01$, $\eta_p^2 = 0.41$). Peak core-to-skin gradient was significantly decreased in the COLD (1.11 ± 0.31°C) compared to the MENT (1.73 ± 0.47°C**)** trial, but not CON (1.62 ± 0.60°C**)** (Table 6.2).

There was a main effect of WBSR between trials ($F_{(2,18)} = 6.15$, $p = 0.01$, $\eta_p^2 = 0.41$). Pairwise comparison identified a significantly greater WBSR in the CON ($p = 0.02$, $d = 1.09$) compared to COLD intervention, but no significant differences between COLD and CON or CON and MENT (Table 6.2).

Table 6.2: Peak physiological variables for the interventions and the differences between interventions. Mean ± SD.

Physiological Variable	**CON**	**COLD**	**MENT**	**Difference CON-MENT**	**Difference COLD-CON**	**Difference COLD-MENT**
ΔT_{re} (°C)	0.53 ± 0.18*	0.15 ± 0.25 #§	0.68 ± 0.27	-0.16 ± 0.15	-0.38 ± 0.26	-0.53 ± 0.30
Peak T_{re} (°C)	37.66 ± 0.30	37.32 ± 0.67#§	37.68 ± 0.36	-0.02 ± 0.17	-0.34 ± 0.16	-0.36 ± 0.20
Peak HR ($b.min^{-1}$)	112 ± 14	105 ± 15	111 ± 15	2 ± 6	-7 ± 9	-6 ± 7
Peak T_{sk} (°C)	36.04 ± 0.70	36.21 ± 0.30	35.99 ± 0.58	0.09 ± 0.63	0.17 ± 0.64	0.27 ± 0.46
Peak core-to-skin gradient (°C)	1.62 ± 0.60	1.11 ± 0.31§	1.73 ± 0.47	-0.11 ± 0.64	-0.51 ± 0.68	-0.62 ± 0.44
WBSR ($L.h^{-1}$)	0.94 ± 0.26	0.62 ± 0.26#	0.80 ± 0.24	0.15 ± 0.36	-0.33 ± 0.28	-0.18 ± 0.24

Abbreviations: CON; control, COLD; cold water ingestion, MENT; L-menthol mouth rinse; Δ; change, T_{re}; rectal temperature, HR; heart rate, T_{sk}; skin temperature, WBSR; whole body sweat rate. * denotes a significant ($p < 0.05$) difference between CON and MENT. # denotes a significant ($p < 0.05$) difference between COLD and CON. § denotes a significant ($p < 0.05$) difference between COLD and MENT.

6.4.3. Perceptual responses

There was no significant interaction for TS ($F_{(4.729,52.56)}$ = 1.50, p = 0.21, η_p^2 = 0.14) or TC ($F_{(4.201,37.809)}$ = 1.69, p = 0.17, η_p^2 = 0.16), across time and intervention. However, there were main effects for intervention at the end of rest for TS ($\chi^2(2)$ = 10.07, p = 0.01) and TC ($\chi^2(2)$ = 8.27, p = 0.02). Follow up Wilcoxon signed rank test identified that TS was significantly lower at the end of rest in COLD compared to MENT (T = 36, p = 0.01, r = -0.44) and CON (T = 5, p = 0.05, r = 0.58). Similarly, TC was significantly lower at the end of rest in COLD compared to the MENT (T = 0.0, p = 0.02, r = -0.50) and trended towards significance compared to CON (T = 0.0, p = 0.059, r = 0.59). The differences were not maintained by the end of exercise for TS ($\chi^2(2)$ = 5.20, p = 0.07) or TC ($\chi^2(2)$ = 2.67, p = 0.26) (Figure 6.4). Therefore, participants at rest felt cooler and more comfortable when drinking cold water compared to swilling menthol. Furthermore, they also felt cooler at rest when drinking cold water compare to control.

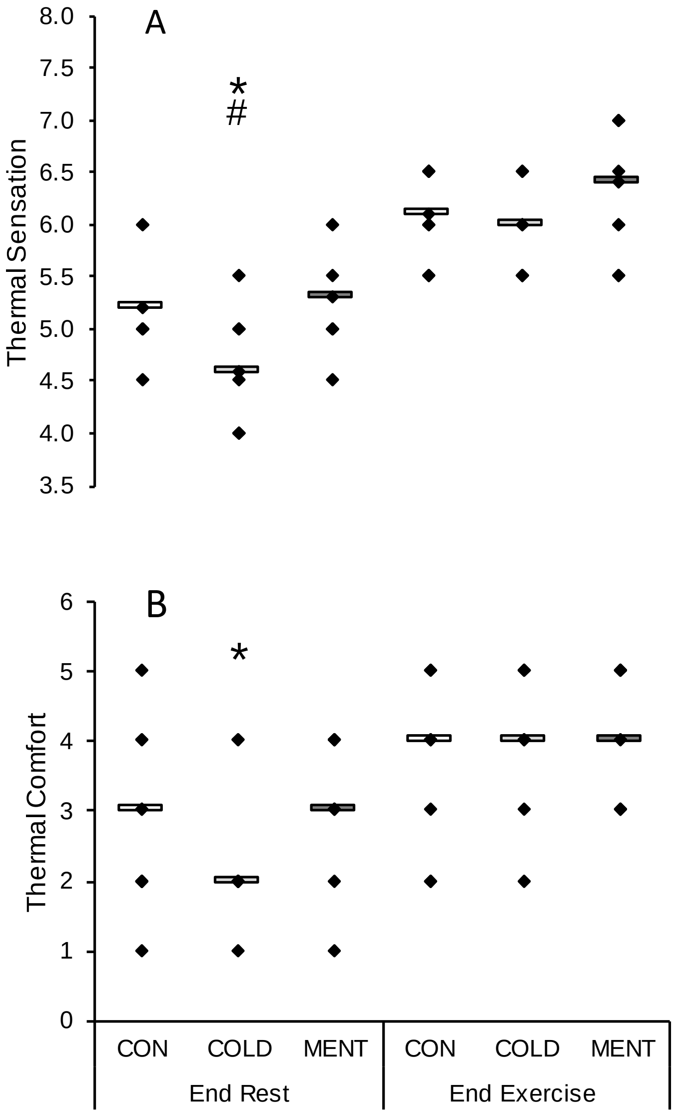


Figure 6.4: Thermal sensation (A) and thermal comfort (B) at the end of rest and exercise. Bars represent the mean (CON; white, COLD; light grey and MENT; dark grey) and the diamonds represent the individual participant data points. Some individual data points overlap, N=10 for all interventions. * denotes that COLD was significantly ($p < 0.05$) lower than MENT. # denotes that COLD was significantly ($p < 0.05$) lower than CON.

There was a significant interaction for ThS ($F_{(2.456,19.651)}$ = 5.02, p = 0.01, η_p^2 = 0.39) across time and intervention. Follow up analysis identified that participants felt significantly less thirsty in the COLD trial compared to the CON trial throughout exercise and at the end of exercise compared to the MENT (Figure 6.5 and Table 6.3).

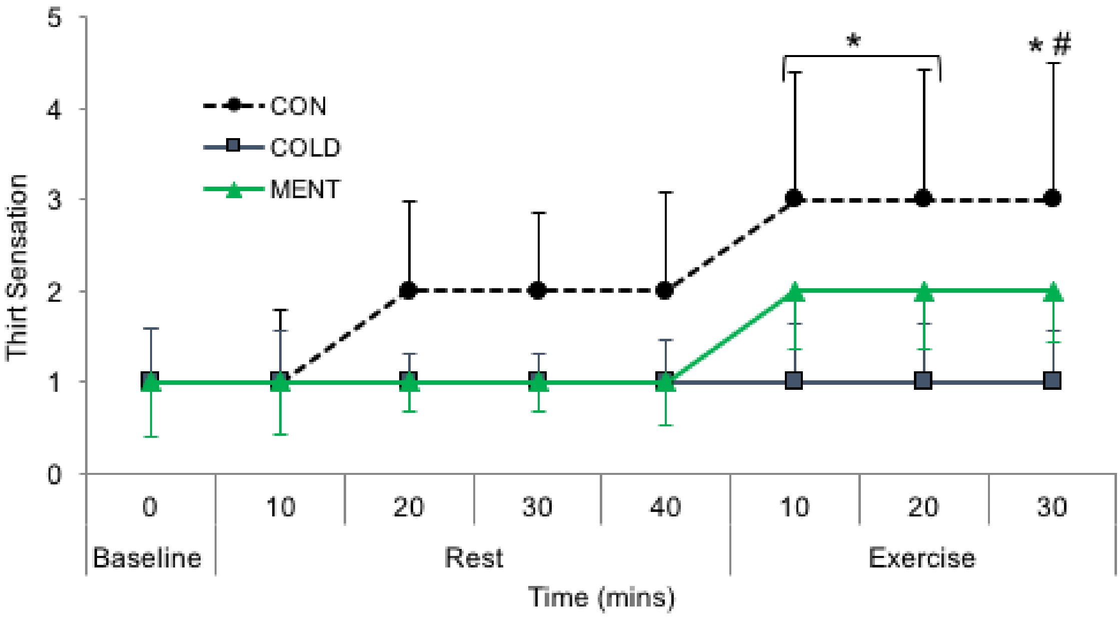


Figure 6.5: Mean ± SD for thirst sensation across time and interventions; CON (black circles), COLD (blue squares) and MENT (green triangles). *denotes a significant difference ($p < 0.05$) between COLD and CON. # denotes a significant difference ($p < 0.05$) between COLD and MENT.

There was no significant interaction for RPE ($F_{(3.011,27.101)}$ = 0.36, p = 0.78, η_p^2 = 0.04) across time and intervention. Likewise, there were no main effects of intervention at the end rest ($\chi^2(2)$ = 4.0, p = 0.14) or exercise ($\chi^2(2)$ = 2.67, p = 0.26) for RPE (Table 6.3).

Table 6.3: End rest and exercise for the perceptual variables. Mean ± SD.

Perceptual Variable	**CON**	**COLD**	**MENT**
End rest ThS	2 ± 1	1 ± 0	1 ± 1
End exercise ThS	3 ± 2	1 ± 0#§	2 ± 1
End rest RPE	6 ± 1	6 ± 0	6 ± 0
End exercise RPE	13 ± 3	13 ± 2	13 ± 2

Abbreviations: CON; control, COLD; cold water ingestion, MENT; L-menthol mouth rinse, ThS; thirst sensation, RPE; rating of perceived exertion. # denotes a significant ($p < 0.05$) difference between COLD and CON. § denotes a significant ($p < 0.05$) difference between COLD and MENT.

6.4.4. Six-minute walking test (6MWT)

There were main effects for intervention for distance completed in the 6MWT ($F_{(2,18)} = 6.72$, $p = 0.01$, $\eta_p^2 = 0.43$). Pairwise comparison identified a significantly greater distance covered in the COLD ($p = 0.01$, $d = 0.53$) compared to MENT intervention, but no significant differences between COLD and CON or CON and MENT (Table 6.4). Likewise, there were main effects for intervention for pre 6MWT T_{re} ($F_{(2,18)} = 24.98$, $p < 0.01$, $\eta_p^2 = 0.74$). Pairwise comparison identified a significantly lower pre 6MWT T_{re} in the COLD compared to MENT ($p = 0.001$, $d = 1.47$) and CON ($p < 0.001$, $d = 1.38$). Similarly, there were main effects for intervention for peak T_{re} in the 6MWT ($F_{(2,18)} = 3.92$, $p = 0.04$, $\eta_p^2 = 0.30$). However, pairwise comparison identified no significant difference between interventions. Similarly, there were main effects for intervention for peak HR in the 6MWT ($F_{(2,18)} = 5.15$, $p = 0.02$, $\eta_p^2 = 0.36$). Pairwise comparison identified a significantly reduced peak HR in the COLD ($p = 0.04$, $d = 0.38$) compared to CON intervention, but no significant differences between COLD and MENT or CON and MENT (Table 6.4). There were no significant main effects for peak perceptual variables in the 6MWT (Table 6.4).

Table 6.4: Performance, physiological and perceptual variables during the 6MWT. Mean ± SD.

6MWT variables	**CON**	**COLD**	**MENT**	**Difference CON-MENT**	**Difference COLD-CON**	**Difference COLD-MENT**
Distance (km)	0.58 ± 0.09	0.61 ± 0.08§	0.57 ± 0.08	0.01 ± 0.04	0.04 ± 0.04	0.04 ± 0.03
Pre 6MWT T_{re} (°C)	37.66 ± 0.30	37.32 ± 0.24#§	37.68 ± 0.36	-0.02 ± 0.17	-0.34 ± 0.16	-0.36 ± 0.20
Peak T_{re} (°C)	37.87 ± 0.36	37.56 ± 0.29	37.88 ± 0.42	-0.02 ± 0.26	-0.21 ± 0.24	-0.23 ± 0.34
Peak HR ($b.min^{-1}$)	129 ± 21	121 ± 21#	126 ± 21	3 ± 8	-7 ± 8	-4 ± 7
Peak TS	6.4 ± 0.7	6.2 ± 0.8	6.3 ± 0.6	0.1 ± 0.6	-0.2 ± 0.7	-0.1 ± 0.7
Peak TC	4 ± 1	4 ± 1	4 ± 1	0 ± 1	0 ± 1	0 ± 1
Peak RPE	14 ± 2	14 ± 2	14 ± 2	1 ± 1	0 ± 2	1 ± 2

Abbreviations: 6MWT; six-minute walk test, CON; control, COLD; cold water ingestion, MENT; L-menthol mouth rinse, T_{re}; rectal temperature, HR; heart rate, TS; thermal sensation, TC; thermal comfort, RPE; rating of perceived exertion. # denotes a significant ($p < 0.05$) difference between COLD and CON. § denotes a significant ($p < 0.05$) difference between COLD and MENT.

6.4.5. Individual responses

To increase the practicality of the intervention, the same volume of water was given to each participant. This section analyses the individual trends in peak and change rectal temperature in relation to participant's body mass. All of the participants had a decrease in peak T_{re} in the COLD compared to CON and MENT (Figure 6.6). Furthermore, all but one participant had a decrease in the change in rectal temperature during exercise in the COLD compared to CON and MENT trials (Figure 6.6). Additionally, there was a moderate correlation ($r = 0.43$, $p > 0.05$) between the body mass of the participant and the magnitude of T_{re} change (Figure 6.7).

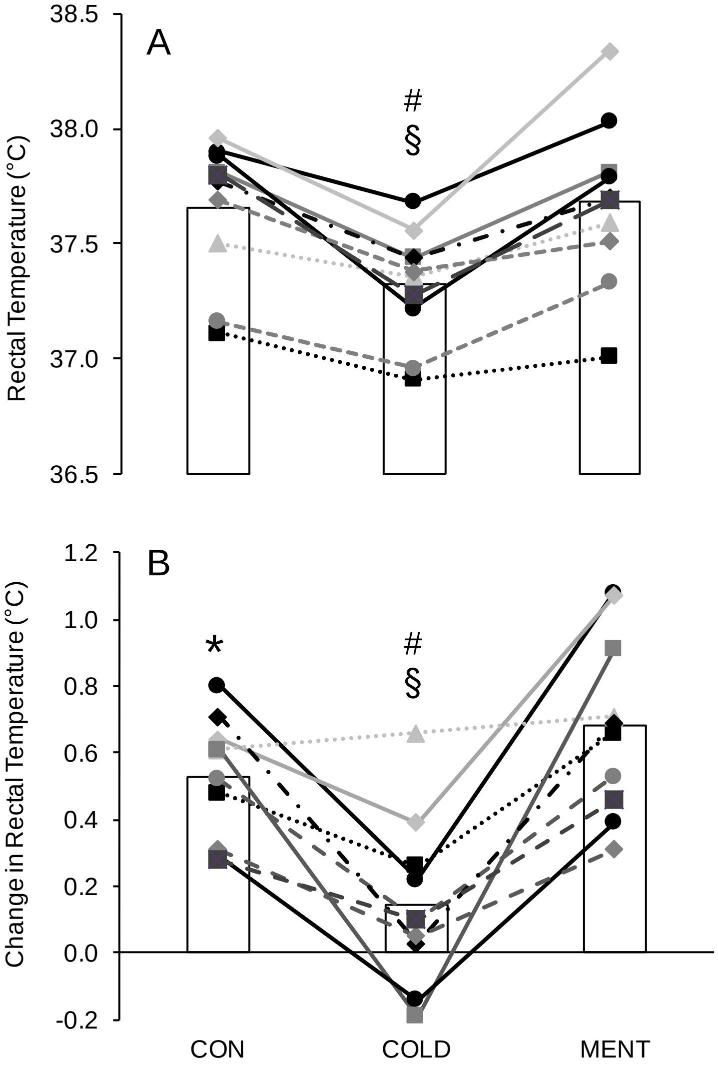


Figure 6.6: Peak rectal temperature (A) and change in rectal temperature (B) in the control (CON), cold water ingestion (COLD) and L-menthol (MENT) trials. Bars represent the mean and the lines and markers represent the individual participant data points (the same line and mark is used for the same individual in A and B). Some individual data points overlap, N=10 for all interventions. * denotes a significant (p < 0.05) difference between CON and MENT. # denotes a significant ($p < 0.05$) difference between COLD and CON. § denotes a significant ($p < 0.05$) difference between COLD and MENT.

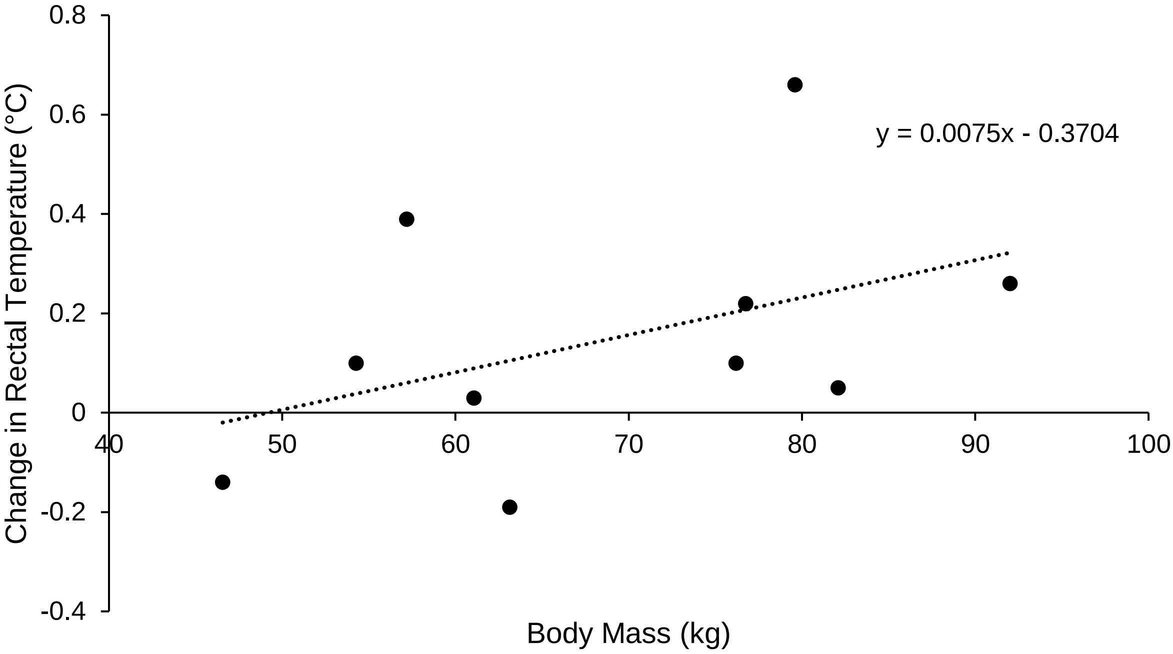


Figure 6.7: Change in rectal temperature in relation to participant's body mass.

Although no cold water ingestion was completed during the 6MWT, findings suggest a trend of a lasting ergogenic effect from the water ingested during the rest period and the 30-min cycle. Of the ten participants, eight walked further in the COLD trial compared to CON and eight walked further in the COLD trial compared to MENT with one participant completing the same distance (Figure 6.8). This could partly be explained by having a lower T_{re} during the COLD 6MWT compared to CON and MENT trials. All but one of the participants had a lower T_{re} at the end of the COLD 6MWT compared to CON and MENT trials (Figure 6.9). Furthermore, the majority of participants had a lower HR at the end of the COLD trial compared to CON (eight out of ten participants had lower HR) and MENT (five out of ten participants had lower HR and three out ten participants had the same HR) (Figure 6.10). This highlights that the physiological strain was less (T_{re} and HR) in the COLD trial allowing participants to walk further.

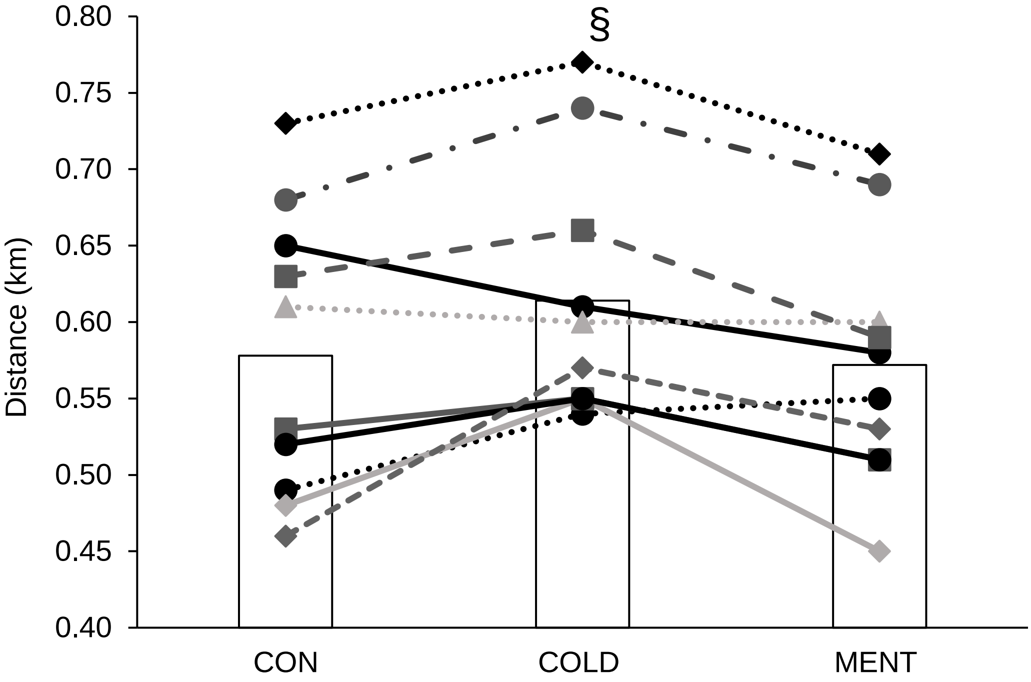


Figure 6.8: Distance completed in the six-minute walk test in the control (CON), cold water ingestion (COLD) and L-menthol (MENT) trials. Bars represent the mean and the lines and markers represent the individual participant data points (the same line and mark is used for the same individual in the previous figures). § denotes a significant ($p < 0.05$) difference between COLD and MENT.

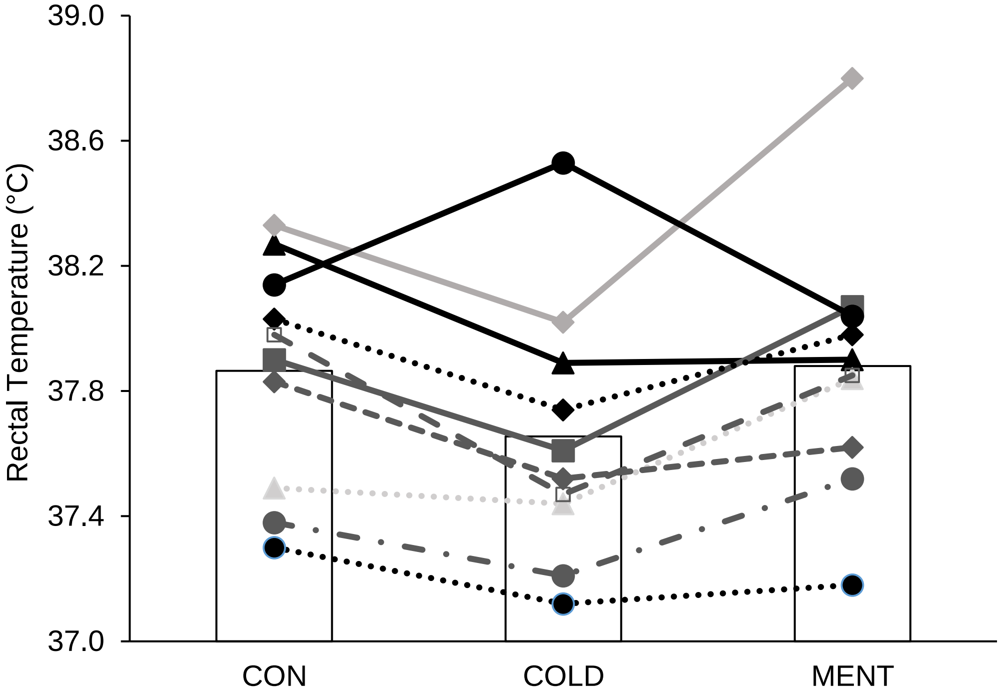


Figure 6.9: Peak rectal temperature in the six-minute walk test in the control (CON), cold water ingestion (COLD) and L-menthol (MENT) trials. Bars represent the mean and the lines and markers represent the individual participant data points (the same line and mark is used for the same individual in the previous figures). Some individual data points overlap, N=10 for all interventions.

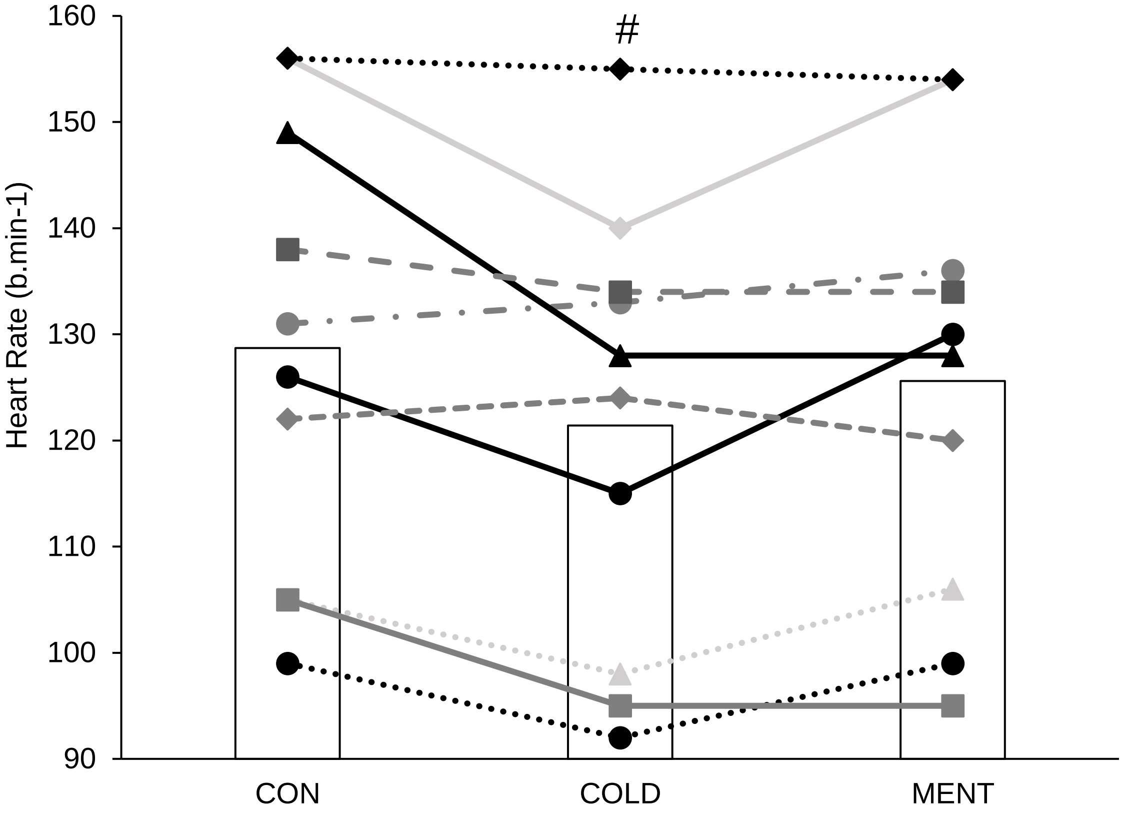


Figure 6.10: Peak heart rate during the six-minute walk test in the control (CON), cold water ingestion (COLD) and L-menthol (MENT) trials. Bars represent the mean and the lines and markers represent the individual participant data points (the same line and mark is used for the same individual in the previous figures). Some individual data points overlap, N=10 for all interventions. # denotes a significant (p < 0.05) difference between COLD and CON.

6.5. Discussion

This is the first study to investigate the effects of acute physical cooling, through cold water ingestion, and perceptual cooling, through L-menthol mouth rinse, on the elderly population while exercising in hot conditions. As hypothesised, findings suggest that COLD reduces physiological strain, with significant reductions in peak T_{re} and ΔT_{re} compared to CON and MENT. Likewise, there is a reduction in peak HR when participants completed the COLD compared to the CON and MENT interventions. Furthermore, the COLD intervention significantly improved TS compared to CON and MENT at the end of rest. Similarly, TC was improved in COLD compared to MENT at the end of rest. Contrary to the second hypothesis, MENT had no effect on elderly people's thermal perception of the environment and was not different from CON during rest or exercise.

6.5.1. Physiological responses

Cold water ingestion leads to a decrease in T_{re} via the internal transfer of heat energy (Jay & Morris, 2018). Heat energy transfers down a temperature gradient whereby, a high-temperature region increases the temperature of a cold-temperature region. Therefore, when internal body temperature is higher than fluid temperature, the body responds by heating the fluid via the temperature gradient created in the stomach (Ross *et al.,* 2013; Jay & Morris, 2018). Consequently, the colder the fluid the greater the temperature gradient (*i.e.,* heat sink) created and the greater potential cooling effect the fluid can have on T_{re} (Jay & Morris, 2018). This study demonstrated, that when drinking 300ml of 4°C water every 10-min for the first 30-min of rest that T_{re} reduced by -0.25 ± 0.26°C, which is less than the reported decrease by Lee *et al.,* (2008) of -0.5 ± 0.1°C in young adults (22 ± 4 yrs). Although the decrease in T_{re} was lower in the elderly in the current study compared to the young adults in the work of Lee *et al.,* (2008), the decrease was maintained throughout exercise in the elderly participants with peak T_{re} in the COLD intervention, -0.21 ± 0.24°C lower than CON and -0.23 ± 0.34°C lower than MENT, at the end of the 6MWT. These results are comparable to Mündel *et al.,* (2006) that presented a -0.25°C difference in peak T_{re} in the cold water (4°C) compared to the CON trial, albeit in a young population (26 ± 7 yrs). High core temperature (> 40°C) is a key contributor to the development of severe heat illness (Nadir *et al.,* 2016). Therefore, heat illness prevention strategies that reduce core temperature (*i.e.,* T_{re}) during rest and exercise, may prevent the onset of severe heat illness. Consequently, drinking cold water periodically has the potential to reduce thermal strain and prevent heat illness.

The primary cause of all excess mortality during periods of hot weather is an underlying cardiovascular deficiency (up to 94%) (Kenney *et al.,* 2014). There are several cardiovascular related benefits from maintaining hydration; preventing the decrease in plasma volume, stroke volume, cardiac output and skin blood flow and attenuating the progressive rise in HR (Noakes, 1993; Cheuvront & Kenefick, 2014). After an initial decrease in plasma volume at the onset of exercise, hydration that equates to fluid loss facilitates maintaining plasma volume. Similarly, when dehydration is avoided stroke volume, cardiac output and skin blood flow are maintained, allowing for optimum thermoregulation (Noakes, 1993; Cheuvront & Kenefick, 2014). In this study, plasma volume, stroke volume, cardiac output and skin blood flow were not measured, however, HR was. When there is a fluid deficiency HR increases (Sawka *et al.,* 2007). The present study found that COLD reduced peak HR compared to CON -7 ± 9 b.min^{-1} and MENT -6 ± 7 b.min^{-1}, albeit non-significantly. Similarly, Mündel *et al.,* (2006) found a 5 b.min^{-1} reduction in peak HR compared to CON with younger adults (26 ± 7 yrs).

Furthermore, T_{sk} can provide an indication of the skin blood flow (SkBF) (Sawka *et al.,* 2011). When T_{sk} is rising it is a result of greater vasodilation and blood flow (Sawka *et al.,* 2011). Maintaining SkBF is important for thermoregulation as it allows for sweat evaporation at the skin surface and for increased heat loss by radiation (Parsons, 2014). In this study, $T_{ski}$was unchanged between interventions, contrary to previous research with young adults where cold fluid ingestion reduced T_{sk} (Lee *et al.,* 2008). However, similar to Jay & Morris (2018) who also found no difference in T_{sk} and SkBF between ice slurry ingestion and control trials. Jay & Morris (2018) explain that there may be thermoreceptors within the abdomen that independently effect thermoregulation, specifically heat loss via evaporation. Consequently, when cold fluids are ingested, T_{sk} and SkBF can be maintained compared to control trials, whilst there is a decrease in evaporative heat loss.

A decrease in evaporative heat loss was evident in this study as WBSR was -0.33 ± 0.28 L.h^{-1} and -0.18 ± 0.24 L.h^{-1} less in COLD compared to CON and MENT. Jay & Morris (2018) explain that net heat loss is reduced when drinking ice slurry/cold drinks (<10°C) under warm, dry and windy conditions, due to the heat loss gained from the cold fluid ingestion being counter-balanced by the reduction in sweat production and evaporation. However, they further explain that net heat loss is dependent on the conditions and the population, for example a firefighter in hot, humid conditions wearing protective equipment, will benefit from a net heat loss by drinking cold fluids. Furthermore, athletes with an injury that decreases sweat output such as; some spinal cord injuries and burn patients, may also have a net heat loss gained from cold fluid ingestion that outweighs the reduction in sweat evaporation. This theory was applied to the elderly population as they have a known reduced WBSR (Inoue *et al.,* 1996; Inoue *et al.,* 1999; Kenney *et al.,* 2014). Elderly people have a reduced sweat rate and sweat gland output compared to matched younger individuals (Inoue *et al.,* 1996, Inoue *et al.,* 1999; Kenney *et al.,* 2014). Therefore, it was hypothesised that due to an already reduced WBSR, the effects of COLD would not further negatively affect WBSR. Despite the negative consequence of COLD on WBSR, interventions that reduce physiological strain whilst preventing dehydration should be considered as a practical heat illness prevention strategy for the elderly.

The message of drinking water during periods of hot weather is prominent within Public Health England’s (PHE) ‘*Heatwave Plan for England’* and ‘*Beat the hea’t* campaign (PHE 2017, PHE 2018). However, the elderly have attenuated thirst response and reduced ability to retain their fluid balance, due to the baroreceptors being less sensitive to hypovolemia (Stachenfeld *et al.,* 1996; Stachenfeld *et al.,* 1997; Kenney & Chiu 2001; Ferry, 2005) and reduced renal function (Kenney & Chiu 2001; Jequier & Constant, 2010; El-Sharkawy *et al.,* 2015). Consequently, the elderly may not feel the need to implement the advice from PHE, putting themselves unknowingly at risk of dehydration. This is supported in this study where participants only became slightly thirsty (3) in the control group. Therefore, the *Heatwave Plan for England* would benefit from vulnerable population specific guidance in the form of; how much, when and at what temperature to drink water. This study can contribute to the elderly specific advice with evidence that suggests that drinking refrigerated water (4°C) periodically reduces thermoregulatory and cardiovascular strain.

6.5.2. Perceptual responses

The purpose of assessing the effects of L-menthol in a population that has a known decreased thermal perception was two-fold. Firstly, testing a perceptual cooling intervention strengthens the methodological approach of testing the effects of a practical cooling intervention. This approach is demonstrated in the Schlader *et al.,* (2011) study, the interventions were; perceptual and physical cooling and heating, to investigate thermoregulatory behaviour during exercise. Secondly, it could provide research-informed evidence for the use or non-use, by the elderly, of cooling products that have L-menthol as its main active cooling substance.

L-menthol was administered as a mouth rinse as it is known to stimulate the greatest perceptual response in young people in comparison to creams and sprays which can also be a mild irritant when applied directly to the skin (Eccles, 2000). L-menthol elicits a cooling sensation by activating the TRPM8 cold receptors and inhibits the calcium currents of neural membranes releasing a cooling sensation (Eccles, 2000; Stevens *et al.,* 2015; Gillis *et al.,* 2016). Several studies have shown the perceptual benefits of L-menthol with athletes, with improvements in TS and RPE (Gillis *et al.,* 2010; Barwood *et al.,* 2015; Flood *et al.,* 2017; Steven & Best, 2017). This study found that L-menthol resulted in no improvements in TS, TC or RPE compared to CON at the end of rest or exercise. Furthermore, it was the COLD intervention that elicited a cooler sensation and the participants felt more comfortable compared to CON and MENT. Consequently, elderly people’s perception of the environment can be improved at rest by drinking refrigerated water, however, the effects do not last during exercise. Moreover, this is the first study to provide evidence that using cooling products that have L-menthol as its active cooling substance will not elicit the proposed cooling sensation within the elderly.

6.5.3. Six-minute walk test

The 6MWT is a validated, simple, safe and cost-effective measure of functional capacity in the elderly (Kervio *et al.,* 2003). It assesses a person's capability of walking unaided, which is an essential activity for daily living and maintaining quality of life (Crapo *et al.,* 2002; Enright, 2003). Kervio *et al.,* (2003) investigated the reliability of the 6MWT with elderly people and found that the CV for distance covered was 3.3%, when participants were given a familiarisation trial. Comparison with other studies is limited due to differences in pre 6MWT protocol, exercise environment and treadmill *vs*. floor procedure. However, as an indication of the performance of other elderly people who are free from disease that would impact walking speed, Stotz *et al.,* (2014) reported a median distance of 0.57km covered when completing the 6WMT in a 30°C environment. Stotz *et al.,* (2014) study highlights the suitability of the 6MWT as a measure of functional capacity in a challenging environment.

The findings from the current study suggest that when COLD is completed periodically during rest and cycling activity prior to the 6MWT, then performance, as defined by distance covered, was improved compared to CON and MENT (COLD; 0.61 ± 0.08km, CON; 0.58 ± 0.09km, MENT; 0.57 ± 0.08km). The distance was significantly further in COLD compared to MENT (+7.3%) and was above the 3.3% CV reported by Kervio *et al.,* (2003) in the COLD compared to CON (6.2%) trial. Additionally, physiological strain, T_{re} and HR, were decreased in the COLD at the end of the 6MWT compared to CON (-0.21 ± 0.24°C and -7 ± 8 b.min^{-1}) and MENT (-0.23 ± 0.34°C and -4 ± 7 b.min^{-1}). Heart rate was decreased in nine out of ten participants in the COLD trial compared to both CON and MENT, albeit the decrease was only significant in COLD compared to MENT. Similarly, T_{re} decreased in eight out of ten participants in the COLD trial compared to CON and six out of ten participants in the MENT.

These results suggest that functional capacity as tested using a 6MWT, can be improved during 35°C, 50% RH when drinking cold water (4°C) periodically. Additionally, even with the greater distance covered, the markers of heat illness and cardiovascular strain are reduced compared to MENT and CON.

6.5.4. Limitations and future considerations

This study is not without its limitations. By research design each trial had a different level of hydration. Maintaining hydration through fluid ingestion during exercise in healthy athletes has the physiological benefit of reducing the rise in T_{re} (Noakes, 1993; Sawka *et al.,* 2007; Cheuvront & Kenefick, 2014). The rise in T_{re} is attenuated when fluid intake matches sweat rate (Noakes, 1993). Therefore, it could be argued that the decrease in peak $T_{re,}$ reduction in the change T_{re} and reduced HR in the COLD trials are a result of hydration differences between the trials as opposed to a direct cooling effect of the water temperature. However, the lack of fluid replacement was intentional for the CON and MENT trials. Firstly, it is well established that the elderly are at an increased risk of dehydration during periods of hot weather (Ferry*,* 2005; Rikkert *et al.* 2009; Jequier & Constant, 2010). Findings from this study suggest that the elderly only became slightly thirsty in the CON trial during exercise. Therefore, in a real-world scenario they are not likely to take on fluid replacement, especially as the current guideline is to drink to thirst (PHE, 2018). Secondly, the wetness of the mouth is considered an important aspect of the menthol intervention (Stevens *et al.,* 2015), therefore to control for this in the CON trial no fluid was given to participants. Consequently, the physiological differences between the trials may be partly attributed to the differences in hydration, however, this does not diminish the key physiological findings in the COLD trial, when the overarching aim is to provide strategies for the prevention of heat illness within the elderly population.

It could also be considered a limitation that the experimenter had control of when the COLD intervention was given to participants. By controlling when the fluid was given to the participants, the behavioural thermoregulation component of implementing a heat illness prevention strategy was omitted. Consequently, with participants only feeling slightly thirsty at the end of exercise in the CON group, elderly people may not implement a drinking-based heat illness prevention strategy. Therefore, with the understanding that COLD can reduce physiological strain in the elderly population, future research should investigate elderly people’s behavioural thermoregulation by allowing them to drink cold water *ad libitum* during rest and exercise. Furthermore, the combined findings of what volume of water reduces physiological strain and that in which the elderly are likely to drink can be utilised to produce educational material specifically for the elderly to reduce heat illness risk.

Thirdly, the results for this study suggest that L-menthol had no perceptual benefit on the elderly during rest or exercise. However, it could be considered a limitation that the elderly participants had a maximum change in T_{re} of 1.08°C and maximum thermal sensation score of 6.5 (between ‘*hot’* and ‘*very hot’*) during the MENT and CON trial. Consequently, the thermal strain may not have been sufficient enough to elicit a change in thermal sensation with L-menthol. Stevens *et al.,* (2015) found significant improvements in thermal sensation, using the same scale (CON; 7, MENT; 6.5, values read off a figure), with L-menthol in young adults that had a change in T_{re} of 2-2.5°C. Similarly, Flood *et al.,* (2017) found significant improvements in thermal sensation when using L-menthol compared to control. The participants within the study had an average rectal temperature >38°C, T_{re} did not reach 38°C in the present study. Although, there may not have been sufficient thermal strain to elicit a cooling sensation effect with L-menthol in the elderly, the purpose of this study was to replicate activities of daily living, and by doing so the L-menthol had no effect on thermal sensation.

Lastly, in line with the ethical approval granted for this study, the participants were habitually active and free from any co-morbidities. Thereby, allowing unaided 6MWT to be completed by the participants. This could be considered a limitation to the degree of application of the research due to elderly people that are frail and those with cardiovascular health problems being at greater risk of heat illness and being less mobile, preventing them from being able to complete a 6MWT unaided. Due to the novelty of this type of research in an elderly population it provides findings in which to build on to further help the most vulnerable elderly populations. Therefore, more acute heat illness prevention research is warranted with elderly people that are at even greater risk of heat illness (*e.g.,* elderly people in care homes). A future consideration for research using more vulnerable elderly people is the type of test used to assess functional capacity, a 6MWT could be inappropriate, however, a get up and go test where the participant could be aided through the movements could provide a suitable alternative.

6.6. Conclusion

This is the first study to provide evidence that COLD reduces physiological strain (T_{re} and HR) in elderly people completing activities of daily living in hot UK climatic conditions. It is also the first study to show no perceptual or functional gain benefits from MENT. Furthermore, the elderly's end exercise perception (TS and TC) of the hot environment did not differ between CON, COLD and MENT. Consequently, the elderly could still be at risk of heat illness, because they do not feel hot and uncomfortable enough to implement physiological strain reducing strategies such as cold water ingestion. Therefore, education of when to implement these strategies without perceptual cues is warranted.

Chapter 7 Phenotypic responses to isothermic and novel heat acclimation in the elderly

7.1. Abstract

Aim: Heat acclimation (HA) can reduce the risk of heat illness. However, research with the most vulnerable population to the heat, the elderly, is limited. The aims of this investigation were twofold; to compare heat adaptations between the elderly (E) and young (Y) to a modified isothermic, short term heat acclimation (STHA) protocol. Secondly, to assess heat adaptations between an elderly novel (EN) and the elderly isothermic STHA group.

Methods: Twenty-six participants (Y: N = 11; age 22 ± 2 yrs, E: N = 8; age 68 ± 3 yrs, EN: N = 7; age 73 ± 3 yrs) completed 2 pre-tests, 5 consecutive days of HA and 2 post-tests. The Y and E, STHA groups completed modified isothermic HA that raised resting rectal temperature (T_{re}) by 1.5°C or to 38.5°C within an hour of entering the 35°C, 50% relative humidity (RH) environment. Thereafter, participants-maintained T_{re} at or above the target T_{re} for an hour. The EN method consisted of 30-min of fixed intensity cycling exercise in normothermic conditions, followed by 30-min of hot water immersion (40°C) finishing with a 30-min resting blanket wrap in normothermic conditions. All participants completed the same pre and post-tests in 35°C, 50% RH. Pre and post-test 1 included a graded exercise test to determine individual power outputs at $3.5 \mathrm{W.kg}^{-1}$ $\dot{H}_{prod}$. Pre and post-test 2 included 30-min rest followed by 30-min of cycling exercise at $3.5 \mathrm{W.kg}^{-1}$ $\dot{H}_{prod}$. Heart rate (HR) and T_{re} were recorded every 5-min; thermal sensation (TS) and thermal comfort (TC) every 10-min, to assess heat adaptations post HA.

Results: Data from pre and post-test 2 was analysed as pre-to-post HA data. In addition, the resting data from day 1 of HA and day 5 of HA was analysed to assess the effects of 4 days of HA. Pre-to-post HA: Resting HR significantly ($p < 0.05$) decreased in the Y (-11 ± 8 $\mathrm{b.min}^{-1}$) whilst there was a meaningful decrease in peak HR (-6 ± 10 $\mathrm{b.min}^{-1}$). However, there was no improvement for either elderly group for resting (E; +2 ± 5 $\mathrm{b.min}^{-1}$ and EN; -4 ± 5 $\mathrm{b.min}^{-1}$) or peak (E; +0 ± 5 $\mathrm{b.min}^{-1}$ and EN; -4 ± 5 $\mathrm{b.min}^{-1}$) HR. Resting T_{re} did not significantly decrease pre-to-post HA in any group; Y (-0.05 ± 0.34°C), E (+0.08 ± 0.23°C) and EN (-0.12 ± 0.24°C). TS significantly decreased pre-to-post HA in Y (-0.4± 0.5) and E (-0.3 ± 0.4), but not EN (0.0 ± 0.4). TC did not change in E (0 ± 1), but decreased meaningfully in Y (-1 ± 1) and EN (-1 ± 1). Day 1 to day 5 HA: There was a significant decrease in resting T_{re} for both elderly groups; EN (-0.33 ± 0.35°C) and E (-0.28 ± 0.26°C), but not Y (-0.04 ± 0.32°C). Resting HR was also improved in the EN (-8 ± 10 $\mathrm{b.min}^{-1}$), however, not in the E (-1 ± 10 $\mathrm{b.min}^{-1}$) and Y (3 ± 7 $\mathrm{b.min}^{-1}$) groups.

Conclusion: Findings suggest that the Y showed some classic phenotypic adaptation to the modified isothermic STHA such as a decrease in resting HR, TS and TC when data was analysed pre-to-post HA, these adaptations were not matched in the elderly groups. However, when resting data was analysed from day 1 to day 5 of HA there were decreases in T_{re} for both elderly groups and HR for the EN group. This may highlight HA decay in the elderly groups between the end of HA and the post HA testing. Novel STHA deserves further investigation to be considered as a heat illness prevention strategy for the elderly.

7.2. Introduction

The elderly are at the greatest risk of suffering a severe heat illness during periods of hot weather (Hajat *et al.*, 2014; Kenney *et al.*, 2014; Smith *et al.*, 2016). In study 2 (Chapter 5, p124), it was highlighted that the elderly could also have a reduced perceptual awareness of increasing environmental temperatures. The findings from study 2 found an increase in thermal strain from 25-35°C in the elderly when exercising at a moderate activity of daily living, without a concurrent perceptual recognition. Therefore, there is the possibility of an attenuated ability to detect thermal discomfort within the environment. Study 3 (Chapter 6, p139) investigated a practical, physical, acute cooling strategy and a perceptual cooling strategy. The main findings from study 3 were a reduced physiological strain (T_{re} and HR) when drinking cold water (4°C) periodically throughout rest and exercise that improved performance in a functional walking test compared to when no cooling was given. It was also the first study to find that L-menthol did not have a cooling effect, nor a performance benefit for elderly people. The next study in this thesis was to investigate a chronic heat alleviating strategy to prevent heat illness in the elderly.

Heat acclimation (HA) is considered the most effective strategy for decreasing the accumulation of thermal strain, resulting in a reduced risk of severe heat illness (Armstrong & Maresh, 1991; Gosling *et al.*, 2008; Périard *et al.*, 2015; Racinais *et al.*, 2015; Minett *et al.*, 2016). To date, the majority of HA research has focused upon improving performance and maintaining the health of athletes (Garrett *et al.*, 2014; Taylor, 2014a; Gibson *et al.*, 2015ab; Mee *et al.*, 2015; Tyler *et al.*, 2016; Willmott *et al.*, 2016; James *et al.*, 2017). Despite the known heat-alleviating benefits of HA in the athletic population, there is currently a dearth of knowledge pertaining to phenotypic responses to standard HA in the elderly. Consequently, there is very little information on optimal HA strategies for the elderly population. Therefore, elderly HA research warrants further investigation due to its potential as a chronic heat-alleviating strategy in the prevention of severe heat illness.

The hallmark physiological adaptations to HA include: a decrease in resting and exercise T_{re}, HR and T_{sk}, an earlier onset of sweating and retention of sodium, an expansion of PV and increased SkBF (Sawka *et al.*, 2011; Taylor, 2014a; Périard *et al.*, 2015; Racinais *et al.*, 2015). These adaptations result in a more efficient thermoregulatory system, whereby excess body heat is transferred to the environment at a greater rate. Consequently, there is improved autonomic protection from heat illness. Furthermore, perceptual responses to the heat also improve with HA (Taylor, 2014a; Tyler *et al.*, 2016). The individual feels cooler, more comfortable and the exercise intensity is easier under the same exercise and environmental conditions.

Adaptations can be achieved through natural (*i.e.,* acclimatisation) or artificial exposure (*e.g.,* heat chamber, sauna or steam room, etc.) to a hot environment (*i.e.,* acclimation), with either the addition or exclusion of exercise (Taylor, 2014a; Périard *et al.*, 2015). The methods of HA include, passive exposure, fixed intensity exercise, self-paced exercise and isothermic HA, with the latter method typically using a set T_{re} of 38.5°C (Taylor & Cotter, 2006). The isothermic model can have sections of passive and exercise heat exposure to maintain a T_{re} of 38.5°C. It is regarded as the optimal method for developing phenotypic adaptations to the heat, due to the constant level of thermal strain across the HA protocol (Taylor, 2014a). It is the T_{re} that is considered to drive the adaptations and T_{re} >38.5°C does not seem to facilitate greater change (Gibson *et al.*, 2015a). To achieve a T_{re} of 38.5°C in a young population has previously required a T_{re} change of 1.29-1.68°C, with an average T_{re} change of 1.46°C (Daanen *et al.,* 2014; Gibson *et al.*, 2015ab; Mee *et al.,* 2015, James *et al.,* 2017; Willmott *et al.,* 2018).

Adaptations are also dependent on previous experience with heat acclimation as well as the duration, frequency and intensity of heat exposure. Athletes that complete re-acclimation develop heat adaptations at a greater rate compared to the original acclimation exposure (Daanen *et al.,* 2017). The duration of each heat acclimation session is typically between 30-120-min, with a frequency rate of once a day (Daanen *et al.*, 2011; Sawka *et al.*, 2011; Périard *et al.*, 2015; Racinais *et al.*, 2015; Minett *et al.*, 2016). More recently, twice daily and non-consecutive day HA approaches have been shown to induce adaptations whilst providing, logistical and timescale benefits (Willmott *et al.*, 2016; Willmott *et al.,* 2018).

To achieve near optimal phenotypic adaptations, 14 days of sufficient heat exposures is required (Périard *et al.*, 2015). However, up to 75% of adaptations can occur within the first 4-7 days of heat exposure (Pandolf *et al.*, 1988). Heat acclimation that is < 7 days is known as short term heat acclimation (STHA) (Garrett *et al.,* 2014; Périard *et al.*, 2015). Current research has investigated the use of isothermic STHA in athletes, with improvements in performance as well as developing phenotypic adaptations (Garrett *et al.*, 2014; Gibson *et al.*, 2015ab; Neal *et al.*, 2016; Willmott *et al.*, 2016; James *et al.*, 2017). For HA to be a feasible strategy for the prevention of severe heat illness in the elderly, the intervention has to be STHA. The current heatwave preparation time given to the UK public is 3 days, the accuracy (± 2°C) of the 3 day MET Office forecasts is ~87% (MET Office, 2018f). The MET Office continuously improve temperature predictions, with the 4 day temperature forecasts being as accurate as the 1 day forecasts were in the 1980's (MET Office, 2018f).

The limited research with the elderly has found that both passive and active HA can provoke the hallmark phenotypic adaptations, as described earlier (Pandolf *et al.*, 1988; Armstrong & Kenney, 1993; Inoue *et al.*, 1999; Best *et al.*, 2014). However, much of the elderly HA research is based on > 5 days of traditional HA using a constant work rate model (*i.e.,* percentage of $\dot{V}O_{2max}$) (Taylor, 2014a; Périard *et al.*, 2015). Further, participants among some of the early HA studies were under the age of 65, which is when an increase in heat-related morbidity and mortality is evident (Hajat *et al.*, 2014; Kenney *et al.*, 2014; Smith *et al.*, 2016). Additionally, the physiological and perceptual responses of the elderly population to an isothermic HA protocol (*i.e.,* constant thermal impulse >38.5°C), which may provide a more complete adaptation (Taylor, 2014a; Périard *et al.*, 2015), has to the researcher's knowledge only been investigated once.

Daanen & Herweijer (2014) are the only researchers to have investigated a form of isothermic STHA comparing young and elderly people. The experimental protocol consisted of a heat strain test (20-min at 50W) completed on day 1 and 5 either side of three daily one-hour exposures of isothermic HA, with a target gastrointestinal temperature (T_{gi}) (*i.e.,* T_c) of between 38-38.5°C. All experimental testing was completed in a 35°C, 40% RH environment. Although an important study, being the first study to investigate STHA in the elderly, findings suggested no phenotypic adaptations took place amongst either the young or elderly participants. Of the eight participants in each group, four elderly and three young participants achieved a T_{gi} >38°C at some point within all three acclimation days. However, an absence of adaptation may have been explained by the shorter duration (60-min HA sessions), low frequency (3 HA days) and, or reduced intensity (50W cycling) of the heat exposure based on current STHA guidelines (Petersen *et al.*, 2010; Garrett *et al.*, 2012; Gibson *et al.*, 2015 ab; Mee *et al.*, 2015; Neal *et al.*, 2016; James *et al.*, 2017; Willmott *et al.*, 2017). Therefore, an isothermic STHA study with elderly participants that increases the thermal strain through; higher core temperatures (*i.e.,* T_c > 38°C), for a longer exposure time and over more days is warranted. Building upon Daanen & Herweijer's (2014) study would determine whether an isothermic STHA is a physiological viable option for the protection of heat illness in the elderly.

Practicality of HA for the elderly extends beyond just the frequency, but also to the accessibility and palatability of a HA intervention. Firstly, isothermic HA requires the monitoring of core temperature, which is often an invasive, impractical measurement (*e.g.,* rectal temperature). Additionally, most isothermic STHA protocols have used a heat chamber to provide the thermal stress, but there has been a growing body of evidence targeted at athletic populations that have investigated more practical HA strategies. The use of passive hot water immersion (HWI) is not a new concept for adapting people to the heat, with studies citing improvements in T_{re}, HR and WBSR after 12 days of HWI dating back to the early 60's (Fox *et al.,* 1963ab). More recent research has focused on the use of HWI as a STHA protocol by implementing it post exercise (Zurawlew *et al.,* 2016). Zurawlew *et al.,* (2016) used young participants completing 40-min of running at 65%

$\dot{V}O_{2max}$ in temperate conditions (18°C) followed by 40-min HWI (40°C) for 6 consecutive days. Findings suggested phenotypic adaptations to the heat with lower resting T_{re} (-0.27°C) and final T_{re} during submaximal exercise in 18°C (-0.28°C) and 33°C (-0.36°C). Sweat onset, T_{sk} and RPE were also lower during submaximal exercise in 18°C and 33°C post HA.

When considering a practical HA protocol for the elderly, the method of submaximal exercise with post exercise HWI is a viable option. Daanen & Herweijer (2014) highlighted the challenges of maintaining exercise in the heat with an elderly population. This alternative method may allow exercise to be completed in thermoneutral conditions for elderly people who are capable of completing physical activity (*i.e.,* those entering old age and in transition), with less thermal strain. Furthermore, the passive aspect of the HWI is achievable for the majority of the elderly population and has the potential to be completed at home.

Therefore, the aims of this investigation were twofold; firstly, to compare the phenotypic heat adaptations to an isothermic STHA protocol, between elderly and young adults. Secondly, to assess differences in phenotypic heat adaptations between a modified isothermic STHA protocol and novel HWI approach, within the elderly population. The study hypothesised; the elderly isothermic STHA would have a similar magnitude of heat adaptation in comparison to the younger adults. Additionally, the elderly novel group would develop classic phenotypic heat adaptations from HWI.

7.3. Methods

7.3.1. Pilot work

Modified isothermic short term heat acclimation

Prior to experimental testing extensive pilot work was completed with young and elderly participants, to inform methodological decisions. The aim of the pilot testing for the modified isothemic heat acclimation was to find a combination of; environment and exercise intensity that changed rectal temperature at a similar rate in young and elderly participants. Firstly, we tested an elderly man (69 years old) in a 40°C, 40%RH environment in accordance to previous HA studies (Gibson *et al.,* 2015ab; Mee *et al.,* 2015). The participant cycled at 1.5W.kg^{-1} for 45-min reaching a peak HR of 162 b.min^{-1}, RPE 18 and a T_{re} 38.57°C; resulting in a T_{re} change of 1.15°C. After exiting the chamber T_{re} continued to rise to a peak of 39.01°C, with a total T_{re} change of 1.59°C. This pilot session highlighted to the researchers the magnitude of the rate in rise in T_{re} post heat exposure could be significant amongst the elderly. A follow up pilot session with the same participant was completed in the same environment and using a lower exercise intensity (1.2W.kg^{-1}) but with a sauna suit top on for the first 15-min. The main outcomes from this session were; a low starting T_{re} of 36.66°C (both pilot sessions were completed in the morning) and that the sauna suit made the participant feel uncomfortably wet throughout the session. The low starting T_{re} was significant for it highlighted the requirement for two isothermic criterion to be considered during the STHA. Due to health and safety requirements in our laboratories, participants must be removed from the environmental chamber if their T_{re} changes by greater than 2°C. Therefore, for this participant to achieve a T_{re} of 38.5°C from isothermic HA, a T_{re} change of 1.84°C would have been required and it is possible that other elderly participants would have come in with a T_{re} < 36.5°C, especially for morning testing (Kräuchi & Wirz-Justice, 1994). It was considered important that the participants were as comfortable as possible during HA sessions to encourage their continued participation in the study, therefore the sauna suits were not used during the experimental testing.

Further elderly participant pilot testing was completed with an elderly woman (71 years old). The initial pilot testing required the participant to cycle at 1.5W.kg^{-1} in a 40°C, 40%RH environment. After 10-min of cycling the exercise intensity was reduced to 1.2W.kg^{-1} due to high HR (168 b.min^{-1}) and RPE (17). The test lasted a further 15-min before the participant was removed from the chamber at their request. The second pilot session that she completed started at 1.2W.kg^{-1} and she complete 45-min of intermittent cycling (5-min cycling, 5-min rest). The participant stayed in the chamber for a further 15-min after cycling to assess stability in T_{re}. Unfortunately, the participant began to feel faint and was removed for the chamber. An explanation to the participant feeling faint could have been venous blood pooling because of the passive recovery every other 5-min. Therefore, this ratio of intermittent exercise was not implemented in the experimental testing.

Two young females (25 ± 0 yrs) completed pilot testing in a 40°C, 40%RH environment cycling at 1.7W.kg^{-1}. After 60-min of cycling the participants had; a change in T_{re} of 1.05°C and 0.81°C, an absolute T_{re} of 38.75°C and 38.34°C and a peak HR of 194 b.min^{-1} and 175 b.min^{-1} and both had a peak RPE of 17. This session demonstrated that although the participants found the exercise physically difficult that T_{re} did not increase as quickly as is needed during experimental testing. The aim was to get to the target T_{re} within an hour of entering the chamber. Therefore, the exercise intensity was increased for the experimental testing with the provision to implement breaks when HR and RPE were very high.

After the pilot testing with the elderly and young participants we asked them what they found most challenging about the session. They found that the 40°C environment made the exercise environment too uncomfortable. Consequently, it was decided to reduce the environmental temperature to 35°C, 50%RH in line with the other testing completed in this thesis, knowing that elderly people could maintain exercise within that environment and it would provide a more comfortable setting for all participants. It was also chosen as when assessing rectal temperature changes during the 30-min cycling in the 35°C, 50%RH in the other studies, it was similar to that achieved in the 40°C, 40%RH environment of the pilot work. Additionally, it highlighted the requirement for two target temperature criterion, due to the low resting temperatures of the elderly participants. The decision to use a 1.5°C change in T_{re} and an absolute target T_{re} of 38.5°C was based on young isothermic HA research, whereby to achieve a target temperature of 38.5°C participants on average needed to change core temperature by 1.46°C (Daanen *et al.,* 2014; Gibson *et al.*, 2015ab; Mee *et al.,* 2015, James *et al.,* 2017; Willmott *et al.,* 2018).

Novel short-term heat acclimation

The initial pilot testing, for the HWI section, of the novel short-term heat acclimation was completed with young adults. Although, young adults would not be used in the experimental testing, the researchers needed to gain an understanding of how the water temperature might change throughout testing and possible core temperature changes. One female participant (25 years old) entered a 40°C water bath, in a standing position, with water up to the clavicle, 40°C was chosen in line with previous HWI research (Zurawlew *et al.,* 2016). After 40-min T_{re} had risen by 1.75°C to 39.3°C and water temperature had dropped by 1.2°C. Similarly, a male participant (37 years old) completed 20-min of cycling at 2.0W.kg^{-1}

in thermoneutral conditions before entering a 40°C water bath, in a standing position, with water up to the clavicle, for a further 20-min. The participant had a 0.77°C change in T_{re} during exercise and a further 1.12°C change in the water bath. Due to the collective T_{re} change nearing 2°C the participant was removed from the water bath. These pilot sessions indicated that in young people it was possible to get the target T_{re} from the HWI within 20-40-min.

A further pilot session was completed with an elderly female (66 years old). The participant completed 30-min of cycling exercise at $1.2W.kg^{-1}$ before entering a 40°C water bath, in semi-supine position, with water up to the sternum. The water depth difference between the young and the elderly was due to maintaining the health and safety of elderly participants. The stand-up water bath, used with the young participants, had a ladder to get in and out of the bath, the ethics committee deemed the ladder and the standing position as unsafe for the use of elderly participants. Therefore, an inflatable water bath was used with the elderly participants, the bath had easy access and when lying in a semi-supine position the water came up to the sternum. After the 30-min cycling T_{re} had risen by 0.55°C and increased a further 0.84°C in the water bath. The participant T_{re} continued to rise post HWI (+0.14°C) with a peak change of 1.53°C from baseline T_{re} to post HWI. This pilot session highlighted that elderly people could increase their T_{re} through thermoneutral exercise as well HWI. This session also highlighted the need to wrap blankets around the participants after HWI to maintain an elevated T_{re} for an extended period of time to facilitate heat adaptations.

7.3.2. Participants

Twenty-six (11 young and 15 elderly) habitually active participants volunteered for the study (Table 7.1), which was completed during March-May, 2018 (average temperature ~10°C, MET Officeb). The experimental protocol was approved by the University's ethics committee and conducted in accordance with the principles of the revised Declaration of Helsinki (WHO, 2013) and the University of Brighton's health and safety procedures (Section 3.1). Prior to testing, participants provided their informed, written consent and a medical questionnaire (Section 3.2). In preparation for testing, participant followed the pre-experimental preparation guidelines (Section 3.3.3).

Table 7.1: Participant demographics. Mean ± SD

Participant demographics	**Young**	**Elderly**	**Elderly Novel**
Sex (M/F)	8M, 3F	7M, 1F	3M, 4F
Age (yrs)	22 ± 2	68 ± 3	73 ± 3
Height (cm)	174 ± 5	175 ± 8	162 ± 7
NBM (kg)	71.79 ± 11.75	74.07 ± 10.42	71.74 ± 18.92
BF (%)	18 ± 7	18 ± 6	29 ± 9

Abbreviations: M; male, F; female, NBM; nude body mass, BF; body fat

7.3.3. Experimental schematic

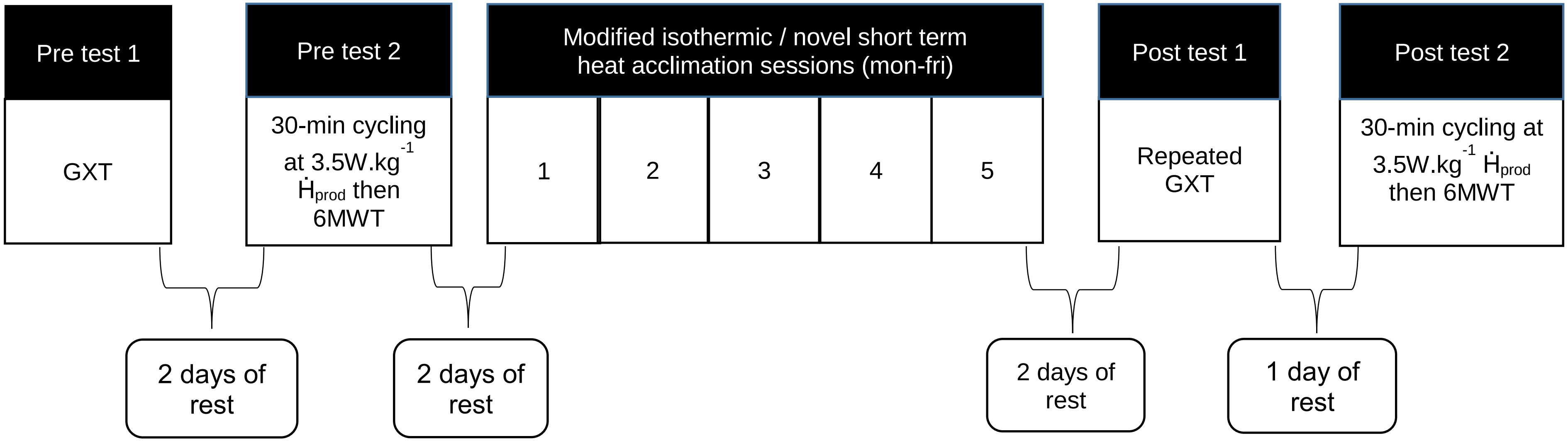


Figure 7.1: A schematic of the experimental design completed in this study.

Abbreviations: GXT; graded exercise test, $\dot{H}_{prod}$; metabolic heat production, 6MWT; six-minute walk test.

7.3.4. Pre and post-test 1

During pre-test 1, hydration (Section 3.4.1), anthropometric (Section 3.4.2) and baseline measures (Section 3.3.4) were collected on all participants, followed by 30-min seated rest within 35°C, 50% RH to familiarise participants with the laser Doppler for the measurement of forearm SkBF (Section 3.4.9). Blood pressure (BP) was taken 20-min into the rest period and retrospectively used to calculate cutaneous vascular conductance (CVC). On completion of rest, the GXT was conducted (Section 3.3.5). The GXT for the young participants was adjusted to account for their superior age-related fitness. Initial start speed was set at 50W and increased in 25W increments. Respiratory gas was collected at the end of each stage to calculate individual resting 1 MET values and exercise intensities equating to 6METs and 3.5W.kg^{-1} $\dot{H}_{prod}$ to be used in pre-test 2 (Section 3.4.7). On completion of the GXT, participants completed a familiarisation of the six-minute walk test (6MWT) (Section 3.3.7).

The GXT procedure was repeated during post-test 1, to re-calculate the 6METs and 3.5W.kg^{-1} $\dot{H}_{prod}$ exercise intensity for post-test 2 to ensure that the training effect of the HA was accounted for (Figure 7.1).

Post heat exposure, the participants completed cooling in line with the environmental physiology health and safety procedures (Section 3.1). This included; cooling fans, ice poles, cooling buckets for hands and feet and cold drinking water (Shirreffs *et al.,* 1996).

7.3.5. Pre and post-test 2

Prior to pre and post-test 2, hydration assessment (Section 3.4.1) and baseline physiological measurements (Section 3.4.4) were recorded. Pre and post-test 2 consisted of the simulated activities of daily living protocol (Section 3.3.6) followed by the 6MWT (Section 3.3.7). Experimental testing was completed within a 35°C, 50% RH environment. During rest, participants remained still with the laser Doppler attached to the same place on the forearm as marked out in pre-test 1, BP was taken at minute 20 and data was used to calculate CVC (Section 3.4.9). Throughout testing, physiological measurements; HR, T_{re}, and T_{sk} were recorded every 5-min. Perceptual measures; TS, TC, and RPE were recorded every 10-min. Post heat exposure, the participants completed cooling in line with the health and safety procedures (Section 3.1). Pre-test 1 and pre-test 2 were separated by at least 2 days of rest. Post-test 1 and post-test 2 were separated by 1 rest day to minimise HA decay.

7.3.6. Modified isothermic short term heat acclimation

Participants in the young and elderly groups completed a modified isothermic STHA for 5 consecutive days, at the same time each day. On arrival, participants completed a hydration assessment (Section 3.4.1) and baseline physiological measurements (Section 3.4.4) were recorded. Additionally, on day 1 and 5 of HA, capillary blood samples were taken to determine PV changes (Section 3.4.8).

The nude body mass (NBM) measurement was used to calculate individual exercise intensities for the participants; 2.3 $W.kg^{-1}$ young males, 2.0 $W.kg^{-1}$ young females, 1.5 $W.kg^{-1}$ elderly males and 1.2 $W.kg^{-1}$ elderly females. Participants completed HA exercise within 35°C, 50% RH environment, on a stationary upright cycle ergometer (Monark 824E, Monark exercise AB, Sweden) (Photo 7.1). The protocol was to increase resting T_{re} by 1.5°C or to 38.5°C within an hour of entering the 35°C, 50% RH environment. As discussed in the pilot work (Section 7.3.1) the reason for having two T_{re} criteria was based on health and safety guidelines. Once the participant had either reached a 1.5°C change or 38.5°C in T_{re}, it was maintained at or above this temperature for an additional hour.

Throughout testing, physiological and perceptual measurements; HR, T_{re}, TS, TC, and RPE were recorded every 5-min. BP was checked throughout testing with the elderly group and a predetermined rest of 5-min was given after 30-min of exercise for all participants. If the prescribed exercise intensity could not be maintained, then it was reduced so that the participants could continue exercising within the hot environment. Post heat exposure, the participants completed cooling in line with the environmental physiology health and safety procedures (Section 3.1). This included; cooling fans, ice poles, cooling buckets for hands and feet and cold drinking water (Shirreffs *et al.,* 1996).

Photo 7.1: Elderly participant at the end of an isothermic heat acclimation session.

7.3.7. Novel short-term heat acclimation

Participants in the elderly novel group completed the novel STHA for 5 consecutive days, at the same time each day. On arrival, participants completed a hydration assessment (Section 3.4.1) and baseline physiological measurements (Section 3.4.4) were recorded. Additionally, on day 1 and 5 of HA, capillary blood samples were taken to determine PV changes pre-to-post HA (Section 3.4.8).

The NBM measurement was used to calculate individual exercise intensities for the participants; 1.5 $W.kg^{-1}$ males and 1.2 $W.kg^{-1}$ females. Participants completed 30-min of exercise within normothermic conditions ~23°C 60% RH, on a stationary upright cycle ergometer (Monark 824E, Monark exercise AB, Sweden) (Photo 7.2, A). When the prescribed exercise intensity could not be maintained, then it was reduced so that the participants could continue exercising for the full 30-min. On completion of exercise, the participants changed into appropriate clothes for HWI. The HWI was 30-min in 40°C water within an inflatable water bath (Photo 7.2, B). BP was checked at the end of the HWI to ensure participants were not hypotensive before getting out. Participants remained in the bath whilst it was emptied, then they slowly stood up with the assistance of the researcher. Once stood up, the participants remained still for a few minutes to ensure they were not dizzy. They then exited the bath with the assistance of the researcher. Participants then dried themselves and put on dry clothes before being wrapped in blankets for the final 30-min of the novel HA protocol (Photo 7.2, C). Throughout testing, physiological and perceptual measurements; HR, T_{re}, TS, TC, and RPE were recorded every 5-min.

Post the blanket wrap, the participants completed cooling in line with the environmental physiology health and safety procedures (Section 3.1). This included; cooling fans, ice poles, cooling buckets for hands and feet and cold drinking water (Shirreffs *et al.,* 1996).

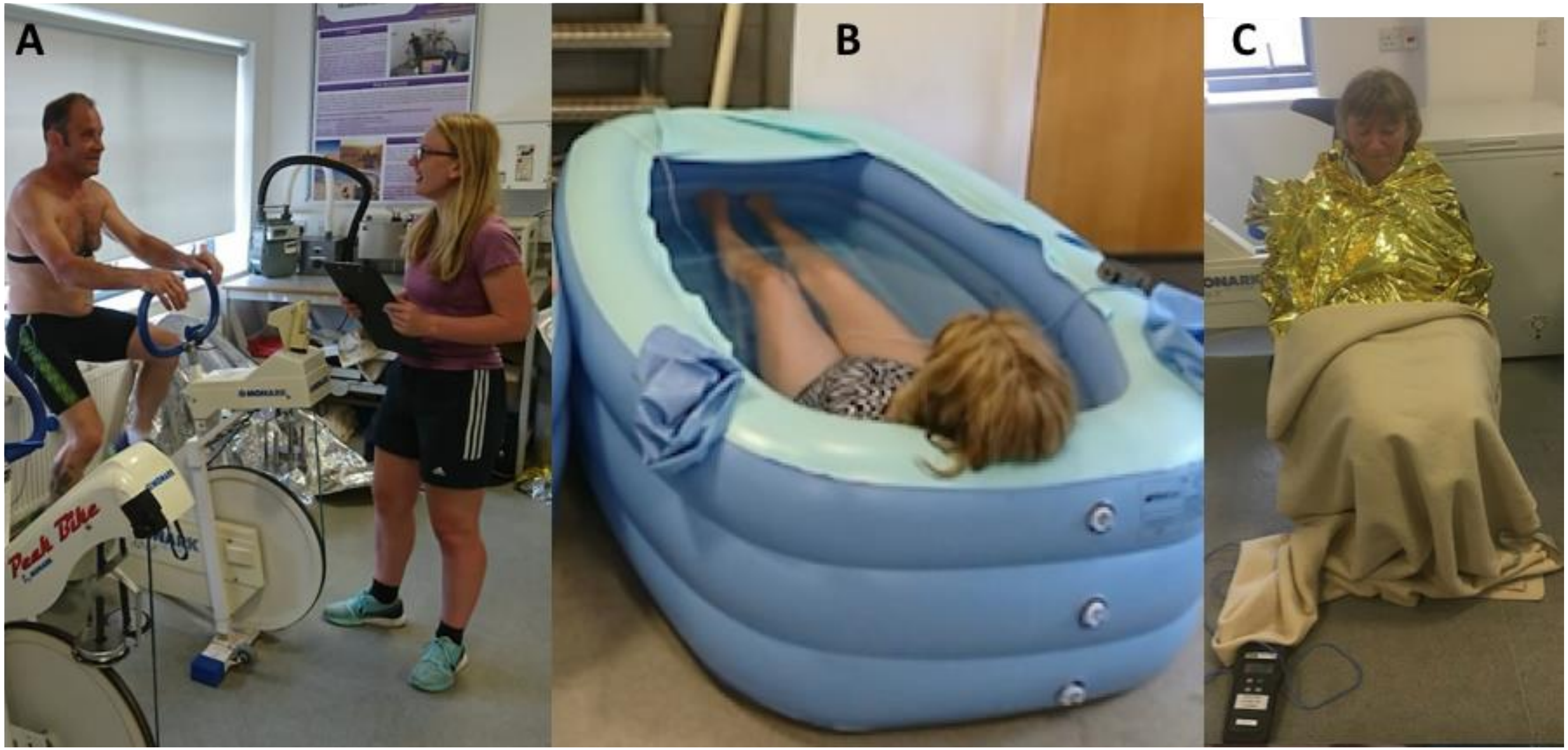


Photo 7.2: Elderly participants at the different stages of the novel heat acclimation session. A; cycling in normothermic conditions, B; 40°C hot water immersion in an inflatable water bath, C; post hot water immersion, wrap in blankets.

7.3.8. Statistical analyses

All data are presented as mean ± SD and were assessed for normality and sphericity prior to further statistical analyses (Section 3.6). When the assumption of sphericity was violated the Greenhouse-Geisser adjustment was used (Section 3.6).

Two-way repeated measures ANOVAs (time*heat acclimation method) were used to analyse interactions. Follow up Bonferroni-corrected post-hoc comparisons were completed if interaction and main effects were observed in the data. Effect sizes were estimated using η_p^2 within statistical ANOVA analysis, to analyse the magnitude and trends of the intervention (Nakagawa and Cuthill, 2007). Effect sizes for t-tests, were categorised as; small (0.2), moderate (0.5), and large (> 0.8) and are presented as *d* (Cohen, 1998: Field, 2017). Data were analysed using SPSS (Version 22.0, SPSS Inc., Chicago, Illinois, USA) with significance set at $p < 0.05$. Predefined analytical limits to highlight meaningful heat adaptations were; ΔT_{re} >0.20°C, ΔHR > -5 b.min^{-1}, ΔWBSR >0.2L.h^{-1}, ΔPV >5% and >Δ1 in perceptual scales (RPE, TS and TC) (Willmott *et al.,* 2016).

7.4. Results

The results are presented in two sections. The first section is a comparison between the young and the elderly using a modified isothermic short term heat acclimation method. The second section is a comparison between the elderly groups, one completed the modified isothermic short term heat acclimation method and the other elderly group completed the novel hot water immersion method.

Baseline measures

Participants' baseline hydration measures were analysed together. Participants arrived at each heat acclimation session hydrated and there was no difference between groups; U_{osmo} ($F_{(8,48)} = 0.76$, $p = 0.64$, $\eta_p^2 = 0.11$) and USG $F_{(8,48)} = 1.36$, $p = 0.24$, $\eta_p^2 = 0.19$).

7.4.1. Modified isothermic short term heat acclimation completed by the young and elderly

Heat acclimation sessions of young and elderly

This section presents the results of the heat acclimation data between the young and elderly during modified isothermic short term heat acclimation.

There was no observed difference, in the time the young and the elderly participants spent with a T_{re} over 38.5°C during the heat acclimation sessions ($F_{(4,68)} = 1.16$, $p = 0.34$, $\eta_p^2 = 0.06$). For time spent above a 1.5°C change in T_{re}, there were main effects for time ($p < 0.05$), which increased over heat acclimation days, and group ($p < 0.05$), whereby the young group spent a significantly longer time above a 1.5°C change in T_{re} compared to the elderly group (Table 7.2).

Figure 7.2 presents the individual responses of the young and elderly to heat acclimation for resting HR and $T_{re.}$ The figure highlights that 2 of the 11 young participants, and 4 of the 8 elderly participants reduced resting HR across 4 days of heat acclimation (*i.e.,* resting HR on day 1 of HA compared to resting HR on day 5 of HA) (Figure 7.2, A). However, there was no statistically observed differences for HR ($F_{(1,17)} = 0.86$, $p = 0.37$, $\eta_p^2 = 0.05$) across the HA days. A greater number of participants presented with reductions in resting T_{re} across HA, 7 of the 11 young and 6 of the 8 elderly had a decline in resting T_{re} after 4 days of HA (Figure 7.2, B). Although, there was no interaction for resting T_{re} ($F_{(1,17)} = 1.52$, $p = 0.23$, $\eta_p^2 = 0.08$), there was a time effect where resting T_{re} decreased from day 1 to day 5 of HA and a group effect where the elderly group had a lower resting T_{re} compared to young. Furthermore, there was a meaningful adaptation and moderate effect size in resting T_{re} in the elderly from day 1 of HA to day 5 (-0.28 ± 0.26°C, $d = 0.64$). This was not present in the young participants (-0.04 ± 0.32, $d = 0.11$) (Table 7.2).

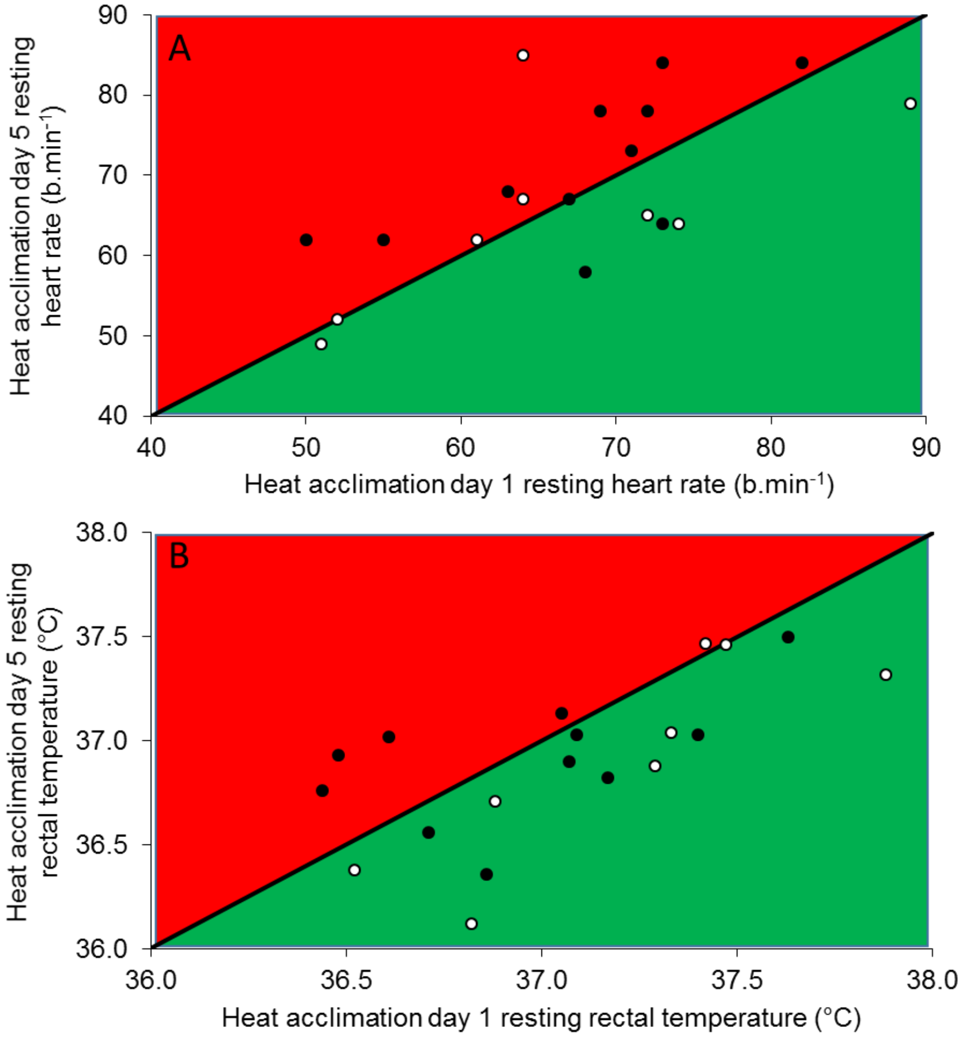


Figure 7.2: Individual data on day 1 and day 5 of heat acclimation for the young (closed circles) and elderly (open circles) for resting measures; heart rate (A) and rectal temperature (B). The black solid line represents the line of equality. Data points within the green section indicate an adaptation after 4 days of heat acclimation via a decrease in resting heart rate (A) and rectal temperature (B).

There was no interaction for average HR ($F_{(4,68)}$ = 1.27, p = 0.29, η_p^2 = 0.07) or peak HR ($F_{(4,68)}$ = 0.62, p = 0.41, η_p^2 = 0.06). However, there were group effects, whereby the young group had a significantly higher average and peak HR compared to the elderly. The main effect of a higher HR in the young group diminished when HR was expressed as a percentage of age-predicted maximum HR (%HR_{max}). Similar to absolute HR, there were no interaction for average ($F_{(4,68)}$ = 0.79, p = 0.53, η_p^2 = 0.05) or peak ($F_{(4,68)}$ = 0.91, p = 0.46, η_p^2 = 0.05) HR when expressed as a %HR_{max}. There were time effects for average HR and average HR expressed as %HR_{max}, whereby HR decreased during heat acclimation sessions (Table 7.2). Likewise, there was no interaction for average T_{re} ($F_{(4,68)}$ = 0.21, p = 0.93, η_p^2 = 0.01), or peak T_{re} ($F_{(4,68)}$ = 0.71, p = 0.59, η_p^2 = 0.04). However, there was a main effect of time, whereby average T_{re} decreased across HA days (Table 7.2).

Fingertip blood samples were taken from willing participants (10 young and 7 elderly modified isothermic participants) to analyse plasma volume changes. In this study, plasma volume changes were not meaningful in young (+3.7%) nor elderly (+4.1%) participants (Table 7.3 and Figure 7.3). However, 6 of 10 young and 4 of 7 elderly participants had a plasma volume expansion >5% and 8 of 10 young and 6 of 7 elderly had a positive increase in plasma volume (Figure 7.3).

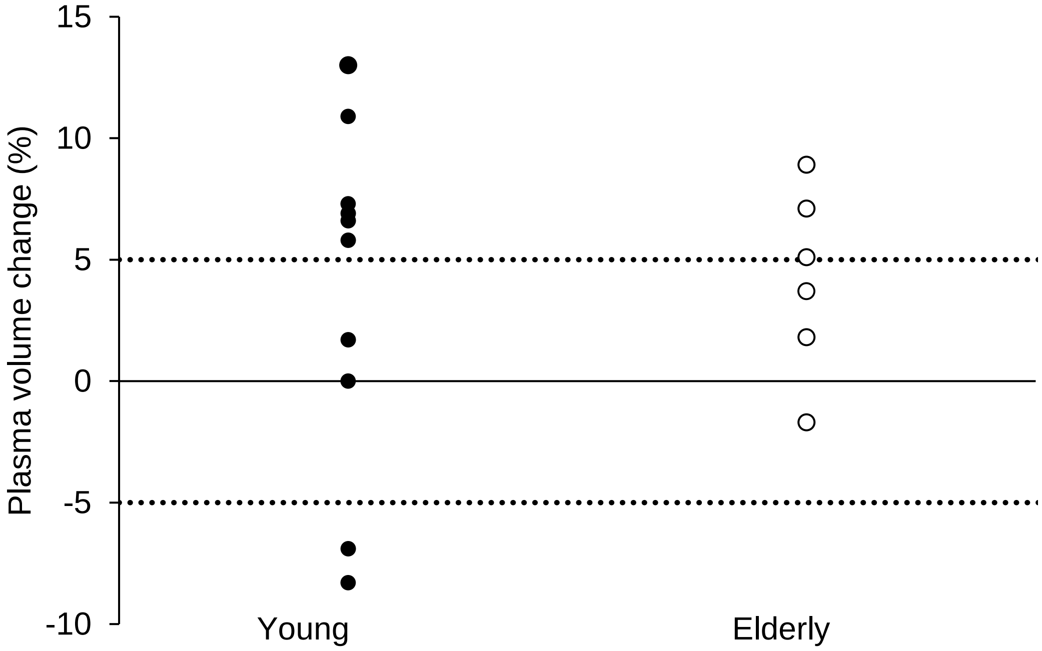


Figure 7.3: Plasma volume changes in the young (closed circles) and elderly modified isothermic (open circles). The dotted lines represents a meaningful increase (+5%) and possible meaningful decrease in plasma volume (-5%).

There was no interaction for the perceptual measures; peak RPE ($F_{(2.271,38.603)}$ = 0.93, p = 0.41, η_p^2 = 0.05), peak TS ($F_{(4,68)}$ =1.67, p = 0.17, η_p^2 = 0.09) and peak TC ($F_{(4,68)}$ = 1.59, p

= 0.19, η_p^2 = 0.09). However, there were main effects for time and group for peak RPE, peak TS and peak TC. Perceptually, heat acclimation became easier across HA sessions and the elderly group felt the exercise was easier and the environment was cooler and more comfortable compared to the young (Table 7.2).

In summary, the physiological strain of the modified isothermic heat acclimation protocol decreased from day 1 to day 5. Average HR and T_{re} decreased across the HA days. Furthermore, the time spent with a T_{re} over 38.5°C was -10 ± 42-min less in the young and -19 ± 28-min less in the elderly on day 5 compared to day 1 of HA. The perceptual strain was also reduced, evident in reductions in RPE, TS and TC from day 1 to day 5 of HA.

Activities of daily living test - pre and post heat acclimation in young and elderly

The data from the second pre and post tests were assessed for phenotypic adaptations to the heat in the young and elderly adults.

There was an interaction in resting HR ($F_{(1,17)}$ = 15.80, $p < 0.01$, η_p^2 = 0.48). Young adults significantly decreased resting HR after completing HA ($p < 0.001$, d = 1.01). Whereas there was no resting HR difference in the elderly group post HA (p = 0.47, d = -0.14) (Table 7.3 and Figure 7.4, A). The individual differences in resting HR are presented in figure 7.4 (A) where 10 of the 11 young and 2 of the 8 elderly participants reduced resting HR from pre-to-post HA. There were no observed differences for exercise related heart rates; average ($F_{(1,17)}$ = 1.14, p = 0.30, η_p^2 = 0.06), average expressed as %HR_{max} ($F_{(1,17)}$ = 1.10, p = 0.31, η_p^2 = 0.06), peak HR ($F_{(1,17)}$ = 1.71, p = 0.21, η_p^2 = 0.09) and peak expressed as % HR_{max} ($F_{(1,17)}$ = 1.48, p = 0.24, η_p^2 = 0.08) did not reduce in either group after completing HA (Table 7.3).

There was a significant interaction for the change in T_{re} from the end of rest to the end of cycling exercise (*i.e.,* change in exercise T_{re}) ($F_{(1,17)}$ = 13.58, $p < 0.01$, η_p^2 = 0.44). The elderly participants change in exercise T_{re} was less (-0.22 ± 0.20°C) after completing HA (p = 0.001, d = 1.63). Whereas, the young had no change in exercise T_{re} (+0.05 ± 0.11°C) after completing HA (p = 0.32, d = -0.32). There were no further observed differences post HA between or within groups for T_{re}; rest ($F_{(1,17)}$ = 0.86, p = 0.37, η_p^2 = 0.05) or peak ($F_{(1,17)}$ = 0.41, p = 0.53, η_p^2 = 0.02) (Table 7.3). Although, not statistically significant, 7 of the 11 young participants had lower resting T_{re} post HA, compared to 2 of 8 elderly participants (Figure 7.4, B).

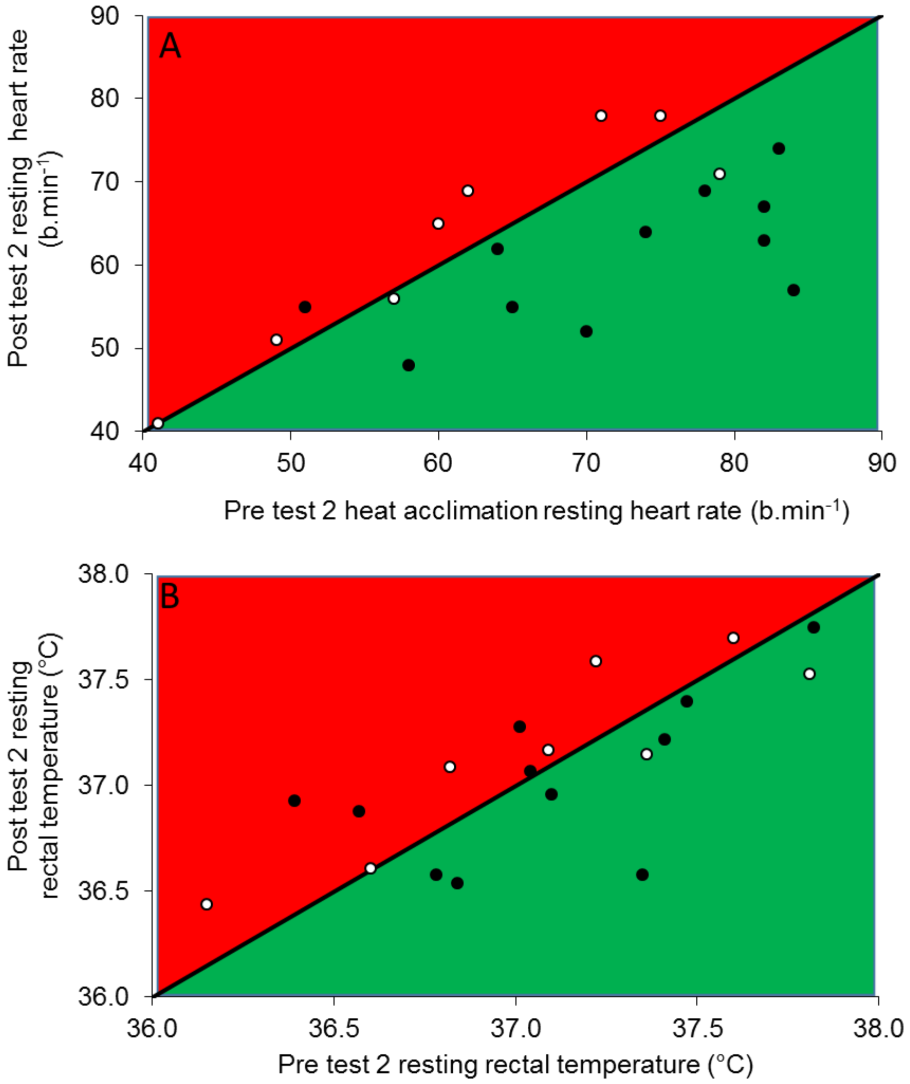


Figure 7.4: Individual data pre and post heat acclimation for the young (closed circles) and elderly (open circles) for resting measures; heart rate (A) and rectal temperature (B). The black solid line represents the line of equality. Data points within the green section indicate an adaptation from the second pre-test to the second post-test via a decrease in resting heart rate (A) and rectal temperature (B).

The was no statistically observed increase in WBSR post HA ($F_{(1,17)} = 1.679$, $p = 0.212$, $\eta_p^2 = 0.090$). However, all the elderly participants had an increase in WBSR post HA (0.18 ± 0.11 $L.h^{-1}$) and 6 of the 11 young participants had an increase in WBSR (-0.04 ± 0.4 $L.h^{-1}$) (Figure 7.5 and Table 7.3).

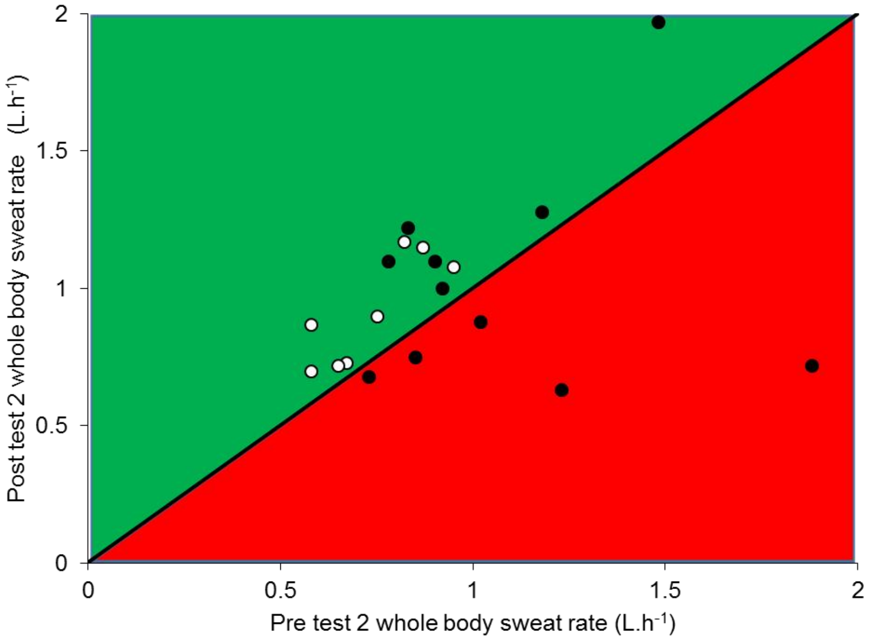


Figure 7.5: Individual data for whole body sweat rate pre and post heat acclimation for the young (closed circles) and elderly (open circles). The black solid line represents the line of equality. Data points within the green section indicate an adaptation from the second pre test to the second post test via an increase in whole body sweat rate post heat acclimation.

There was no difference in peak skin temperature between groups, pre-to-post heat acclimation ($F_{(1,17)} = 0.26$, $p = 0.62$, $\eta_p^2 = 0.02$). However, there was a time effect, whereby peak skin temperature decreased after completing HA. Likewise, there was no observed increase in CVC post HA ($F_{(1,17)} = 2.01$, $p = 0.18$, $\eta_p^2 = 0.11$), indicative of no change in forearm SkBF. There was no difference in core-to-skin gradient between groups, pre-to-post heat acclimation ($F_{(1,17)} = 0.34$, $p = 0.57$, $\eta_p^2 = 0.02$). However, there was a main effect of time whereby, core-to-skin gradient increased post HA (Table 7.3).

There was no difference in peak RPE between groups, pre-to-post heat acclimation ($F_{(1,17)} = 0.89$, $p = 0.36$, $\eta_p^2 = 0.05$). However, there was a main effect of time, whereby peak RPE decreased post HA. Similarly, there was no interaction for peak TS ($F_{(1,17)} = 0.88$, $p = 0.36$, $\eta_p^2 = 0.05$), but a main effect of time, whereby participants felt cooler post HA. There was no observed difference for peak TC ($F_{(1,17)} = 2.06$, $p = 0.17$, $\eta_p^2 = 0.11$) (Table 7.3).

Six-minute walk test (6MWT)

The 6MWT was used as test of functional capacity. Data was assessed for post heat acclimation improvements. There was no observed interaction for distance completed in the 6MWT ($F_{(1,17)} = 1.22$, $p = 0.29$, $\eta_p^2 = 0.07$). However, there were main effects of time and group, whereby distance increased post HA and young adults walked significantly further than the elderly. Similarly, there was no interaction for end T_{re} ($F_{(1,17)} = 4.08$, $p = 0.06$, $\eta_p^2 = 0.19$), end HR ($F_{(1,17)} = 1.32$, $p = 0.27$, $\eta_p^2 = 0.07$) or end HR expressed as %HR_{max} ($F_{(1,17)} = 1.88$, $p = 0.19$, $\eta_p^2 = 0.10$). There was a significant group effect for end HR, whereby the young group had a higher HR than the elderly. There was no difference in the perceptual markers; end RPE ($F_{(1,17)} = 0.02$, $p = 0.89$, $\eta_p^2 = 0.001$) and end TC ($F_{(1,17)} = 0.02$, $p = 0.89$, $\eta_p^2 < 0.01$). There was an observed interaction for end TS ($F_{(1,17)} = 0.55$, $p = 0.47$, $\eta_p^2 = 0.03$). The difference was the young felt significantly cooler post HA ($p = 0.02$, $d = 0.88$), but there were no differences in the elderly group ($p = 0.585$, $d = -0.19$) (Table 7.4).

In summary, there were some phenotypic HA responses among the young and elderly when they completed modified isothermic HA. The greatest response for the young was a reduction in resting HR (-11 ± 8 $b.min^{-1}$) post HA. In the elderly, the reduction in the change in exercise T_{re} and increases in WBSR indicate an adaptive response to HA. Both groups reduced skin temperature and increased core-to-skin gradient after HA, highlighting a greater heat loss efficacy post HA. Functional capacity as defined by greater distance in the 6MWT improved for both groups. Perceptually, the young and elderly felt the exercise was easier and the environment was cooler on completion of HA.

7.4.2. Comparison of heat acclimation methods, isothermic and novel hot water immersion within an elderly population

Heat acclimation sessions for elderly modified isothermic and novel groups

In the modified isothermic method, the aim was to increase T_{re} to drive phenotypic heat adaptations. This differs from the novel HWI method, as the purpose was to investigate a practical alternative HA method for the elderly. Therefore, the T_{re} was monitored throughout, but the HWI method was based on duration in the water and not on how long a specific T_{re} was maintained. However, there was no observed difference in the time spent with a T_{re} above 38.5°C between elderly groups, across HA days ($F_{(4,52)} = 0.90$, $p = 0.47$, $\eta_p^2 = 0.06$). There was a main effect of time, whereby time spent with a T_{re} above 38.5°C decreased over HA days. Likewise, there was no interaction in the time spent with a T_{re} that was 1.5°C higher than pre HA session ($F_{(2.143,27.859)} = 1.41$, $p = 0.26$, $\eta_p^2 = 0.10$) (Table 7.2).

Figure 7.6 presents the individual responses of the both elderly HA groups for resting HR and T_{re}. The figure highlights 4 of the 8 isothermic and 5 of 7 novel participants reduced resting HR across 4 days of heat acclimation (*i.e.,* resting HR on day 1 of HA compared to resting HR on day 5 of HA) (Figure 7.6, A). Furthermore, 6 of the 8 isothermic and 5 of 7 novel participants had a reduced resting T_{re} after 4 days of HA (Figure 7.6, B). There were no observed differences between-groups, across HA days for resting; HR ($F_{(4,52)} = 1.50$, $p = 0.25$, $\eta_p^2 = 0.10$) or T_{re} ($F_{(4,52)} = 2.18$, $p = 0.08$, $\eta_p^2 = 0.14$). There was an effect of time in which resting T_{re} decreased during HA (Figure 7.6 and Table 7.2). The time effect decrease in resting T_{re} during HA indicates that both groups developed resting T_{re} adaptations.

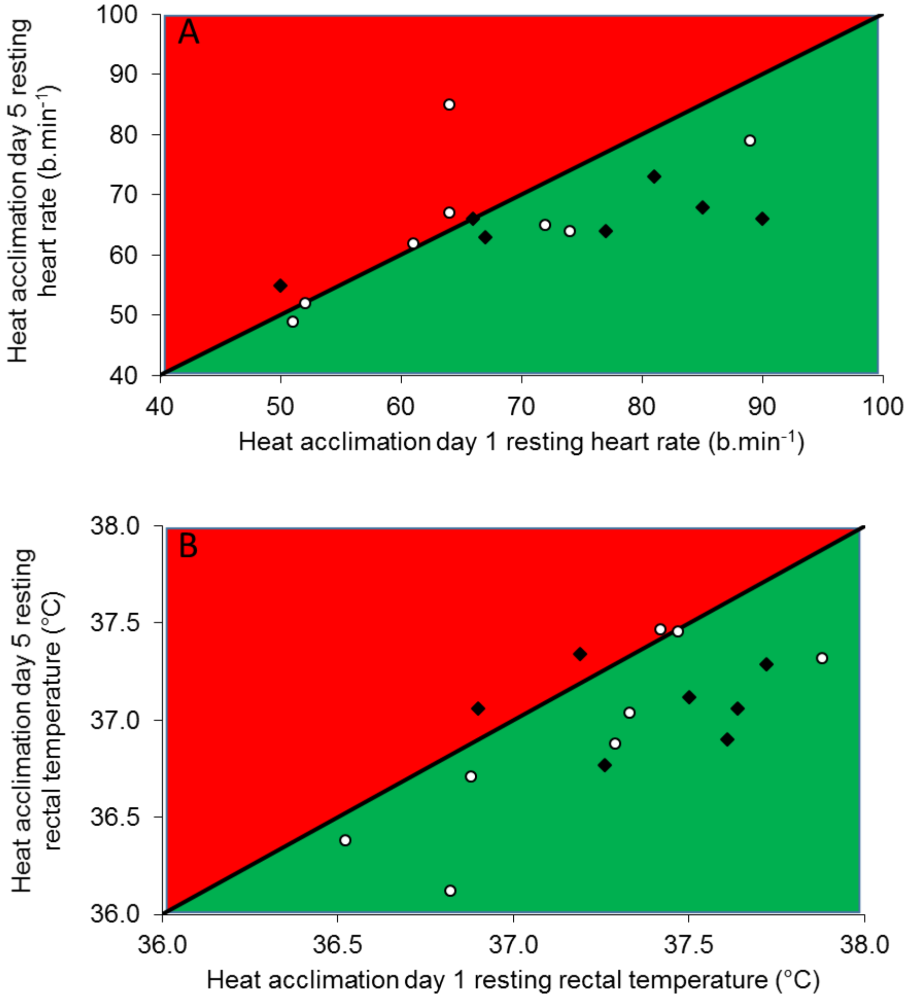


Figure 7.6: Individual data on day 1 and day 5 of heat acclimation for the elderly isothermic group (open circles) and the elderly novel group (black diamonds) for resting measures; heart rate (A) and rectal temperature (B). The black solid line represents the line of equality. Data points within the green section indicate an adaptation after 4 days of heat acclimation via a decrease in resting heart rate (A) and rectal temperature (B).

The was no interaction for average HR ($F_{(4,52)}$ = 0.56, p = 0.69, η_p^2 = 0.04) and average HR expressed as %HR$_{max}$ ($F_{(4,52)}$ = 0.56, p = 0.70, η_p^2 = 0.04). However, there were group effects, the modified isothermic group had a significantly higher average HR compared to the novel HWI group. Average HR was likely higher due to the longer exercise periods required in the modified isothemic method compared to the novel HWI group. There was no observed difference for peak HR ($F_{(4,52)}$ = 0.18, p = 0.95, η_p^2 = 0.01) and peak HR expressed %HR$_{max}$ ($F_{(4,52)}$ = 0.18, p = 0.95, η_p^2 = 0.01) (Table 7.2).

There was no interaction for average T$_{re}$ ($F_{(4,52)}$ = 1.55, p = 0.20, η_p^2 = 0.11). However, there was a main effect of time, whereby average T$_{re}$ decreased across HA days. There was an observed effect for peak T$_{re}$ ($F_{(4,52)}$ = 2.89, p = 0.03, η_p^2 = 0.18), where follow-up analysis indicated a significantly higher peak T$_{re}$ on day 3 of HA in the novel hot water immersion group compared to the adapted isothermic group (Table 7.2).

Fingertip blood samples were taken from willing participants (7 elderly modified isothermic and 6 elderly novel participants) to analyse plasma volume changes. In this study, plasma volume changes were not meaningful in either elderly group; modified isothermic (+4.1%) and novel (0.01%) participants (Table 7.4 and Figure 7.7).

Figure 7.7: Plasma volume changes in the elderly modified isothermic (open circles) and elderly novel (black diamonds) groups. The dotted line represents a meaningful increase (+5%) and possible meaningful decrease in plasma volume (-5%).

There were no differences observed for peak RPE ($F_{(2.384,30.993)}$ = 0.50, p = 0.64, η_p^2 = 0.04) and peak TS ($F_{(4,52)}$ = 0.60, p = 0.66, η_p^2 = 0.04). There was a main effect of time for peak TS in which participants felt cooler as they progressed through the heat acclimation sessions. There was an interaction for peak TC ($F_{(4,52)}$ = 0.61, p = 0.34, η_p^2 = 0.18). Follow up analysis identified that the modified isothermic group were significantly more comfortable during the second day of heat acclimation compared to the first (Table 7.2).

In summary, the physiological strain in the elderly for the modified isothermic and the novel heat acclimation protocols decreased from day 1 to day 5. Average HR and T_{re} decreased across the HA days. Furthermore, the time spent with a T_{re} over 38.5°C was -19.38 ± 28.09-min less in the elderly in the modified isothermic group and -9.55 ± 16.95-min less in the elderly novel group, on day 5 compared to day 1 of HA. Thermal sensation from day 1 to day 5 of HA was reduce, highlighting a decrease in perceptual strain during the course of HA.

Activities of daily living - pre and post heat acclimation for elderly modified isothermic and novel groups

The data from the second pre and post tests were assessed for phenotypic adaptations to the heat in the elderly adults.

There was an observed significant interaction in resting HR ($F_{(1,13)} = 4.78$, $p = 0.05$, $\eta_p^2 = 0.27$). However, follow up analysis did not identify where the significant differences were. The individual differences in resting HR are presented in figure 7.8 (A) where 2 of the 8 modified isothermic elderly participants and 6 of the 7 novel elderly participants reduced their resting HR from pre-to-post HA. There were no further observed difference for HR; average ($F_{(1,13)} = 3.13$, $p = 0.10$, $\eta_p^2 = 0.19$), average expressed as % HR_{max} ($F_{(1,13)} = 3.09$, $p = 0.10$, $\eta_p^2 = 0.19$), peak HR ($F_{(1,13)} = 1.92$, $p = 0.19$, $\eta_p^2 = 0.13$) and peak expressed as %HR_{max} ($F_{(1,13)} = 2.02$, $p = 0.18$, $\eta_p^2 = 0.14$) for either group (Table 7.3).

There were no observed interactions for T_{re}; resting ($F_{(1,13)} = 2.56$, $p = 0.13$, $\eta_p^2 = 0.17$), change in exercise ($F_{(1,13)} = 2.62$, $p = 0.13$, $\eta_p^2 = 0.16$) and peak ($F_{(1,13)} = 1.34$, $p = 0.27$, $\eta_p^2 = 0.09$) (Table 7.3). When analysing the individual resting T_{re} data, 2 of 8 modified isothermic elderly participants and 5 of the 7 novel elderly participants had a reduction in resting T_{re} from pre-to-post HA. (Figure 7.8, B).

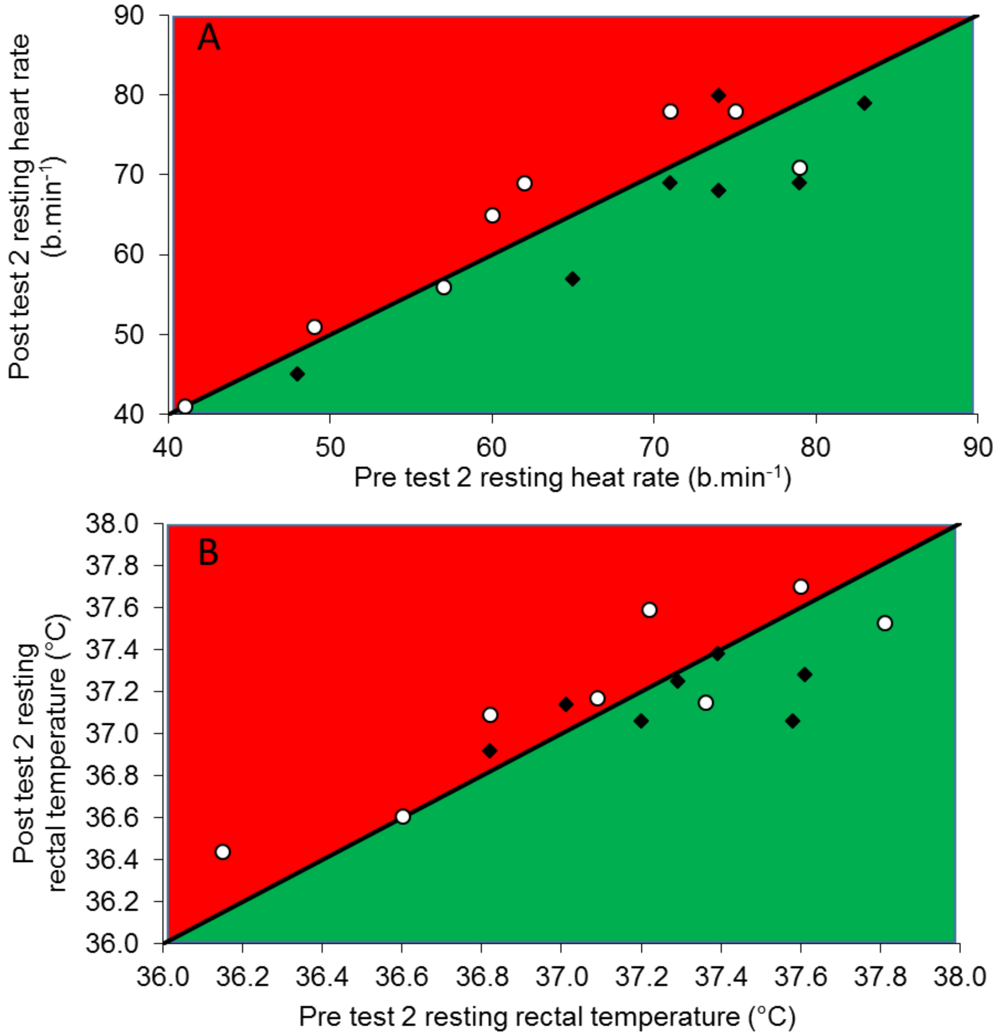


Figure 7.8: Individual data pre and post heat acclimation for the young elderly modified isothermic (open circles) and elderly novel (black diamonds) for resting measures; heart rate (A) and rectal temperature (B). The black solid line represents the line of equality. Data points within the green section indicate an adaptation from the second pre-test to the second post-test via a decrease in resting heart rate (A) and rectal temperature (B).

There was no observed increase in WBSR post HA ($F_{(1,13)} = 3.28$, $p = 0.09$, $\eta_p^2 = 0.21$). However, all of the elderly modified isothermic group had an increase in WBSR post HA (0.18 ± 0.11 L.h^{-1}) and 5 of the 7 young participants had an increase in WBSR (-0.10 ± 0.41 L.h^{-1}) (Figure 7.9 and Table 7.3).

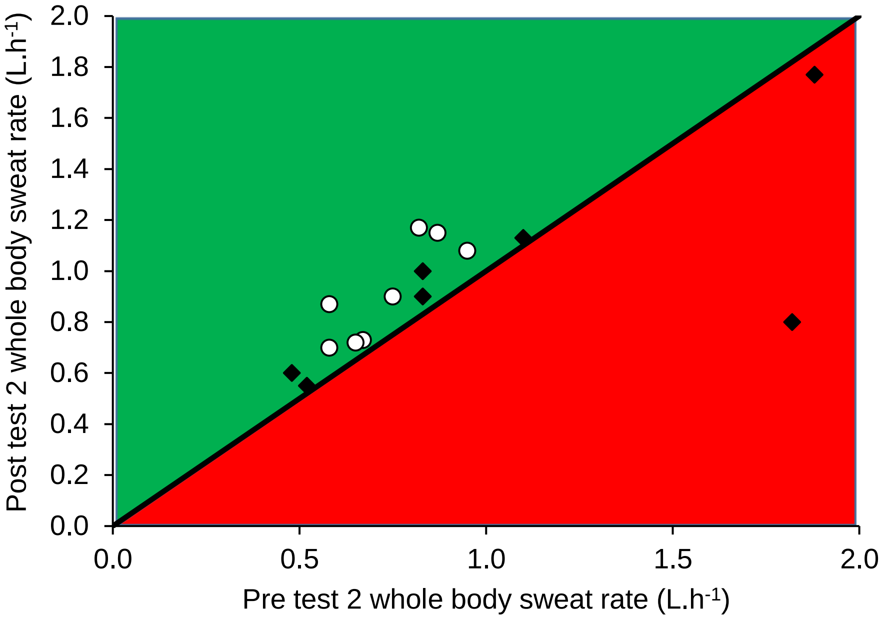


Figure 7.9: Individual data for whole body sweat rate pre and post heat acclimation for the elderly modified isothermic group (open circles) and the elderly novel group (black diamonds). The black solid line represents the line of equality. Data points within the green section indicate an adaptation from the second pre-test to the second post-test via an increase in whole body sweat rate post heat acclimation.

Similarly, there was no interaction for peak skin ($F_{(1,13)} = 0.002$, $p = 0.97$, $\eta_p^2 = 0$) nor CVC post HA ($F_{(1,13)} = 0.22$, $p = 0.65$, $\eta_p^2 = 0.02$). Likewise, there was no interaction for core-to-skin gradient ($F_{(1,13)} = 0.02$, $p = 0.89$, $\eta_p^2 < 0.01$), however, there was a group effect, whereby the novel elderly group had a significantly greater core-to-skin gradient compared to the adapted isothermic group (Table 7.3).

There was no interaction in the perceptual markers; RPE ($F_{(1,13)} = 0.09$, $p = 0.77$, $\eta_p^2 = 0.01$), TS ($F_{(1,13)} = 0.87$, $p = 0.37$, $\eta_p^2 = 0.06$) and TC ($F_{(1,13)} = 1.63$, $p = 0.22$, $\eta_p^2 = 0.11$) (Table 7.3).

Six-minute walk test for elderly modified isothermic and novel group

The 6MWT was used as test of functional capacity. Data was assessed for post heat acclimation improvements. There was no observed interaction for distance completed in the 6MWT ($F_{(1,13)}$ =0.05, p = 0.83, $\eta_p^2 < 0.01$). However, there was a main effect of time, whereby distance significantly increased post HA. Similarly, there was no interaction for end T_{re} ($F_{(1,10)}$ = 0.01, p = 0.93, $\eta_p^2 < 0.01$), end HR ($F_{(1,13)}$ = 1.10, p = 0.31, $\eta_p^2 = 0.08$) or end HR expressed as % HR_{max} ($F_{(1,13)}$ = 1.12, p = 0.31, $\eta_p^2 = 0.08$). There was no difference in the perceptual markers; RPE ($F_{(1,13)}$ = 0.47, p = 0.51, $\eta_p^2 = 0.04$), TS ($F_{(1,13)}$ = 0.52, p = 0.49, $\eta_p^2 = 0.04$) and TC ($F_{(1,13)}$ = 0.22, p = 0.65, $\eta_p^2 = 0.02$) (Table 7.4).

In summary, there were some phenotypic HA responses among both elderly groups completing the different heat acclimation methods. The majority of the novel HWI participants had an adaptive response in resting T_{re} and HR from day 1 to day 5 of HA, which was well maintained into the pre-to-post HA tests. The isothermic elderly group had increases in WBSR indicate an adaptive response to HA. Both groups improved 6MWT waking performance post HA.

Table 7.2: Time at target rectal temperature, physiological and perceptual variables for the young, elderly and elderly novel groups, across heat acclimation days. Mean ± SD.

Variable	**Group**	**Heat acclimation days**					**Δ Day 1 - Day 5**
		Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	
Time spent > 38.5°C (min)	Young	41 ± 38	37 ± 27	27 ± 20	20 ± 25	31 ± 30	-10 ± 42
	Elderly	31 ± 34	28 ± 29	15 ± 28	29 ± 30	4 ± 9	-19 ± 28#
	Elderly Novel	19 ± 21	19 ± 18	20 ± 16	14 ± 15	4 ± 6	-10 ± 17#
Time spent > Δ 1.5°C (min)	Young	54 ± 18*	51 ± 26*	43 ± 28*	56 ± 19*	58 ± 19*	4 ± 28†
	Elderly	5 ± 14*	5 ± 14*	30 ± 18*	30 ± 31*	20 ± 24*	15 ± 28†
	Elderly Novel	6 ± 15	0 ± 0	8 ± 11	7 ± 13	6 ± 13	0 ± 22
Rest HR (b.min^{-1})	Young	68 ± 9	67 ± 9	70 ± 9	68 ± 6	71 ± 9	3 ± 7
	Elderly	66 ± 12	70 ± 15	63 ± 11	68 ± 9	65 ± 12	-1 ± 10
	Elderly Novel	74 ± 14	69 ± 12	67 ± 9	70 ± 10	65 ± 5	-8 ± 10
Average HR across the HA session (b.min^{-1})	Young	178 ± 13 *	178 ± 7*	174 ± 8*	175 ± 11*	172 ± 9*	-5 ± 9†
	Elderly	144 ± 14*§	139 ± 10§*	142 ± 14*§	139 ± 11*§	141 ± 11*§	-3 ± 12†
	Elderly Novel	133 ± 17	128 ± 15	128 ± 17	127 ± 17	128 ± 13	-5 ± 6
Average HR expressed as %HR$_{max}$(%)	Young	75.4 ± 8.9	74.0 ± 5.6	73.2 ± 4.0	70.6 ± 6.0	70.7 ± 5.2	-4.7 ± 5.8†
	Elderly	67.5 ± 22.4	67.3 ± 23.9	67.4 ± 22.4	65.2 ± 23.3	66.1 ± 23.4	-0.1 ± 5.7†
	Elderly Novel	65.8 ± 23.0	63.7 ± 22.6	64.3 ± 22.3	62.4 ± 21.5	61.7 ± 21.8	-3.4 ± 5.1
Peak HR (b.min^{-1})	Young	178 ± 13 *	178 ± 7*	174 ± 8*	175 ± 11*	172 ± 9*	-5 ± 9
	Elderly	144 ± 14*	139 ± 10*	142 ± 14*	139 ± 11*	141 ± 11*	-3 ± 12
	Elderly Novel	133 ± 17	128 ± 15	128 ± 17	127 ± 17	128 ± 13	-5 ± 6
Peak HR expressed as %HR$_{max}$ (%)	Young	89.6 ± 6.7	89.7 ± 3.6	87.7 ± 4.5	88.3 ± 5.6	86.9 ± 4.9	-2.8 ± 4.5
	Elderly	94.5 ± 9.0	91.2 ± 6.9	93.4 ± 8.8	90.9 ± 5.9	92.4 ± 4.7	-2.0 ± 7.9
	Elderly Novel	90.7 ± 11.1	86.7 ± 9.8	86.7 ± 11.5	86.3 ± 11.8	86.8 ± 8.9	-3.4 ± 4.1

Rest T_{re} (°C)	Young	36.96 ± 0.38	37.05 ± 0.35	37.07 ± 0.42	36.91 ± 0.29	36.91 ± 0.30	-0.04 ± 0.32
	Elderly	37.20 ± 0.43	37.19 ± 0.35	36.98 ± 0.44	36.93 ± 0.51	36.92 ± 0.50	-0.28 ± 0.26#
	Elderly Novel	37.40 ± 0.30	37.22 ± 0.16	37.35 ± 0.22	37.25 ± 0.30	37.08 ± 0.20	-0.33 ± 0.35#
Average T_{re} across the HA session (°C)	Young	38.17 ± 0.33	38.18 ± 0.16	38.08 ± 0.13	38.07 ± 0.19	38.05 ± 0.21	-0.11 ± 0.32 †
	Elderly	38.00 ± 0.43	38.02 ± 0.31	37.84 ± 0.38	37.90 ± 0.39	37.84 ± 0.37	-0.11 ± 0.16 † #
	Elderly Novel	38.11 ± 0.17	38.02 ± 0.21	38.11 ± 0.13	37.96 ± 0.21	37.83 ± 0.14	-0.28 ± 0.16 #
Peak T_{re} (°C)	Young	38.63 ± 0.34	38.61 ± 0.12	38.59 ± 0.06	38.55 ± 0.17	38.54 ± 0.22	-0.09 ± 0.37
	Elderly	38.32 ± 0.48	38.42 ± 0.31	38.34 ± 0.33	38.42 ± 0.36	38.30 ± 0.34	-0.01 ± 0.22
	Elderly Novel	38.67 ± 0.25	38.58 ± 0.32	38.72 ± 0.30 ‡	38.45 ± 0.27	38.37 ± 0.24	-0.19 ± 0.21
Peak RPE	Young	17 ± 1*	17 ± 1*	17 ± 2*	17 ± 1*	17 ± 2*	-1 ± 2 †
	Elderly	15 ± 2*	14 ± 2*	15 ± 2*	14 ± 2*	14 ± 1*	-1 ± 1 †
	Elderly Novel	15 ± 3	15 ± 3	15 ± 3	15 ± 4	14 ± 3	-1 ± 2
Peak TS	Young	7.1 ± 0.4*	7.0 ± 0.6*	7.0 ± 0.5*	7.0 ± 0.5*	7.0 ± 0.4*	-0.1 ± 0.5†
	Elderly	6.6 ± 0.7*	6.1 ± 0.4*	6.4 ± 0.5*	6.0 ± 0.8*	6.1 ± 0.9*	-0.5 ± 0.5†#
	Elderly Novel	6.4 ± 0.8	6.1 ± 0.7	6.2 ± 1.0	5.9 ± 1.0	6.3 ± 1.0	-0.1 ± 0.7#
Peak TC	Young	5 ± 1*	5 ± 1*	5 ± 1*	5 ± 1*	5 ± 1*	0 ± 1†
	Elderly	5 ± 1*	4 ± 1*∝	4 ± 1*	5 ± 1*	4 ± 1*	-1 ± 1†
	Elderly Novel	4 ± 1	4 ± 2	5 ± 2	4 ± 1	4 ± 2	0 ± 1

Abbreviation: HR; heart rate, T_{re}; rectal temperature, RPE; rating of perceived exertion, TS; thermal sensation, TC; thermal comfort. * represents a significant ($p < 0.05$) between-group (young and elderly) difference across heat acclimation sessions. † represents a significant ($p < 0.05$) within- group (young and elderly) difference across heat acclimation sessions. # represents a significant ($p < 0.05$) within- group (elderly and elderly novel) difference across heat acclimation sessions. § represents a significant ($p < 0.05$) between-group (elderly and elderly novel) difference across heat acclimation sessions. ‡ represents a significant difference ($p < 0.05$) from elderly and elderly novel. ∝ represents a significant difference from day 1 to day 2 of heat acclimation.

Table 7.3: Physiological and perceptual variables in the young, elderly and elderly novel groups, during rest and activities of daily living testing, pre and post heat acclimation and change from pre-to-post heat acclimation. Mean ± SD.

	Pre Heat Acclimation			**Post Heat Acclimation**			**Pre-to-post change**		
Variable	**Young**	**Elderly**	**Elderly Novel**	**Young**	**Elderly**	**Elderly Novel**	**Young**	**Elderly**	**Elderly Novel**
Rest T_{re} (°C)	37.07 ± 0.42	37.08 ± 0.54	37.27 ± 0.29	37.02 ± 0.37	37.16 ± 0.45	37.16 ± 0.16	-0.05 ± 0.34	0.08 ± 0.23	-0.12 ± 0.24
Peak T_{re} (°C)	37.38 ± 0.25	37.52 ± 0.45	37.81 ± 0.33	37.41 ± 0.28	37.62 ± 0.38	37.77 ± 0.24	0.03 ± 0.20	0.09 ± 0.22	-0.04 ± 0.22
Δ in exercise T_{re} (°C)	0.47 ± 0.15	0.64 ± 0.13	0.49 ± 0.44	0.52 ± 0.18	0.42 ± 0.12	0.51 ± 0.21	0.05 ± 0.11	-0.22 ± 0.20*	0.02 ± 0.36
Rest HR ($b.min^{-1}$)	72 ± 11	62 ± 13	71 ± 11	61 ± 8	64 ± 13	67 ± 12	-11 ± 8*	2 ± 5	-4 ± 5
Average HR ($b.min^{-1}$)	122 ± 15	106 ± 18	116 ± 19	119 ± 14	106 ± 21	113 ± 20	-4 ± 10	0 ± 4	-3 ± 4
Average HR expressed as $\%HR_{max}$ (%)	61.8 ± 7.5	69.3 ± 11.9	79.1 ± 13.9	59.9 ± 7.1	69.5 ± 13.6	76.9 ± 14.1	-1.8 ± 5.0	0 .6 ± 2.8	-2.3 ± 2.6
Peak HR ($b.min^{-1}$)	129 ± 15	110 ± 19	122 ± 20	123 ± 14	110 ± 22	118 ± 21	-6 ± 10	0 ± 5	-4 ± 5

Peak HR expressed as %HR$_{max}$ (%)	64.9 ± 7.5	72.2 ± 12.7	83.0 ± 14.3	62 .1 ± 7.3	72. 0 ± 14.6	80.2 ± 14.5	-2.8 ± 5.3	-0.2 ± 3.4	-2.8 ± 3.6
PV (%)	-	-	-	-	-	-	+ 3.7	+ 4.1	+ 0.1
Peak T$_{sk}$ (°C)	36.19 ± 0.31	36.25 ± 0.13	35.97 ± 0.44	36.03 ± 0.28	35.98 ± 0.50	35.69 ± 0.71	-0.17 ± 0.27†	-0.27 ± 0.58†	-0.28 ± 0.40
Peak core-to-skin gradient (°C)	1.34 ± 0.40	1.45 ± 0.40#	2.11 ± 0.49 #	1.52 ± 0.33	1.74 ± 0.47 #	2.37 ± 0.75 #	0.17 ± 0.34†	0.29 ± 0.57†	0.25 ± 0.40
WBSR (L.h^{-1})	1.07 ± 0.35	0.73 ± 0.14	1.07 ± 0.58	1.03 ± 0.38	0.92 ± 0.20	0.96 ± 0.41	-0.04 ± 0.48	0.18 ± 0.11	-0.10 ± 0.41
CVC	0.52 ± 0.20	0.58 ± 0.19	0.52 ± 0.22	0.49 ± 0.17	0.75 ± 0.38	0.59 ± 0.38	-0.03 ± 0.24	0.17 ± 0.36	0.07 ± 0.45
RPE	12 ± 2	12 ± 2	14 ± 3	10 ± 2	11 ± 2	14 ± 4	-2 ± 2†	-1 ± 2†	-1 ± 2
TS	5.7 ± 0.5	5.9 ± 0.5	6.1 ± 0.9	5.3 ± 0.3	5.6 ± 0.4	6.1 ± 1.1	-0.4 ± 0.5†	-0.3 ± 0.4†	0.0 ± 0.4
TC	3 ± 1	3 ± 1	4 ± 1	2 ± 1	3 ± 1	4 ± 2	-1 ± 1	0 ± 1	-1 ± 1

Abbreviations: T$_{re}$; rectal temperature, Δ; change, HR; heart rate, PV; plasma volume WBSR; whole body sweat rate, CVC; cutaneous vascular conductance, RPE; rating of perceived exertion, TS; thermal sensation, TC; thermal comfort * represents a significant ($p < 0.05$) within-group difference from pre-to-post heat acclimation. † represents a significant ($p < 0.05$) heat acclimation effect (young and elderly). # represents a significant ($p < 0.05$) between-group (elderly and elderly novel) difference.

Table 7.4: Performance, physiological and perceptual variables in the 6MWT completed pre and post heat acclimation. Mean ± SD.

	Pre Heat Acclimation			Post Heat Acclimation			Pre-to-post change		
Variables	**Young**	**Elderly**	**Elderly Novel**	**Young**	**Elderly**	**Elderly Novel**	**Young**	**Elderly**	**Elderly Novel**
Distance (m) [%change]	0.75 ± 0.04†	0.59 ± 0.14†	0.50 ± 0.14	0.78 ± 0.07†	0.64 ± 0.11†	0.54 ± 0.14	30 ± 40* [+4.2 ± 5.3]	50± 30*§ [+10.3 ± 9.4]	50 ± 20§ [9.9 ± 3.4]
Peak T_{re} (°C)	37.48 ± 0.39	37.83±0.41	38.02 ±0. 33	37.64 ± 0.31	37.70 ± 0.47	37.87 ± 0.25	0.16 ± 0.29	-0.13 ± 0.33	-0.15 ± 0.17
End HR (b.min^{-1})	166 ± 12 †	130 ± 15†	128 ± 18	165 ± 18 †	135 ± 16 †	129 ± 19	-1 ± 14	5 ± 6	1 ± 8
End HR expressed as % HR$_{max}$ (%)	83.9 ± 6.9	85.0 ± 9.9	86.8 ± 11.9	85.0 ± 7.5	88.3 ± 10.5	87.5 ± 12.0	1.1 ± 4.7	3.3 ± 3.9	0.7 ± 5.5
End TS	6.0 ± 0.6	5.6 ± 0.7	6.0 ± 1.0	5.5 ± 0.6	5.8 ± 0.5	5.9 ± 1.2	-0.6 ± 0.7#	0.1 ± 0.4	-0.1 ± 0.9
End TC	4 ± 1	4 ± 1	4 ± 1	3 ± 1	3 ± 1	4 ± 2	-1 ± 1	0 ± 1	0 ± 2
End RPE	14 ± 2	13 ± 1	14 ± 3	14 ± 2	13 ± 1	13 ± 3	0 ± 2	0 ± 1	0 ± 2

Abbreviation: T_{re}; rectal temperature, HR; heart rate, RPE; rating of perceived exertion, TS; thermal sensation, TC; thermal comfort. * represent a significant (p <0.05) within-group (young and elderly) difference post heat acclimation. † represents a significant (p <0.05) between- group (young and elderly) difference. # represent a significant (p <0.05) between and within-group (young and elderly) difference post heat acclimation. § represent a significant (p <0.05) within-group (elderly and elderly novel) difference post heat acclimation.

7.5. Discussion

7.5.1. Physiological findings

This is the first study to use a modified isothermic STHA protocol with the elderly for 5 consecutive days and compare adaptations to a young group completing the same protocol. Additionally, it is also the first study to use a novel STHA approach, in which participants cycled in thermoneutral conditions, then completed passive hot water immersion (40°C), before being wrapped in blankets, in a novel combination to elicit phenotypic heat adaptation.

The main findings from this study were that the young and elderly isothermic groups and the novel elderly group developed some but not all meaningful adaptations following HA as defined by the predefined analytical limits for meaningful adaptation; ΔT_{re} >0.20°C, ΔHR > -5 b.min^{-1} ΔWBSR >0.2L.h^{-1}, ΔPV >5% and >1 in perceptual scales (RPE, TS and TC) (Willmott *et al.,* 2016).

A reduction in rectal temperature is a pertinent adaptation to the heat as it may lead to the reduction in the number of heat illnesses (Armstrong & Maresh, 1991; Gosling *et al.*, 2008; Périard *et al.*, 2015; Racinais *et al.*, 2015; Minett *et al.*, 2016). A meaningful reduction, amongst the young, in resting and exercise T_{re} is a reported >0.20°C; with adaptations ranging -0.1 to - 0.5°C, post heat acclimation (Tyler *et al.,* 2016). Resting T_{re} from day 1 to day 5 of heat acclimation in this study (*i.e.,* 4 consecutive days of HA) decreased meaningfully in both elderly groups; isothermic (-0.28 ± 0.26°C, *d* = 0.64) and novel (-0.33 ± 0.35°C, *d* = 1.10). This data suggests that the modified isothermic and the novel protocols were of sufficient physiological and thermal strain to elicit central thermoregulatory adaptations via a decrease in resting T_{re} after 4 days of heat stress. The young participants' resting T_{re} was unchanged (-0.04 ± 0.32°C, *d* = 0.11) from day 1 to day 5 of HA, indicating insufficient thermal strain after 4 days of modified isothermic HA. It is perhaps unsurprising that the young observed no change in resting T_{re}, as previous HA research by Petersen *et al.,* (2010) also found no change in T_{re} after 4 days of HA, albeit with a high intensity exercise protocol rather than modified isothermic HA protocol.

Resting and peak T_{re} from the pre-to-post HA test resulted in no meaningful adaptation across all groups: young isothermic (resting T_{re}; -0.05 ± 0.34°C, *d* = 0.13, peak T_{re}; 0.03 ± 0.20°C, *d* = 0.13), elderly isothermic (resting T_{re}; 0.08 ± 0.23°C, *d* = -0.15, peak T_{re}; 0.09 ± 0.22°C, *d* = -0.21) and elderly novel (resting T_{re}; -0.12 ± 0.24°C, *d* = 0.40, peak T_{re}; -0.04 ± 0.22°C, *d* = 0.12). Despite no meaningful changes in all groups for resting and peak T_{re} from pre-to-post HA, there was a meaningful adaptation in ΔT_{re} during the activities of daily living exercise, from pre-to-post HA, for the elderly modified isothermic group (-0.22 ± 0.20°C, *d* = 1.63). Due to no change in resting and peak T_{re}, the meaningful change in ΔT_{re} was likely the result of a slower rate in rise of core temperature during activities of daily living exercise in the post heat acclimation test. This adaptation was not matched in the young (+0.05 ± 0.11°C, *d* = -0.32) nor the elderly novel (+0.02 ± 0.36°C *d* = -0.05) groups (Table 7.3).

The slower increase in T_{re} could be explained by the elderly modified isothermic group all having an increase in WBSR, with a large effect size (+0.18 ± 0.11 L.h^{-1}, *d* = -1.32) that was not matched in the young (-0.04 ± 0.48 L.h^{-1}, *d* = 0.11) nor elderly novel (-0.10 ± 0.41 L.h^{-1}, *d* = 0.25) groups. The increase in WBSR is an indication of a greater heat loss efficiency as evaporation of sweat is the mechanism for greatest excess heat loss (Sawka *et al.,* 2011; Taylor, 2014a; Tansey & Johnson, 2015). The adaptations in sweat rate for the elderly modified isothermic group could have developed centrally with a decrease in individual sweating thresholds (*i.e.,* lower rectal temperature at the point of sweating) or peripherally, with an increase in eccrine sweat gland activity (Sato & Sato 1983; Sato *et al.,* 1990; Shibasaki *et al.,* 2006; Périard *et al.,* 2015), or both centrally and peripherally. The greater heat loss through evaporation in the elderly modified isothermic group could have resulted in a slow rise in core temperature because there was less heat being stored.

The differences in WBSR between the elderly groups could be explained by the differences in the HA stimulus. The modified isothermic elderly group completed exercise-heat stress in a humid environment, thus providing a stimulus to the eccrine glands to lose excess heat. Therefore, there are possible peripheral changes to the eccrine glands with increased sensitivity and size. Whereas sweat evaporation was prevented over the majority of the skin surface area during hot water immersion, therefore eccrine glands are less likely to be stimulated enough to develop peripheral adaptations.

As well as improvements to T_{re} and WBSR, cardiovascular strain is typically reduced on completion of heat acclimation and are the first adaptations to develop (Sawka *et al.,* 1983; Périard *et al.,* 2015). Cardiovascular adaptations are significant for the prevention of severe illness during periods of hot weather as the primary course of all excess mortality during periods of hot weather is an underlining cardiovascular problem (Kenney *et al.,* 2014). In a young population, a meaningful adaptation in plasma volume expansion is >5% and a meaningful decrease in resting and exercise HR is > 5 b.min^{-1} (Taylor, 2014a; Périard *et al.,* 2015; Tyler *et al.*, 2016; Willmott *et al.,* 2016). Plasma volume expansion can develop in the first 2-6 days of heat exposure (Sawka *et al.,* 1983; Périard *et al.,* 2015). The increase in plasma volume allows for greater cardiovascular stability during heat stress as stroke volume and cardiac output can be maintained whilst the body sweats to evaporate excess heat. In this study, plasma volume changes were not meaningful in young (+3.7%), elderly

(+4.1%) nor elderly novel (+0.1%) groups (Table 7.3). However, 6 of 10 young participants had a plasma volume expansion >5% and 8 out of 10 had a positive increase in plasma volume. This superior cardiovascular stability was evident in the young group's resting and exercise HR changes post HA. The young had a decrease in their pre-to-post HA resting HR (-11 ± 8 $b.min^{-1}$) and peak HR (-6 ± 10 $b.min^{-1}$). The adaptations in resting and exercise HR in the young are similar to that found in a meta-analysis of heat adaptations utilising STHA methods (-5 ± 1 $b.min^{-1}$, N = 60) (Tyler *et al.,* 2016). The elderly modified isothermic group had a similar plasma volume expansion compared to the young (elderly +4.1% *vs.* young +3.7%) with only 3 of 6 (some participants opted not to have their blood taken) having a plasma volume expansion >5%. However, the elderly group did not have the same meaningful differences in their pre-to-post HA, resting HR (+2 ± 5 $b.min^{-1}$) and peak HR (0 ± 5 $b.min^{-1}$). The elderly novel group had no participants with a plasma volume expansion >5% and similar to the modified isothermic group, found no adaptation in their resting HR (+4 ± 5 $b.min^{-1}$). However, there was -4 ± 5 $b.min^{-1}$ decrease in the novel elderly group's peak HR.

Improvements in cardiovascular stability may also be developed through central changes to the heart, as well as increases in plasma volume (Garrett *et al.,* 2009; Garrett *et al.,* 2011; Periard *et al.,* 2016). Garrett *et al.,* (2009) found a significant decrease in exercise cardiac frequency (*i.e.,* increased cardiovascular stability) without a subsequent significant increase in plasma volume expansion (+4.2%). The changes in exercise cardiac frequency were explained by possible increases in ventricular contractility, that has been evident in rats (Horowitz & Meiri, 1993). The extent of central cardiovascular adaptations to the heat in humans is currently unknown, due to to invasive nature of measurements (Garrett *et al.,* 2009; Garrett *et al.,* 2011; Periard *et al.,* 2016). Therefore, it is plausible that there are are age-related differences in central cardiovascular adaptations to the heat. Especially as this study found differences in cardiovascular adaptations between young and elderly in the modified isothermic group.

The differences within the groups for T_{re} and HR can partially be explained by research design. Participants completed their second post-test (*i.e.,* the test used for pre-to-post analysis) five days after the last HA session. This was designed to allow for rest days, accounting for participant fatigue and to be able to re-prescribe exercise intensity. The process of re-prescribing exercise intensity for HA studies is considered good scientific practice (Patterson *et al.,* 2014). The re-prescription of exercise intensity allows the researcher to make greater inferences as to the magnitude of adaptations gained in the heat acclimation protocol, thereby separating training status from acclimation status. This is because when exercise intensity is not re-prescribed the differences in physiological markers pre-to-post HA could be the result of greater fitness gained during intense exercise every day during HA rather than an adaptation to the environment per se. However, in this study the delay between post HA and the second post test (5 days) could have resulted in the diminishing of heat adaptations gained. Heat acclimation decay research suggests that for every day away from heat exposure there is a decrease in physiological adaptations, with a 2.6% decrease in core temperature adaptation and a 2.3% decrease in HR adaptation (Daanen *et al.,* 2017). The data from this study supports a decay in HA adaptation in the elderly groups because resting T_{re} and HR from day 1 to day 5 of HA had a greater adaptive response compared to pre-to-post HA data (activities of daily living protocol). The elderly modified isothermic group had a meaningful decrease in resting T_{re} of -0.28 ± 0.26°C from day 1 to day 5 of HA, whereas in the pre-to-post HA testing there was no change in the elderly modified isothermic group's resting T_{re} (+0.08 ± 0.23°C). Likewise, the elderly novel group had a meaningful decrease in resting T_{re} of -0.33 ± 0.35°C from day 1 to day 5 of HA, and only a decrease of -0.12 ± 0.24°C in the pre-to-post test data. There was no adaptive response or difference between the elderly modified isothermic group resting HR data from day 1 to day 5 of HA to pre-to-post data, -1 ± 10 $b.min^{-1}$ and 2 ± 5 $b.min^{-1}$. However, the elderly novel group did have an adaptive response from day 1 to day 5 of HA in resting HR of -8 ± 10 $b.min^{-1}$, which diminished in the pre-to-post testing to -4 ± 5 $b.min^{-1}$. Therefore, in the elderly groups the data from day 1 to day 5 of HA that represents 4 consecutive days of HA may give a greater indication of adaptation than the data from pre-to-post HA. This differing response between day 1 vs day 5 HA and pre-to-post HA, has implications towards how future heat acclimation studies using an elderly population are designed.

Although, HA decay may explain decreases in adaptive responses in T_{re} in the elderly modified isothermic and the novel groups, and resting HR responses in the elderly novel group, it does not explain the young participants T_{re} and HR responses. An insufficient magnitude of HA stimulus could explain why there was no change in T_{re} either from day 1 to day 5 or pre-to-post HA. It is widely accepted that a consistent thermal strain ($T_{re} >$ 38.5°C) across heat acclimation days for a sustained period of time on each day (~60-min) develops phenotypic adaptations to the heat (Gibson *et al.,* 2015ab; Tyler *et al.,* 2016; Willmott *et al.,* 2016; James *et al.,* 2017). In this study, the classic isothermic method of a $T_{re} >$ 38.5°C was modified to ensure the safety of the elderly participants. Some participants arrived for testing with a resting $T_{re} <$ 36.5°C and therefore could not increase $T_{re} >$ 38.5°C because of a safety limit of a Δ 2°C in our laboratories. An additional criterion for both groups of $T_{re} > \Delta 1.5$°C from resting was subsequently implemented based on previous isothermic HA research with young participants requiring an average change of 1.46°C to achieve an absolute T_c of 38.5°C (Daanen *et al.,* 2014; Gibson *et al.*, 2015ab; Mee *et al.,* 2015, James *et al.,* 2017; Willmott *et al.,* 2018). However, having the two-criterion resulted in some people having a $T_{re} > \Delta 1.5$°C on some days and an absolute $T_{re} >$38.5°C on other days, leading to inconsistency in the method of thermal strain. This is evidenced by the time spent T_{re} >38.5°C and T_{re} >Δ1.5°C across heat acclimation (Table 7.2). By day 5 of heat acclimation the young spent 31 ± 30-min with T_{re} >38.5°C and 58 ± 19-min with T_{re} >Δ1.5°C; a decrease of -10 ± 42-min and an increase of 4 ± 28-min from day 1. Similarly, by day 5 of heat acclimation the elderly spent 4.3 ± 9.3-min with T_{re} >38.5°C and 20 ± 24-min with T_{re} >Δ1.5°C; a decrease of -19 ± 28-min and an increase of 15 ± 27-min from day 1. The inconsistency in level of thermal strain and time spent T_{re} >38.5°C and >Δ1.5°C < 60-min across heat acclimation days, could have attributed to the minimal meaningful phenotypic adaptations. This is because to optimise adaptation to the heat a sufficient exercise-heat stress is required to initiate an imbalance in thermal homeostasis (Taylor *et al.,* 2014a). Then the exercise-heat stress needs to be maintained over a sufficient amount of time (*i.e.,* current HA research suggests 5 days, Tyler, *et al.,* 2016), If not then adaptations will plateau (Taylor *et al.,* 2014a).

The process of optimising adaptation can also explain the lack of HR decrease in the elderly compared to the young group. As a safety measure, elderly participants had an upper limit of cardiovascular stress of 90% of age predicted HR_{max} (Leon *et al.,* 2013). However, using a % HR_{max} becomes less accurate for the use of elderly people as their actual HR maximum is higher (Tanaka *et al.,* 2011). Therefore, although HR data expressed as $\%HR_{max}$ highlights that the young and elderly groups had a similar cardiovascular strain during the HA sessions, the young could have been under more stress then the elderly. Consequently, the cardiovascular stress in the HA for the elderly groups may have been insufficient to develop cardiovascular adaptations such as HR and plasma volume expansion.

Alternatively, the time-course of adaptation could be different between the young and elderly. Although, cardiovascular adaptations are the first to develop in a young population (Sawka *et al.,* 2011; Périard *et al.,* 2015), there is insufficient evidence to suggest the same for the elderly. In this study greater adaptation were evident in T_{re} compared to cardiovascular adaptations, after 4 days of HA in both elderly groups. Furthermore, the magnitude of adaptation potential could differ between the young and elderly. This study used Willmott *et al's,* (2016) predefined analytical limits for meaningful adaptation (ΔT_{re} >0.20°C, ΔHR >-5 $b.min^{-1}$ ΔWBSR >0.2$L.h^{-1}$, ΔPV >5% and >Δ1 in perceptual scales, RPE, TS and TC). However, it is unknown whether these changes can be considered meaningful for the elderly, for example the WBSR change of 0.18 ± 0.11 $L.h^{-1}$ in the modified isothermic group may be meaningful due to the known age-related deterioration in sweat loss capacity.

7.5.2. Perceptual findings

Heat acclimation also improves participants' perception of the environment in which they can feel the exercise is easier, and the environment is cooler and more comfortable (Neal *et al.,* 2016; Tyler *et al.,* 2016; Willmott *et al.,* 2016). Meaningful changes in these parameters are an improvement of 1 on their respective scales (Willmott *et al.,* 2016, Tyler *et al.,* 2016). RPE improved for young (-2 ± 2), elderly (-1 ± 2) and elderly novel (-1 ± 2) post heat acclimation. Improvements in RPE are associated with a corresponding decrease in cardiovascular and thermal strain during exercise (Armstrong & Maresh, 1991). In this study the young had the greatest improvement in RPE and the greatest decrease in peak HR (-6 ± 10 $b.min^{-1}$) post HA compared to both elderly groups. The improvement in RPE in the young is most likely attributed to the changes in peak HR as there was no difference in peak T_{re} pre-to-post HA (0.03 ± 0.20ºC).

Thermal sensation improvements are associated with decreases in T_{sk} (Flouris & Schlader, 2015). This is interesting because the greatest decrease in T_{sk} was in the elderly novel group (-0.28 ± 0.40ºC), unsurprising as maximum T_{sk} was likely achieved during the HWI, therefore provided a constant drive for adaptation (Zurawlew *et al.,* 2016). However, the elderly novel group had the least response in TS improvement (0 ± 0.4), which contrasts Zurawlew *et al.,* (2016) research with a young population as they found a significant improvement in T_{sk} and TS after the completion of temperate exercise and HWI heat acclimation. The lack of improvement in TS could further highlight the reduced perceptual awareness that the elderly could have to the environment as observed in studies 2 (Chapter 5, p124) and 3 (Chapter 6, p139) of this thesis. This is further supported by the young data, that had the least decrease in T_{sk} however, had a significant improvement in TS post HA (-0.4 ± 0.5). Furthermore, TC improved for young (-1 ± 1) and elderly novel (-1 ± 1), but not the elderly modified isothermic group (0 ± 1) post HA. These results indicate that heat acclimation did have the same effect across groups on the perceptual markers of heat strain during exercise with this change being the greatest in the young, possibly due to an age-related reduction in perceptual awareness.

7.5.3. Six-minute walk test

The performance in the 6MWT was improved in all groups; young (4.2 ± 5.3 %), elderly (10.3 ± 9.4 %) and elderly novel (9.9 ± 3.4 %). The increases in all the groups are above the 3.3% CV for a 6MWT when familiarisation trial is given (Kervio *et al.,* 2003). The improvements in the 6MWT for the elderly groups are similar to other exercise intervention studies that used an elderly population, with improvements ranging from 4.6-17.3 % (Mangione *et al.,* 1999; Kolbe-Alexander *et al.,* 2006; Locks *et al.,* 2012). The improvements in the elderly groups in this study were acquired with no significant differences in the physiological (*i.e.,* T_{re} and HR) or perceptual variables (*i.e.,* RPE, TS and TC). This performance adaptation highlights an improvement in functional capacity post heat acclimation. The improvements maybe attributed to the training required to complete heat acclimation and greater fitness gains in the elderly group due to the self-paced requirement of the 6MWT.

7.5.4. Future directions

The future of heat acclimation research with the elderly population should initially investigate the time-course of adaptation in the elderly. This is because the time-course of heat adaptations may differ to a young population, in which Armstrong & Maresh (1991) and more recently, Periard *et al.,* (2015) have summarised. Based upon the data of this research study, it may be possible to heat acclimate the elderly population within 6-8 days, using the proposed novel heat acclimation protocol. Six days of temperate exercise and HWI in young have developed significant phenotypic adaptations (Zurawlew *et al.,* 2016). However, additional days for the elderly may be required to allow for cardiovascular and sweat adaptations to develop, possibly via the increase in exercise intensity over the course of the protocol (*i.e.,* a progressive model). If this type of protocol were able to develop phenotypic adaptations, it could then lead to re-acclimation research with the elderly population. In a young population re-acclimation develops the same or greater magnitude of phenotypic adaptations to the heat when compared to the original heat acclimation (Daanen *et al.,* 2017). Therefore, re-acclimation has the potential to offer a practical chronic heat illness prevention intervention, as elderly people could complete a longer period of acclimation in the spring, and re-acclimate within a few days of the announcement of a heat wave.

7.6. Conclusion

This is the first study to use a modified isothermic short term heat acclimation protocol with the elderly for 5 consecutive days and compare adaptations to a young group completing the same protocol. This study differed from previous age-comparative heat acclimation research by increasing the level of thermal and physiological strain during heat acclimation and by including additional heat acclimation sessions.

The increased physiological strain resulted in some phenotypic heat adaptations in the isothermic HA groups (day 1 to day 5 of HA). The majority of the young (7/11) had a reduction in resting T_{re} and there was a significant reduction in resting HR from the pre-to-post tests for this group. The elderly group all had an increase in WBSR and the majority (6/8) also had a reduction in resting T_{re}. Consequently, this study highlights the possibility for the elderly to adapt physiologically to the heat. However, further research into frequency, intensity and duration of heat acclimation with the elderly, as well as timing of post tests requires further investigation. The additional research is required to prevent a type two error conclusion that the elderly cannot acclimate via modified isothermic heat acclimation.

Furthermore, this study was the first to use a novel short-term heat acclimation approach, in which participants cycled in thermoneutral conditions, completed passive hot water immersion (40°C) and blanket wrapping to elicit phenotypic heat adaptations. This novel approach found meaningful, phenotypic adaptations in resting T_{re} (-0.33 ± 0.35°C) and HR (-8 ± 10 b.min^{-1}) across 4 days of heat acclimation, highlighting the potential for this novel chronic heat acclimation method in becoming a practical heat alleviating strategy for the elderly. In a real-world scenario, the UK public will have up to 5 days to prepare for a heat wave, this study has found that meaningful resting physiological changes can develop within 4 days of completing 30-min of exercise in normothermic conditions, followed by 30-min of passive hot water immersion and ending with a 30-min blanket wrap. These adaptations did partly decay when analysing the pre-to-post HA tests. This highlights the importance of timing of the post HA testing, to avoid HA decay.

To complete HA with the elderly, it is recommended that it is completed with the supervision of a trained individual. This is due to the physiological strain that is required by the participants during these programmes, during the current study three elderly people developed syncope across protocols. Therefore, research with the elderly may be better focused on practical, acute strategies that can be implemented by the target population themselves and immediately. Additionally, research into novel heat acclimation strategies should continue to further our understanding out heat adaptation in older age.

Chapter 8 General discussion

Chapter 8 presents an overview of the aims, hypotheses and key findings of the individual experimental studies within this thesis. It then explains the elderly populations' physiological and perceptual responses to UK summer climatic conditions whilst completing exercise equating to activities of daily living, with and without acute and chronic heat illness prevention strategies. Thirdly, it provides target population specific ideas for research dissemination. It then considers the practicalities of completing research with an elderly population. Finally, it proposes ideas for future research with the aim to prevent heat illness, practically, within the elderly population.

8.1. Thesis findings

Study 1 (Chapter 4, p108) of this thesis investigated the validity and reliability of a new heat illness susceptibility questionnaire (HIS-Q). It was hypothesised that the HIS-Q would demonstrate significant construct validity, via the decrease of heat illness symptoms on completion of a short-term heat acclimation protocol. This hypothesis was accepted as there was a significant decrease in individual HIS-Q scores between session 1 and 10 of heat acclimation. This result indicated that the HIS-Q is a sensitive tool for detecting changes in heat illness symptoms. This study was also the first to use T_{re} as a form of construct validity for the HIS-Q because it is reasonable to expect heat illness scores to increase with $T_{re,}$ as it is a marker of heat illness. This study found no correlation between peak T_{re} and peak HIS-Q scores. Although no correlation was found, it was determined that a reduced range in T_{re} values may explain the lack of correlation. In addition to validity, the HIS-Q was theorised to be reliable during a repeated measures laboratory protocol consisting of acute exercise-heat stress. This was accepted as the HIS-Q's intra-class correlation coefficients (ICC) demonstrated moderate reliability (ICC > 0.5) in accordance with Koo and Li, (2016). Furthermore, across all trials only one point lay outside the LoA (Figure 4.4): HST1 and HST2; ICC = 0.67, mean bias (LoA) = 1.25 (-4.17, 6.67); HST1 and HST3; ICC = 0.55, mean bias (LoA) = 1 (-4.29, 6.29); HST2 and HST3; ICC = 0.67, mean bias (LoA) = -0.25 (-4.99, 4.49). Consequently, the HIS-Q warrants further investigation within field-based events and prolonged exercise-heat stress to promote greater physiological strain across markers that may underpin progression to heat-related illness. Supporting the HIS-Q's validity and reliability across a greater number of heat stress scenarios.

Study 2 (Chapter 5, p124) was the first study in this thesis to use an elderly population. It was also the first study to investigate elderly peoples' physiological and perceptual responses to exercise at different intensities that simulated activities of daily living, across UK summer climatic conditions. It was hypothesised that the elderly would have an increase in thermal and physiological strain with an increase in environmental temperature and exercise intensity. This hypothesis was accepted as thermal and physiological strain markers did significantly increase with environmental temperature and exercise intensity. Peak T_{re} and ΔT_{re} are thermal strain markers that increased with environmental conditions and exercise intensity. Therefore, indicating a thermal strain increase with exercise intensity. However, the second hypothesis that the elderly would feel warmer and more uncomfortable with increases in environmental temperature and exercise intensity was rejected. There was no change in TC ('*just uncomfortable*') and only non-significant changes in RPE (14 ± 2 *vs.* 15 ± 2) and TS (6.0 ± 1.0 *vs.* 6.5 ± 0.5) at 6 MET, 25°C compared to 35°C. Therefore, study 2 demonstrated that the elderly could have a decreased perceptual awareness of environmental temperature increases, due to increases in thermal strain without a concurrent perceptual recognition.

Study 3 (Chapter 6, p139) was the first study in this thesis to investigate a practical heat illness prevention intervention for the elderly population. It was also the first to adapt an acute cold water ingestion protocol, previously used with young participants, for the elderly. The purpose was to investigate the physiological and perceptual responses of elderly people to a physical cooling intervention during exercise simulating moderate activities of daily living in the hottest UK summer climatic conditions. Further, novelty was added to this study by investigating the physiological and perceptual responses to L-menthol, a perceptual cooling substance, in an elderly population for the first time. It was hypothesised that elderly peoples' physiological and perceptual strain would decrease when drinking refrigerated water (4°C) periodically throughout rest and exercise. A secondary hypothesis was that L-menthol would decrease perceptual strain, whilst having no effect on physiological strain. The first and second hypothesis could be partially accepted. Peak T_{re} was significantly lower in the cold water ingestion trial compared to control (-0.34 ± 0.16°C) and L-menthol (-0.36 ± 0.20°C) at the end of the activities of daily living exercise. There was also a trend for end exercise HR to decrease in the cold water ingestion trial compared to control (-7 ± 9 $b.min^{-1}$) and L-menthol (-6 ± 7 $b.min^{-1}$). This is evidence that cold water ingestion reduces physiological strain in the elderly whilst L-menthol has no physiological benefits. Furthermore, there was no difference in end exercise TS and TC between trials. Therefore, there was no perceptual improvements with either cold water ingestion or L-menthol mouth rinse. Consequently, study 3 demonstrates that physiological strain can be reduced in the elderly when periodically drinking cold water (4°C) during rest and activities of daily living, whilst data suggests no perceptual cooling benefit of L-menthol for the elderly population.

Study 4 (Chapter 7, p167) was the first study in this thesis to investigate a chronic heat illness prevention intervention for the elderly population. As well as investigating a modified isothermic heat acclimation with the young and elderly, the study also investigated a novel temperate exercise-hot water immersion heat acclimation protocol with the elderly. The purpose was to investigate the phenotypic adaptations to the different heat acclimation protocols. It was hypothesised that the elderly and young would have similar magnitudes of adaptation to the modified isothermic protocol. Furthermore, that the hot water immersion STHA would elicit phenotypic responses to the heat. One of the main findings from the study was; that the young and elderly modified isothermic groups did not have the same magnitude of adaptation when analysing the pre-to-post heat acclimation tests, which included exercising at a moderate activity of daily living (*i.e.,* 6 METs). The young had a significant decrease in resting HR (-11 ± 8 b.min^{-1}) as well as a meaningful decrease in peak HR (-6 ± 10 b.min^{-1}) from their pre-to-post STHA testing, that was not matched in the elderly modified isothermic group. Furthermore, all elderly participants in the modified isothermic group had an increase in WBSR that was not matched in the young group. Moreover, the greater adaptation response for the elderly participants was evident across the 4 days of heat acclimation, compared to the pre-to-post STHA testing. The novel heat acclimation approach found meaningful, phenotypic adaptations in resting T_{re} (-0.33 ± 0.35°C) and HR (-8 ± 10 b.min^{-1}) across 4 days of heat acclimation. Additionally, the modified isothermic elderly group approach found meaningful, phenotypic adaptations in resting T_{re} (-0.28 ± 0.26°C), but not resting HR (-1 ± 10 b.min^{-1}) across 4 days of heat acclimation. These adaptations may have decayed due to the inclusion of rest days to account for participant fatigue. Furthermore, the re-prescription of the exercise intensity, that equates to moderate activities of daily living (*i.e.,* 6 METs), whilst providing greater methodological accuracy may have reduced the observed changes within the exercise data pre-to-post STHA. Therefore, study 4 suggests an age-related time-course difference during modified isothermic heat acclimation. Further age-related research to investigate the time-course of elderly adaptation through this method is warranted along with the time-course of adaptation decay. Additionally, the study demonstrated that phenotypic adaptation can develop in the elderly using a novel STHA approach which involves; exercising in thermoneutral condition, followed by hot water bathing (40°C), followed by blanket wrapping. This method may offer a more palatable form of chronic heat adaptation for the elderly and warrants further research into its optimisation.

A summary of the hypothesis and if they were accepted or rejected is displayed in table 8.1.

Table 8.1: Outcomes of the thesis hypotheses.

Hypotheses	Accept	Reject
Study 1: The validity and reliability of a new heat illness susceptibility questionnaire (HIS-Q)		
The HIS-Q would demonstrate significant construct validity, via the decrease in individual HIS-Q scores on completion of a short-term heat acclimation protocol.	✓	
The HIS-Q would demonstrate reliability during a repeated measures laboratory protocol consisting of exercise-heat stress.	✓	
Study 2: Elderly peoples' physiological and perceptual responses to exercise at different intensities that simulated activities of daily living, across UK summer climatic conditions		
The elderly would have an increase in physiological and thermal strain with an increase in environmental temperature and exercise intensity.	✓	
The elderly would feel warmer and more uncomfortable with increases in environmental temperature and exercise intensity.		✓
Study 3: Elderly peoples' physiological and perceptual responses to physical and perceptual cooling during simulated activities of daily living in UK summer climatic conditions		
Elderly peoples' physiological strain would decrease when drinking cold water (4°C) periodically throughout rest and exercise.	✓	
Elderly peoples' perceptual strain would decrease when drinking refrigerated water periodically throughout rest and exercise.		✓
Elderly peoples' physiological strain would not decrease when completing an L-menthol mouth rinse.	✓	
Elderly peoples' perceptual strain would decrease when completing an L-menthol mouth rinse.		✓

Study 4: Age-related phenotypic responses to isothermic heat acclimation, and a comparison of phenotypic response between elderly groups completing either isothermic or novel heat acclimation	
The elderly and young would have similar magnitude of phenotypic adaptations to the modified isothermic protocol in the pre-to-post heat acclimation tests.	✓
The novel short-term heat acclimation would elicit phenotypic adaptive response to the heat in the pre-to-post heat acclimation tests.	✓

8.2. The UK's elderly population and summer climatic conditions

To the researcher's knowledge, prior to the research completed within this thesis, there had been no specific investigations into how elderly people, within the UK, physiologically and perceptually respond during rest and exercise equating to activities of daily living in UK summer climatic conditions. This is surprising as the UK's elderly population is growing (Office of National Statistics, 2014; National Institutes of Health, 2016; Office of National Statistics, 2017) and there is an increasingly warmer climate, leading to a greater severity, intensity and frequency of hot weather days and heatwaves, globally and within the UK (Perkins *et al.,* 2012; Kenney *et al.,* 2014; Arbuthnott *et al.,* 2016; Mora *et al.,* 2017; Sanderson *et al.,* 2017). Furthermore, there is a wealth of research that has found that the elderly are at a physiological disadvantage in dissipating excess heat, compared to the young during rest and exercise-heat stress (Inoue *et al.* 1996; Kenney & Munce, 2003; Larose *et al.,* 2013ab; Kenney *et al.,* 2014; Stapleton *et al.,* 2014abc; Kenny *et al.,* 2016). The reduced age-related capacity to thermoregulate is due to an attenuated reflex response, reduced redirection of blood flow to the skin, decreased cardiac output, deterioration of the cutaneous blood vessels and reduced sweat rate (Kenney & Munce, 2003; Kenney *et al.,* 2014). Consequently, the elderly are at a greater risk of severe heat illness and the current advice given to the elderly by Public Health England is to not complete exercise during periods of hot weather (PHE, 2015). Whilst this advice will reduce metabolic heat production and therefore heat balance can be better maintained, there are potential negative consequences for the elderly population if they do not maintain physically active lifestyles. These consequences include an increased risk of: type 2 diabetes, heart disease, several types of cancer and stroke, obesity, contribution to poor mental health, increase frailty and increase social isolation (Scarborough *et al.,* 2011; Kohl *et al.,* 2012; PHE, 2016). Furthermore, it has been suggested that by choosing to not challenge our bodies to stress (*e.g.,* physically and environmentally) that the physiological capacity to maintain thermal homeostasis decreases, as people of all ages and genders become increasingly more reliant on heat-alleviating strategies (Tipton, 2018). Therefore, it is plausible to suggest that by not exposing the elderly to exercise-heat stress there will be a further augmentation to their already reduced capacity to themoregulate.

To that end, this thesis aimed to provide specific research informed advice for the elderly for them to be able to maintain safe and effective exercise during periods of hot weather in the UK. Firstly, it was imperative to understand how the elderly physiologically and perceptually responded during activities of daily living across UK summer climatic conditions. Thereafter, to investigate elderly specific practical acute and chronic heat illness prevention strategies that allow the maintenance of activities of daily living. Furthermore, to present the research outcomes to Public Health England to influence their *'Beat the heat'* campaign, ensuring the research in this thesis impacts the target population (*i.e.,*. the elderly population).

8.2.1. The physiological and perceptual responses of the elderly during rest and activities of daily living in UK summer climatic conditions

Study 2 (Chapter 5, p124) investigated the physiological and perceptual responses of the elderly to exercise equating to different activities of daily living in UK summer climatic conditions. The exercise intensities equated to light house hold chores (2 MET), gardening activity (4 MET) and moderate aerobic exercise (*i.e.,* dancing brisk walking, 6 MET), whilst environmental temperatures were 15°C (average summer temperature in the UK), 25°C and 35°C (highest average recorded temperature in the UK).

The elderly's physiological responses to an increase in environmental temperature were similar to the thermoregulatory model by Flouris & Schlader (2015) for young adults (Figure 8.1). The elderly responded to an increase in environmental temperature with an increases in T_{sk} (Figure 8.2). Skin temperature increases with SkBF, a mechanism that deteriorates with advanced age (Martin *et al.,* 1995; Holowatz *et al.,* 2010; Holowatz & Kenney, 2010). Age-related decrease in maximum SkBF are due to; structural deteriorations in the blood vessels, a reduced redirection of blood flow to the skin and a reduction in vasodilation (Holowatz & Kenney, 2010; Kenney *et al.,* 2014). Study 2 found that peak and change in T_{sk} significantly increased between 15-35°C and 25-35°C in all exercise conditions. One example is during the 6 MET trials, in 15°C and 35°C; peak T_{sk} was 29.06 ± 1.37°C compared to 36.11 ± 0.44°C and ΔT_{sk} 0.59 ± 0.74°C compared to 1.27 ± 0.73°C. Therefore, study 2 showed that the elderly can periodically increase skin temperature with increases in UK summer climatic conditions, when exercising at an intensity that equates to different activities of daily living for 30-min. This is despite having a known deterioration in maximum SkBF.

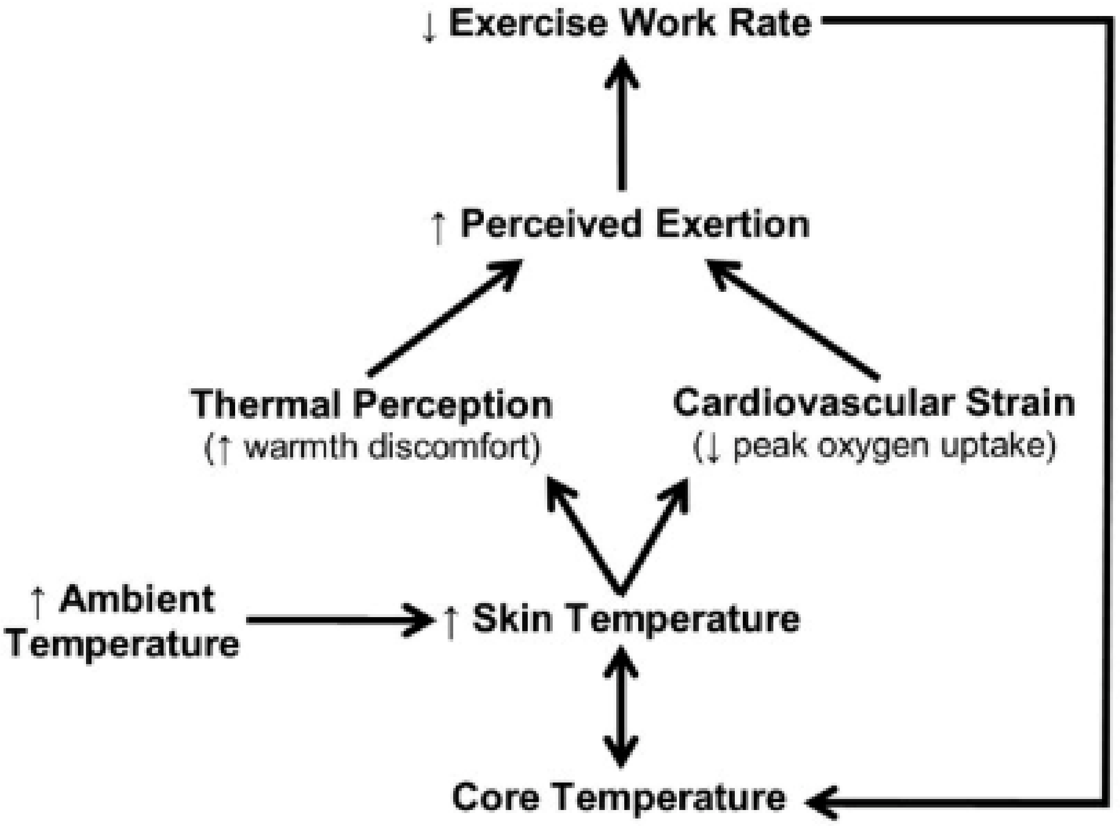


Figure 8.1: Factors that influence behavioural thermoregulation during exercise in the young (Flouris & Schlader, 2015).

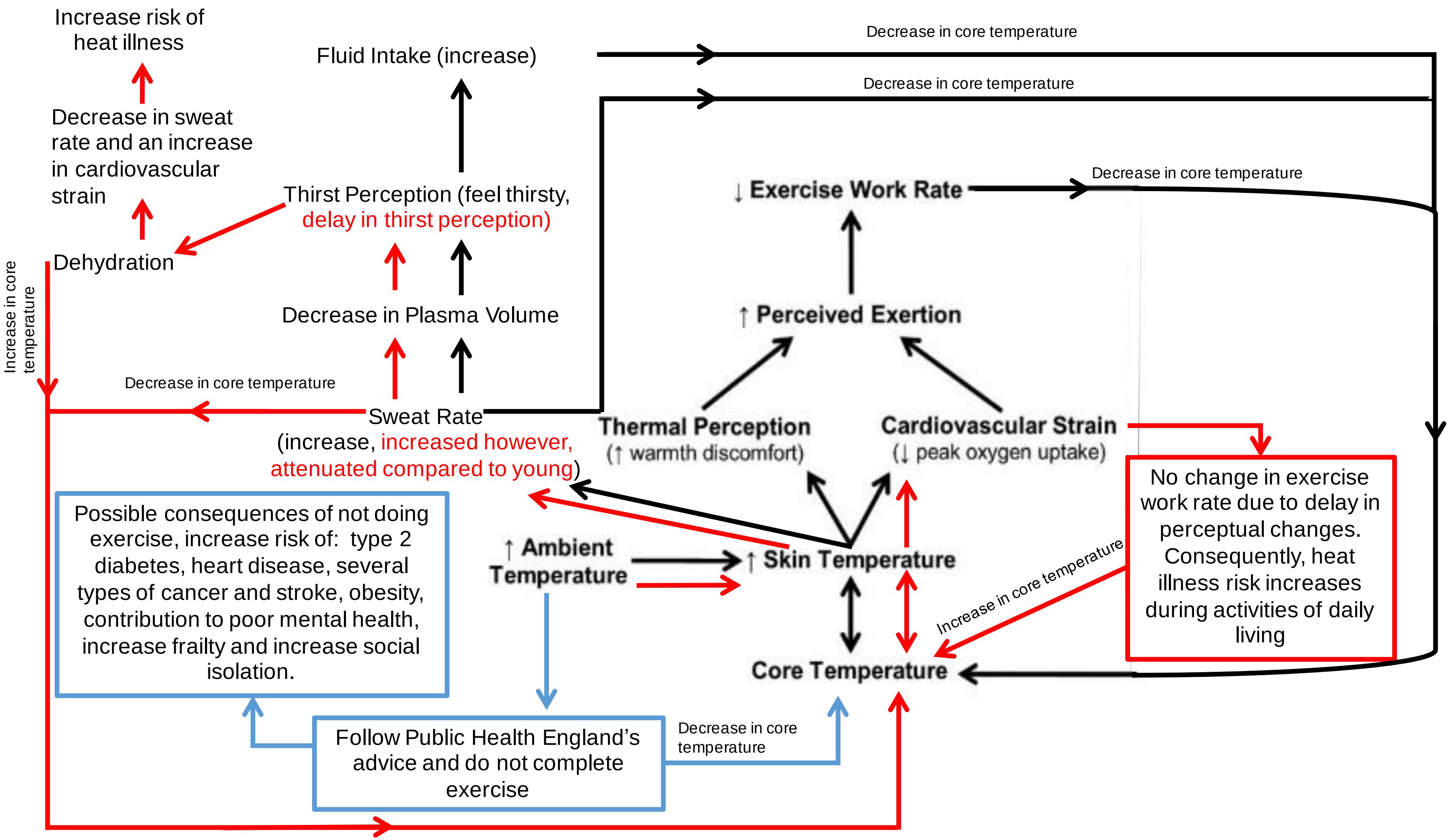


Figure 8.2: Factors that influence behavioural thermoregulation during exercise in the young and elderly. The black arrows represent the physiological and perceptual responses of the young and is the model from Flouris & Schlader (2015), with the addition of sweat rate. The red arrows and boxes represent the proposed model of the physiological and perceptual responses of the elderly based on findings from study 2 (Chapter 5, p124) and the effects of L-menthol in study 3 (Chapter 6, p139). The light blue arrows and boxes represent the effects of following the current advice from Public Health England.

An increase in SkBF leads to increases in radiative and evaporative heat loss at the skin, this being part of the autonomic thermoregulation to maintain a heat balance (*i.e.,* a normal core temperature) (Parsons, 2014). Evaporation is the most effective mechanism for excess heat loss in humans (Sawka *et al.,* 2011; Taylor, 2014a) and as well as having a known deterioration in SkBF amongst the elderly, there are age-related decrease in sweat gland output (Inoue *et al.,* 1996; Kenney & Munce, 2003; Balmain *et al.,* 2018). Consequently, the elderly will store greater amounts of heat (Stapleton *et al.,* 2014b). Study 2 found only a significant increase in WBSR between 15-35°C trials; for example at 2 METs, 15°C trial WBSR was 0.21 ± 0.14 $L.h^{-1}$ and at 35°C WBSR was 0.41 ± 0.37 $L.h^{-1}$. Although there are age-related deteriorations in autonomic thermogulation, in study 2 these deteriorations did not result in significant increases in peak T_{re} when environmental temperature was increased. At 4 MET, 15°C peak T_{re} was 37.28 ± 0.26°C, while at 35°C peak T_{re} was 37.41 ± 0.36°C. This highlights that the elderly are able to maintain a heat balance during UK summer climatic conditions whilst completing activities of daily living for 30-min.

According to Flouris & Schlader's (2015) model of behavioural thermoregulation increases in core and skin temperature lead to an increase in cardiovascular strain (Figure 8.1). Study 2 found no statistical difference in HR (*i.e.,* a marker of cardiovascular strain) with an increase in environmental temperature. However, in the 6 MET trial, in 25°C peak HR was 110 ± 18 $b.min^{-1}$ compared to 118 ± 23 $b.min^{-1}$ in 35°C, which is a 7.3% increase. Therefore, although not statistically significant this would constitute a meaningful increase in cardiovascular strain with an increase in environmental temperature (Figure 8.2).

Study 2 has shown that the elderly have similar physiological responses to an increase in environmental temperature that Flouris & Schlader (2015) would expect in a young population (Figure 8.1). However, perceptually there maybe differences between young and elderly adults. The purpose of the Flouris & Schlader (2015) model was to depict the role of perception on regulating exercise work rate (*i.e.,* thermoregulatory behaviour). In the young, when T_{sk} increases, there is a subsequent increase in cardiovascular strain and an increase in thermal discomfort (Figure 8.1). The increases in cardiovascular strain and thermal discomfort drive the thermoregulatory behaviour through an increase in the perception of effort. Exercise work rate is decreased, leading to a reduction in metabolic heat production and consequently, T_c. Study 2 found no statistical differences in TC with an increase in environment temperature, additionally there was no change in TC in the elderly during the 6 MET trial, in 25°C and 35°C; peak TC was 3 ± 1 (*just uncomfortable*). Furthermore, study 2 found no change in RPE between 15°C and 25°C at 6 METs (14 ± 1) and only non-significant increase to 15 ± 1 in the 35°C trial. This further indicates a possible decrease in perceptual awareness of the elderly population.

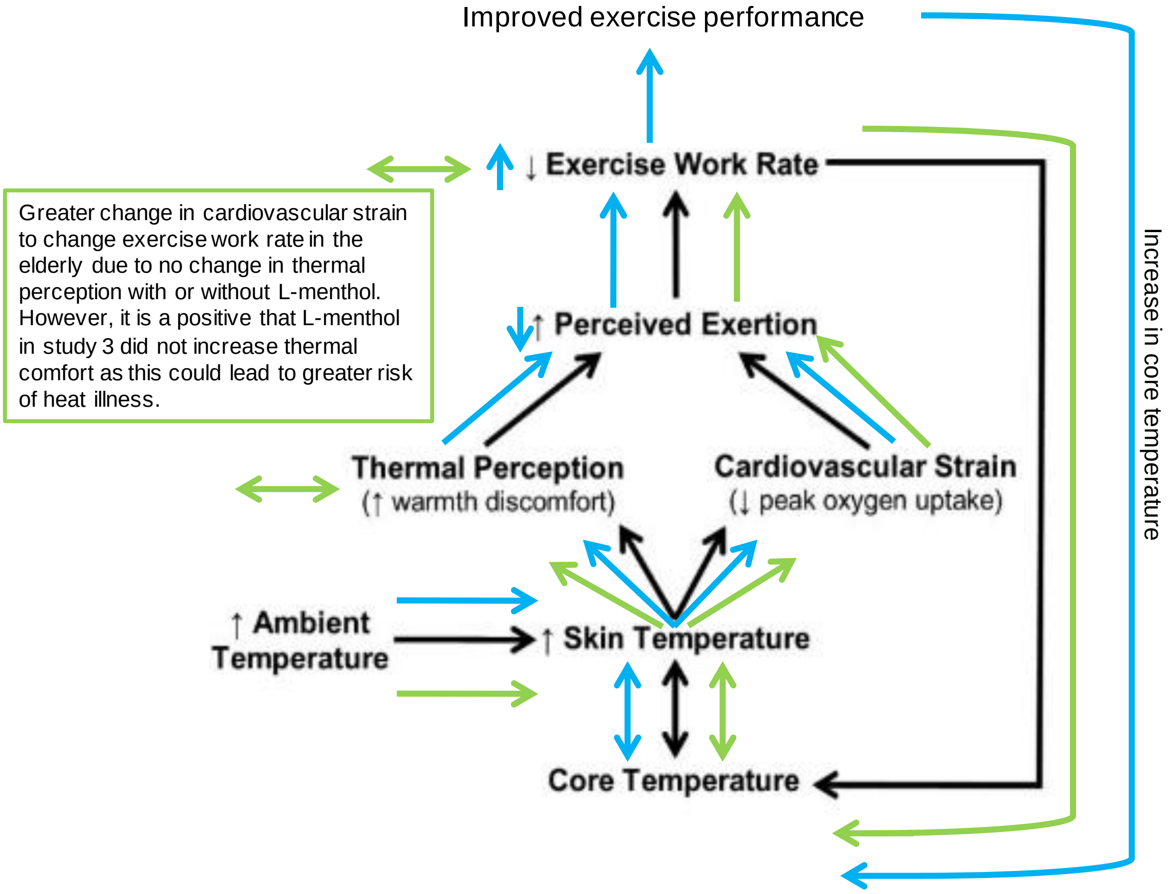
Figure 8.2 represents the physiologically and perceptually response of the elderly to increases in environmental temperatures, adapting the thermoregulatory model of Flouris & Schlader (2015) from young individuals using the data from study 2. Figure 8.2 depicts how physiological markers of heat strain are increasing, however, the data suggests a possible delay in the elderly's perceptual responses to increasing environmental temperature. Although, this delay did not result in hyperthermia in the elderly during study 2, it could have greater consequences during sustained heat stress and exercise-heat stress. Hot weather days and heatwaves are sustained periods of heat stress and the elderly store greater amounts of heat compared to young adults due to their reduced physiological capacity to lose excess heat via convection and evaporation (Kenney & Munce, 2003; Kenney *et al.,* 2014; Notley *et al.,* 2018b). Furthermore, study 2 suggests that the elderly are at further risk of heat accumulation as they do not have an increase in thermal discomfort with a significant increase in peak T_{sk} and ΔT_{sk}, that is present in the young population (Figure 8.2). Consequently, the elderly could be unknowingly putting themselves at risk of severe heat illness because they do not feel uncomfortable enough to implement thermoregulatory behaviours. Additionally, figure 8.2 includes PHE's current advice for avoiding heat illness and the potential long-term effects of following such advice.

.8.2.2. Physiological and perceptual responses to acute physical and perceptual cooling in the elderly

Study 3 (Chapter 6, p139) investigated the physiological and perceptual responses of the elderly, to physical and perceptual cooling in the hottest UK summer climatic conditions whilst at rest, exercising at an intensity equating to moderate activities of daily living and a 6MWT.

The purpose of study 3 was to provide evidence of a practical cooling strategy for the elderly population that would decrease the thermal strain of the environment, whilst maintaining hydration. Hydration was considered important due to the age-related differences in the perception of thirst (Figure 8.2). Figure 8.2 includes an addition for the role of sweat rate and maintaining hydration in the young to the Flouris & Schlader (2015) thermoregulatory model. It illustrates that an increase in T_{sk} and $T_{c,}$ leads to increase in sweat rate (for evaporative heat loss). Consequently, plasma volume will decrease leading to a decrease in pressure detection by the baroreceptor and an increase in the sensation of thirst (Kenney & Chiu, 2001). The thirst sensation drives the behaviour to seek fluids to maintain hydration (Kenney & Chiu, 2001). Hydration effects T_c whereby, if a person is dehydrated their T_c will rise (Kenney & Chiu, 2001; Sawka *et al.,* 2007; Cheuvront & Kenefick, 2014). Previous research evidence has shown that the elderly do not respond to the decrease in pressure in the baroreceptors, as a result of the decrease in plasma volume, with an increase in thirst sensation (Stachenfeld *et al.,* 1997). Consequently, the elderly do not feel thirsty and do not seek fluid ingestion, leading to dehydration and increase risk of severe heat-related illness.

Study 3 also investigated the perceptual effects of L-menthol on an elderly population. Figure 8.3 depicts the effects L-menthol can have on thermal perception and subsequent RPE and exercise work rate, in a young and elderly population. The figure highlights that a decrease in thermal perception via the application of L-menthol can result in no change in RPE and exercise work rate, a benefit for exercise performance despite an increase in $T_{c,}$ due to no change in metabolic heat production. Figure 8.3 also highlights that L-menthol had no effect on the elderly’s thermal perception in study 3. To the researcher’s knowledge prior to study 3, no research had investigated the perceptual and physiological effects of L-menthol on an elderly population.



Greater change in cardiovascular strain to change exercise work rate in the elderly due to no change in thermal perception with or without L-menthol. However, it is a positive that L-menthol in study 3 did not increase thermal comfort as this could lead to greater risk of heat illness.

Figure 8.3: Factors that influence behavioural thermoregulation during exercise in the young with (blue, evidence from Gillis *et al.,* 2010; Schlader *et al.,* 2011; Lee *et al.,* 2012; Gillis *et al.,* 2016) and without (black, Flouris & Schlader, 2015) L-menthol. The green represents no change in thermal perception in the elderly population (Study 3, p139).

Cold water ingestion had the hypothesised physiological benefits of a decrease in HR and T_{re}, in the elderly. Heart rate tended to be lower in the cold water ingestion compared to the control, (-7 ± 9 $b.min^{-1}$) and L-menthol (-6 ± 7 $b.min^{-1}$), albeit not significantly but was a similar reduction compared to previous research using cold water ingestion with young adults (5 $b.min^{-1}$, Mündel *et al.,* 2006) (Figure 8.4). The reduction in cardiovascular strain is likely due to increase in plasma volume with the increased fluid intake compared to the other trials. Rectal temperature significantly decreased compared to control (-0.34 ± 0.16°C) and L-menthol (-0.36 ± 0.20°C) at the end of the activities of daily living exercise (Figure 8.4). Although not significant a meaningful decrease was also evident at the end of the 6MWT compared to control (-0.21 ± 0.24°C) and L-menthol (-0.23 ± 0.34°C). The decrease in T_{re} was a result of heat energy transfer from the warmer body temperature to the cold fluid.

There were no differences in T_{sk} between control (36.04 ± 0.70°C), L-menthol (35.99 ± 0.58) and cold water ingestion (36.21 ± 0.30°C) trials and additionally, there was no difference to the 6 MET, 35°C trial completed in study 2 (36.11 ± 0.44°C) (Figure 8.4). Changes in T_{sk} as a result of drinking cold fluid/ice slurry has varied in the literature with new evidence suggesting that there are abdominal thermoreceptors that independently effect thermoregulation (Jay & Morris, 2018). This theory may explain why in this study there was no change in T_{sk} with a decrease in WBSR in the cold water ingestion trial of -0.33 ± 0.28 $L.h^{-1}$ and -0.18 ± 0.24 $L.h^{-1}$ compared to the control and L-menthol.

Study 3 also investigated the perceptual responses during rest and exercise. L-menthol was used to investigate a potential perceptual cooling effect on the TRM8 receptors. L-menthol did not elicit a change in the TRM8 receptors within the oral cavity that was perceived as a cooling effect for the elderly population. There was no change in TS (cold water ingestion; 6.0 ± 0.4; control; 6.1 ± 0.4, L-menthol; 6.4 ± 0.6) or TC (cold water ingestion; 4 ± 1; control; 4 ± 1; L-menthol; 4 ± 1) between trials (Figure 8.2). Improved TS and TC can lead to performance benefits in the young (Figure 8.3). As a consequence of no change in TS or TC, there was no performance benefit in the 6MWT (cold water ingestion; 0.61 ± 0.08 km; control; 0.58 ± 0.09, L-menthol; 0.57 ± 0.08). Therefore, there was no perceptual or performance benefit of administering L-menthol with an elderly population (Figure 8.2). Study 3 also measured the participants thirst perception. It found that the participants were only '*slightly thirsty'* throughout the activities of daily living exercise testing. This is significant due to the possible real world implications. If an elderly person does not feel thirsty they are at an increased risk of dehydration and severe heat illness (Figure 8.2). Study 3 was able to reduce the risk of dehydration whilst reducing the physiological strain of the exercise-heat stress (Figure 8.4).

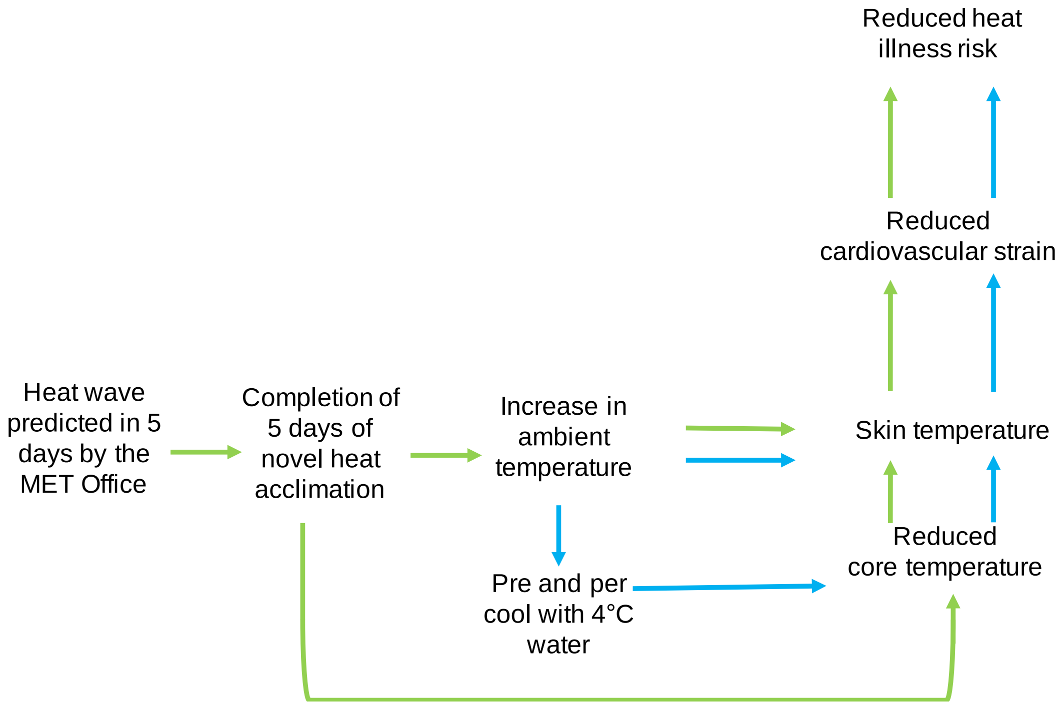


Figure 8.4: The effects of acute (blue) and chronic (green) heat illness prevention strategies on physiological markers of thermal strain.

8.2.3. Physiological and perceptual responses of the elderly to chronic heat exposure

Study 4 (Chapter 7, p167) investigated the phenotypic responses of the young and elderly, to a modified isothermic HA and an additional elderly group to novel HA protocol including; 30-min exercise in thermoneutral conditions, 30-min hot water bathing (40°C) and 30-min of seated rest in thermoneutral conditions with a blanket wrap.

The *'classic'* phenotypic markers to heat adaptation include; reductions in heart rate and core temperature and a higher sweat rate (Sawka *et al.,* 2011). According to Willmott *et al.,* (2016) meaningful adaptations in these markers in the young are T_{re} >0.20°C, ΔHR >-5 $b.min^{-1}$ ΔWBSR >$0.2L.h^{-1}$. In study 4, the elderly modified isothermic group had a meaningful reduction in resting T_{re} (-0.28 ± 0.26°C), but not HR (-1 ± 10 $b.min^{-1}$) after 4 days of heat acclimation (day 1 to day 5 of HA). These changes diminished by the post tests: T_{re}; 0.08 ± 0.23°C, HR; 2 ± 5 $b.min^{-1}$. The elderly modified isothermic group's WBSR did increase in all participants but the change may not be considered meaningful (0.18 ± 0.11 $L.h^{-1}$), in accordance with Willmott *et al.,* (2016) predefined analytical limits for meaningful adaptation. However, a greater sweat rate indicated a greater capacity to lose excess heat in a population that has a diminished evaporative heat loss capacity. Therefore, an increase of 0.18 ± 0.11 $L.h^{-1}$in the elderly population maybe meaningful, especially as this adaptation was not matched in the young group (-0.04 ± 0.48 $L.h^{-1}$). This also highlights that the modified isothermic HA protocol challenged the thermoregulatory system enough to elicit central and peripheral changes. This is due to a decrease in T_{re} from 1 to day 5 of HA (*i.e.,* a central change) and increase in WBSR pre-to-post HA (*i.e.,* indication of peripheral changes to the eccrine glands) (Periard *et al.,* 2015).

The novel HA has the potential to be a heat illness prevention strategy for the elderly (Figure 8.4). This is evident from similar reductions in resting values of T_{re} and HR, to that of the modified isothermic group, after four consecutive days of hot water immersion preceded by exercise in temperate conditions. There was a significant reduction in resting T_{re}, -0.33 ± 0.35°C, from day 1 to day 5 of novel HA. This is an indication of a central adaptation, therefore there is the possibility of an early onset of sweating and SkBF. Although, WBSR and SkBF were measured and there were no improvements, these measures were completed as part of the pre-to-post testing, in which post testing was completed 5 days after the last HA session. This presents a possible decay in the central (*i.e.,* T_{re}) and peripheral (*i.e.,* changes in the size and output of the eccrine glands) adaptations. There is a reported 2.6% decrease in core temperature adaptation for every day of heat acclimation decay in the young (Daanen *et al.,* 2017). Heat adaptation decay in the elderly is unknown, but it may be greater than in the young as evidenced by the greater decline in T_{re} adaptation after 5 days of no heat acclimation session.

Additionally, a meaningful decrease in resting HR was observed from day 1 to day 5 of HA (-8 ±10 $b.min^{-1}$), which indicates a decrease in cardiovascular strain. These changes also diminished in the pre-to-post HA testing (-4 ± 5 $b.min^{-1}$). Despite, the decrease in resting HR, plasma volume, another marker of cardiovascular adaptation, did not improve from day 1 to day 5 of HA.

An element of study 4 was to find a palatable HA for the elderly. There was no difference in average RPE in the elderly novel group (10 ± 1) compared to the elderly modified isothermic group (10 ± 1). This highlights, that the elderly groups did not feel any difference in how hard the protocols were, which is surprising as there was considerable more rest in the novel protocol compared to the modified isothermic. However, average HR was significantly less in the elderly novel group (100 ± 12 $b.min^{-1}$) compared to the elderly modified isothermic group (113 ± 10 $b.min^{-1}$), indicating less cardiovascular strain whilst completing the novel HA. Therefore, with minimal phenotypic differences between the two groups the novel approach seems to currently provide the most practical and less strenuous form of HA for the elderly.

Overall, a greater adaptive response was evident in the elderly groups when phenotypic responses were assessed from day 1 to day 5 of HA compared to pre-to-post testing in the elderly, possibly due to adaptation decay in between HA and post test. The rapid changes in resting T_{re} and HR, highlight the possible benefit that short term heat acclimation could have in preparation for a heat wave. Figure 8.4 highlights how both acute cool water ingestion and chronic novel HA can be used as a strategy for the prevention of heat illness via the reduction of resting T_{re} and reduced HR (*i.e.,* cardiovascular strain).

8.2. Recommendations for heatwave policy for the elderly population

Prior to starting the research in this thesis, a theoretical model was created (Figure 8.5). From the outset of the research the purpose was to provide practical recommendations for the prevention of heat illness in the elderly to impact public health heat wave policy positively. The theory was that heat illness risk in the elderly would increase with environmental temperature and exercise intensity. Furthermore, that heat illness risk would decrease with acute and chronic heat alleviation strategies. Additionally, that heat illness risk would increase with perceptual cooling methods that do not physically cool individuals.

This thesis suggests that figure 8.5 could be displayed within Public Health England's '*Beat the heat*' campaign documentation, so that elderly people can easily visualise the benefits of completing acute and chronic heat illness prevention strategies.

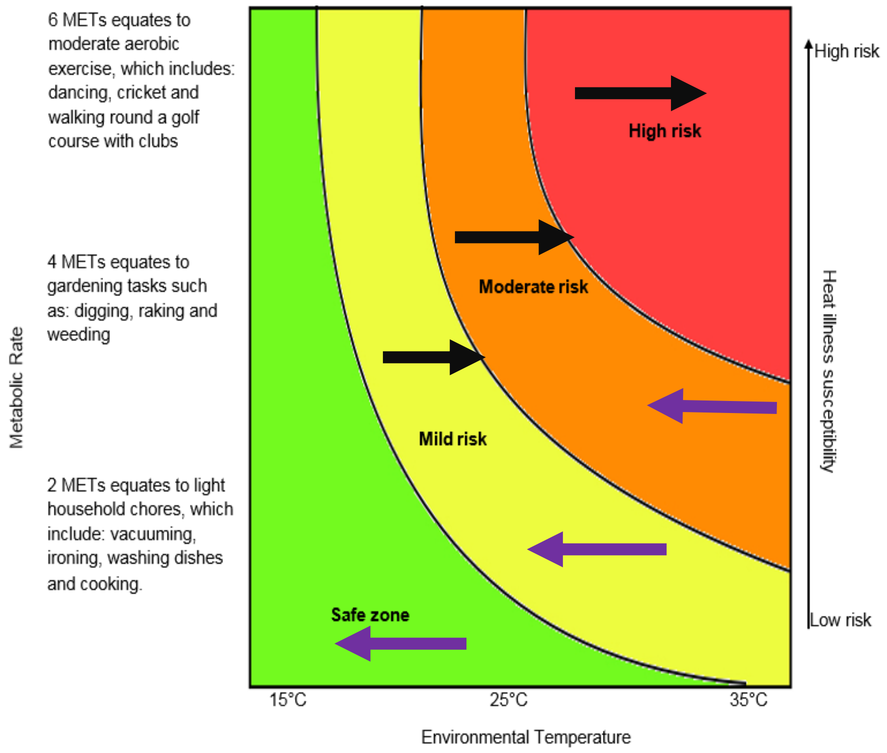
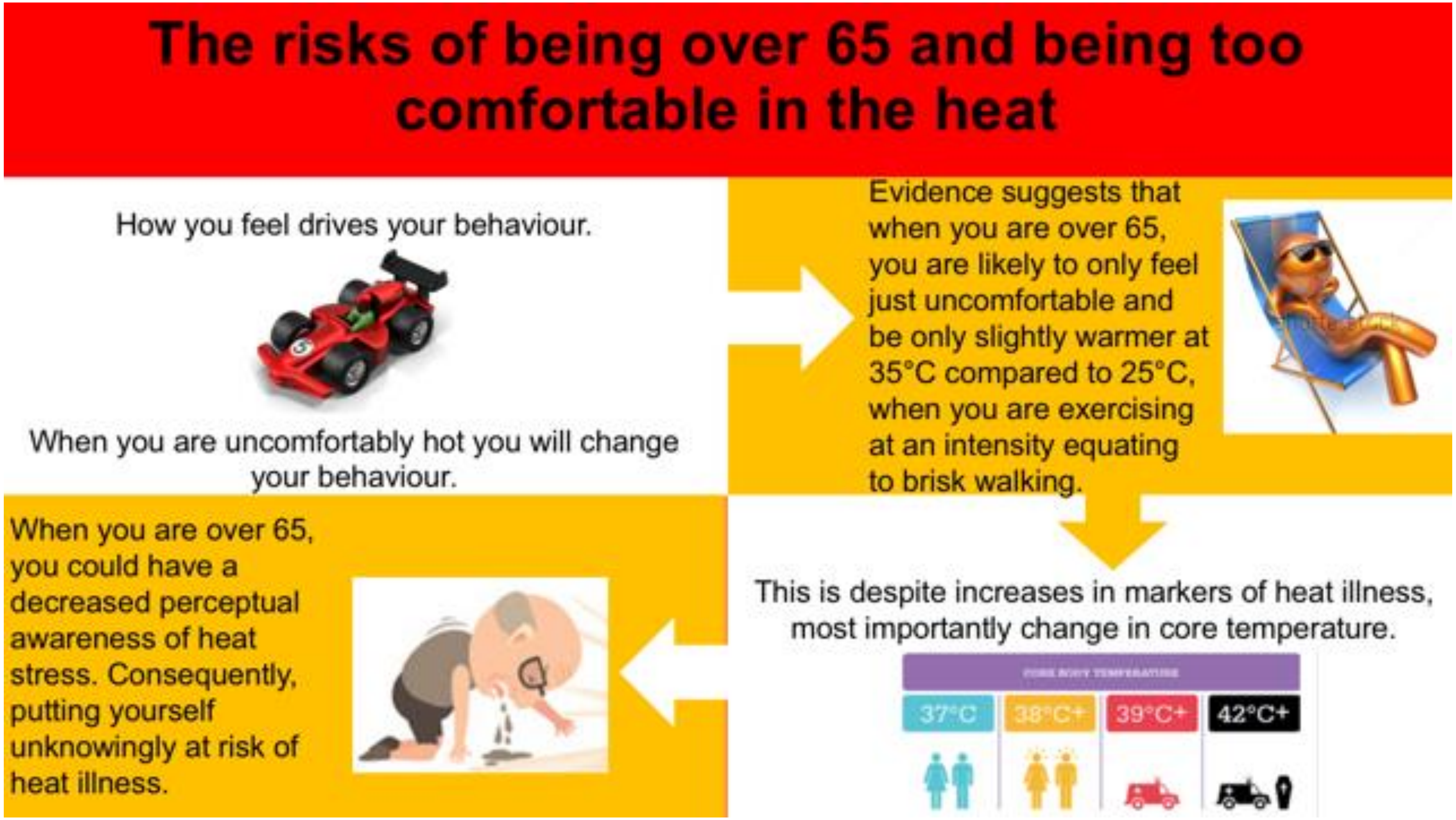


Figure 8.5: Represents the theoretical framework of elderly peoples' heat illness risk during UK summer climatic conditions. Black arrows represent the positive shift in heat illness risk when using physical cooling or heat acclimation interventions. Theoretically the interventions move the quadrants to the right, which increases the size of the safe zone and decreases the size of the high risk zone. Purple arrows represent the negative shift in heat illness risk when using perceptual cooling. Theoretically perceptual cooling move the quadrants to the left, which decreases the size of the safe zone and increases the size of the high risk zone.

In addition to the theoretical model being displayed within the '*Beat the heat*' campaign, the other novel research findings within this thesis present the opportunity to produce other educational material specifically for heat-related illness prevention for the elderly during periods of hot weather:

- A new HIS-Q is reliable during acute exercise-heat stress and is a sensitive tool for detecting changes in individual HIS-Q scores.
- Evidence suggests that the elderly have a decreased perceptual awareness with increases in environmental temperature.
- Drinking cold water periodically during rest and exercise reduces physiological strain in hot UK summer climatic conditions.
- Perceptual cooling via L-menthol does not reduce perceptual strain in the elderly.
- Modified isothermic heat acclimation develops different phenotypic adaptations in the elderly and young.
- Exercise, hot water immersion (40°C) and blanket wrapping develops phenotypic adaptation in the elderly after four consecutive days.

A series of infographics could be published as part of a national campaign to reduce heat illness risk in the elderly population (Figure 8.6-8.8). Figure 8.6 is an infographic illustrating how elderly people physiologically and perceptually respond to exercise at different intensities that simulate activities of daily living, across UK summer climatic conditions. Figure 8.7 is a second infographic explaining the benefits of drinking cold water regularly during rest and activities of daily living for the elderly, being an acute intervention that is readily available to all. Figure 8.8 is the last infographic created from the data collected for this thesis. The infographic explains the potential physiological benefits, and health and safety considerations of novel heat acclimation that includes hot water immersion. These infographics are an example of how policy makers can disseminate research to the target population. It is suggested that these infographics are displayed in places where elderly people are likely to see them including notice boards located at; ageing related charities, doctors' surgeries, supermarkets and health clubs with elderly membership and group classes aimed at the elderly (*e.g.,* elderly specific fitness classes).



The risks of being over 65 and being too comfortable in the heat

How you feel drives your behaviour.

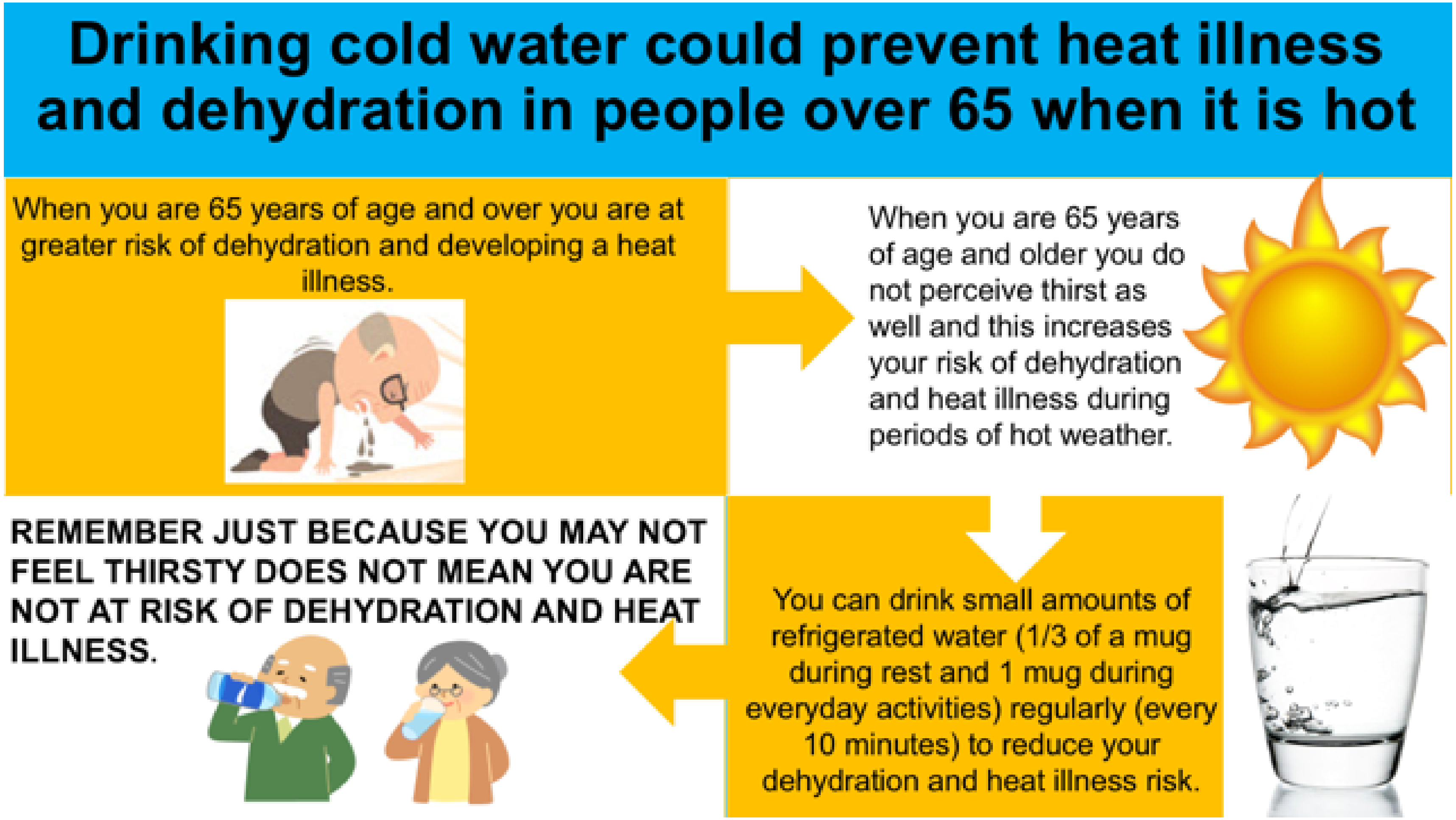
When you are uncomfortably hot you will change your behaviour.

Evidence suggests that when you are over 65, you are likely to only feel just uncomfortable and be only slightly warmer at 35°C compared to 25°C, when you are exercising at an intensity equating to brisk walking.

This is despite increases in markers of heat illness, most importantly change in core temperature.

When you are over 65, you could have a decreased perceptual awareness of heat stress. Consequently, putting yourself unknowingly at risk of heat illness.

Figure 8.6: Infographic highlighting the potential dangers of an increasing warmer climate for an elderly population. Infographic is based on data from study 2 (Chapter 5, p124).



Drinking cold water could prevent heat illness and dehydration in people over 65 when it is hot

When you are 65 years of age and over you are at greater risk of dehydration and developing a heat illness.

When you are 65 years of age and older you do not perceive thirst as well and this increases your risk of dehydration and heat illness during periods of hot weather.

You can drink small amounts of refrigerated water (1/3 of a mug during rest and 1 mug during everyday activities) regularly (every 10 minutes) to reduce your dehydration and heat illness risk.

REMEMBER JUST BECAUSE YOU MAY NOT FEEL THIRSTY DOES NOT MEAN YOU ARE NOT AT RISK OF DEHYDRATION AND HEAT ILLNESS.

Figure 8.7: Infographic highlighting the potential benefits of drinking cold water, when UK environmental temperature is high, for the elderly population. Infographic is based on data from study 3 (Chapter 6, p139).

Exercise, hot baths and blankets have the potential to reduce heat illness risk in people over 65 years old

When you are 65 years of age and over, you are at an increased risk of heat illness due to your advanced age and the impact of global warming.

Evidence suggests that you can complete 30-min of some what hard exercise in room temperature conditions, followed by 30-min of hot water bathing (40°C) and ending with a 30-min blanket wrap everyday for 4 days to reduce your heat illness risk.

Your heat illness risk is reduced due to meaningful changes in resting heart rate and resting body temperature after 4 days. This results in better protection against the harmful effects of the heat.

WARNING!!

Hot baths can make some people feel faint, so if you plan to use this heat alleviating strategy, it should be completed under supervision by someone with appropriate training.

Figure 8.8: Infographic highlighting the potential benefits of novel heat acclimation that includes hot water immersion for the prevention of heat illness during a heatwave, for the elderly population. Infographic is based on data from study 4 (Chapter 7, p167).

8.3. Reflections and practical considerations when conducting research with the elderly population

8.3.1. Prior to testing

This thesis was the first time the principal investigator had conducted research with a population that is considered vulnerable. Through completing the research in this thesis, there has been several practical considerations that may not have been considered if research were to have been completed with a different research population.

One of the first practical consideration was the level of vulnerability of the potential participants. As a researcher the aim was to complete studies that worked with the most vulnerable elderly population. This is because they are the most at risk of suffering a heat related illness or a cardiovascular event during periods of hot weather (Kenney *et al.,* 2014; Smith *et al.,* 2016). Therefore, the research would have the greatest practical impact if it was completed with the most vulnerable participants. However, the studies in this thesis were the first to complete exercise under environmental extremes within an elderly population at the University of Brighton. Consequently, the research ethics committee were cautious as to the level of vulnerability of the participants, especially as this was the principal investigator's first studies with an elderly population. The principal investigator had to attend a tier 2 ethics committee and defend elements of the proposed research prior to any testing with the elderly population. The ethics committee were pleased to be informed of the controls that were to be implemented for research completion including; that the principal investigator would go on an advanced first aid training course, complete ECG analysis training and would only use participants if they were signed off by their G.P as fit to complete research testing. These are all additional measures that are not required if a PhD student is testing a young healthy student population.

Further to the additional measures required for testing, the method for participant recruitment differs from a young student population. As mentioned, these were the first environmental studies to use an elderly population, therefore there was no readily available participants for testing. This differs from studies that use young healthy populations, as typically completing research in a university often leads to the willingness of students to take part in studies. Therefore, several recruitment techniques were used; firstly, advertisement through local radio and newspapers explaining the purpose of testing and how people could get involved. Secondly, stalls were set up at local events that would naturally attract the target population. Thirdly, posters were put up in the town centre. The researcher also attended fitness classes for the over 55's looking for people 65 and older. It was also important that potential participants could contact the researcher via phone as some of the participants did not use email. After the initial recruitment the other studies were easier to recruit for due to positive word of mouth communication throughout the community, about the research and what could be gained by participating.

The decision was also made to buy additional testing equipment for the elderly population. The department did not have access to a recumbent bike, this type of bike offers an elderly person; greater comfort via the back support compared to an upright cycle ergometer (Gostic, 2005), this was considered important to the study for participant adherence. Moreover, of greater importance is that the Ottawa research group (*e.g.,* Kenny, Stapleton and Larose) completed their exercise research with the elderly using a recumbent cycle ergometer (Larose, *et al.*, 2013ab: Stapleton *et al.*, 2014bc; Kenny *et al.*, 2016). Furthermore, there is dispute over the physiological and biomechanical differences in completing exercise on an upright compared to a recumbent cycle ergometer (Scott *et al.,* 2006). These include possible differences in; HR, $\dot{V}O_2$ consumption, blood pressure, weight-bearing, range of motion at the hip and specific muscle activation (Scott *et al.,* 2006). Therefore, to control for those possible differences and to allow for greater comparisons between research studies a recumbent cycle ergometer was purchased via a research grant secured for the research in this thesis.

8.3.2. During testing

During experimental testing for the HA study there were population specific observations that should be noted to highlight the additional challenges with completing exercise-heat stress research with an elderly population. There were three cases of syncope. The development of each case was slightly different. Two of the three cases were in low body mass females, after completing exercise in the heat and moving into a stationary position on a chair they began to feel faint. The reason the participant felt faint could have been due to blood pooling (Brignole *et al.,* 2018). The reduced venous return after the completion of cycling exercise could have led to a decrease in blood pressure resulting in syncope (Brignole *et al.,* 2018). The third case was in a low body mass male who felt faint after the completion of the hot water immersion. It is widely accepted that postural changes from a supine to an upright position can causes a drop in blood pressure (> 20mmHg systolic and >10mmHg diastolic), leading to syncope (Mader, 1989; Finucane *et al.,* 2014; Brignole *et al.,* 2018). The risk of postural syncope increases with age (Finucane *et al.,* 2014; Brignole *et al.,* 2018). Consequently, the male participant could have experienced a decrease in blood pressure after a sustained period in a supine position (30-min) before going into a standing upright position.

Another observation and challenge when completing HA with the elderly was maintaining enough physical activity to drive heat adaptation. The priority during testing was to maintain the health and safety of the participants. Therefore, guidelines of physical strain were set as; 90% of age predicted HR_{max}, hypotension (*i.e.,* a decrease of >10mmHg in systolic pressure) or hypertension (increase >250mmHg in systolic pressure or >115 mmHg in diastolic blood pressure) and if the participants requested a rest (Leon *et al.,* 2013). It was observed that the elderly were less likely to request a break compared to the young. Speculating on this observation, it might be due to not wanting to seem as if they could not do what was asked of them or they were not aware of their individual physical limits.

Overall, testing with the elderly population during this thesis was a challenging but hugely rewarding experience. Additional care is required to ensure the safety of participants, however, the additional time required to put in place the additional methods is saved later in projects when participants turn up on time for testing and complete the study. Furthermore, the life stories that the participants share during testing means that the researcher learns far more than if their study hypothesis can be accepted or rejected.

8.4. Future directions

The findings in this thesis provide a starting point for future heat illness prevention research with the vulnerable elderly population. Study 1 (Chapter 4, p108), investigated a new heat illness susceptibility questionnaire (HIS-Q). The HIS-Q could be a standalone thesis project. This is due to potential future developmental research into the HIS-Q's reliability and development of additional versions for different populations, including the elderly. The Lake Louise questionnaire is an example of an environmental illness questionnaire (*i.e.,* acute mountain sickness [AMS]) that required several iterations before becoming the '*gold standard'* questionnaire for the detection of AMS severity (Sampson & Kobrick, 1980; Sampson *et al.,* 1983; Wright *et al.,* 1985; Roach *et al.,* 1993). Since becoming the gold standard measure for AMS there has been development into versions for children (Southard *et al.,* 2007). The HIS-Q has the potential to be the equivalent of the Lake Louise questionnaire for the prevention of heat illness. The first future study for the HIS-Q is to investigate its validity during field-based events and prolonged exercise-heat stress. The findings from this research will highlight the HIS-Q's effectiveness of detecting heat illness in a young physically active population. Furthermore, events that require prolonged exercise in the heat often have medical professionals that can confirm a diagnosis of heat illness when the HIS-Q is completed, validating the questionnaire under different exercise-heat stress conditions.

In studies 2-4 (Chapters 5-7, p124, p139 and p167) the elderly participants were healthy and habitually active individuals, due to the ethical approval granted for the studies. Although direct measurements of fragility were not measured during this study, when using either the de Morton Mobility Index (DEMMI) (Davison & Keaton, 2008) or the Speechly & Tinetti scale (1991), none of the participants in this thesis would have been considered frail or in transition. Frail elderly people and those transitioning from healthy to frail, present a greater risk of developing a heat illness during periods of hot weather (Flynn *et al.,* 2005; Hajat *et al.,* 2007; Hajat *et al.,* 2014). Consequently, the physiological and perceptual responses reported in this thesis could be different in an elderly population who are classified as in transition or frail. Therefore, further research should include the DEMMI and Speechly & Tinetti scales to classify transition and frail elderly populations and report on their physiological and perceptual responses during UK summer climatic conditions, whilst completing activities of daily living that reflect their physical capabilities. The findings from this research will provide a greater understanding of how the most vulnerable in our society respond to the heat. Moreover, even greater vulnerable population specificity of heat illness prevention strategies could be provided if acute and chronic heat alleviating strategies are investigated within the most vulnerable.

Additionally, due to experimental design the participants' clothing was controlled in all the studies. Consequently, 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. Furthermore, behaviour was controlled in study 3 (Chapter 6, p139) by providing cold water periodically rather than allowing the participants to drink *ad libitum*. Therefore, a series of studies investigating the behavioural responses of the elderly to the heat and to heat illness prevention strategies is warranted. It is important to understand elderly peoples' behaviour during periods of hot weather as there is a near infinite number of conscious behaviours available to prevent the rise of core temperature and prevent heat illness (Schlader *et al.,* 2010; Flouris, 2011; Schlader, 2014; Flouris & Schlader, 2015). Additionally, findings from study 2 (Chapter 5, p124) suggested a decreased perceptual awareness in the elderly, therefore they may require further education of the dangers of hot weather and the behaviours they can implement to prevent them developing heat illness, as they may not feel uncomfortable enough to implement conscious thermoregulatory behaviours.

Further research should continue to investigate practical acute heat illness prevention strategies for the elderly population. The acute intervention strategies could investigate the minimum about of water required to prevent heat illness during activities of daily living in hot UK summer climatic conditions. Furthermore, do the elderly drink enough *ad libitum* when cold fluids are available to prevent heat illness during activities of daily living in UK hot summer climatic conditions. The findings will provide more specific drinking guidelines for the elderly during periods of hot weather, preventing heat illness and dehydration. Additionally, acute cooling research should investigate the possible combined effect of different cooling methods on precooling and percooling. Bongers *et al.,* (2014) state that an *'aggressive'* cooling approach via the combination of internal and external cooling, applied pre and per exercise-heat exposure has a greater ergogenic effect on exercise performance. It is unknown the additional benefits that external cooling could have on the elderly population, whilst they take internal cooling via cold water ingestion. One example of a more *'aggressive'* cooling strategy for the elderly would be to use cooling garments and ice pack at rest prior to completing activities of daily living, whilst also taking cold fluids periodically. This would minimise the weight of the garment as worn at rest, it will also maximise the cooling surface area with the addition of the ice packs and maximise core temperature cooling via the cold fluids. During exercise the elderly can continue to internally per-cool via cold water ingestion and holding cooling packs, periodically. Although, hand cooling packs do not offer a large surface area of cooling, they do provide a practical intervention that the elderly may consider achievable when completing activities of daily living compared to a large surface area cooling garments. These type of *'aggressive'* cooling techniques have the potential to be implemented periodically throughout a hot weather day or throughout a heat wave. Consequently, the benefits of pre- and per-cooling can be replicated on the same individual multiple times a day during periods of hot weather.

There is also further chronic heat-illness prevention research to be completed with the elderly population. Firstly, an investigation into the effects of more heat acclimation days to understand the mechanisms of heat adaptation in the elderly would seem appropriate. This should be completed with considerable thought of the pre and post HA tests to prevent heat adaptation decay. Additional research into optimising the novel hot water immersion HA should be investigated. The approach used in this thesis found decreases in resting HR and T_{re} after 4 days of HA, however one person developed syncope, therefore immersion time at the start of the HA may need to be reconsidered to minimise the risk of developing syncope from the heat or via long periods in supine position. Once a greater understanding of elderly heat acclimation has been acquired, elderly re-acclimation can be investigated. In a young population re-acclimation develops phenotypic adaptations of; lower HR and T_{re} and increase WBSR, to the heat more quickly in comparison to the original heat acclimation (Daanen *et al.,* 2017). Additionally, there is evidence that the magnitude of HR adaptation is greater in the re-acclimation than the original adaptations developed during HA (Daanen *et al.,* 2017). Therefore, re-acclimation has the potential to offer a practical chronic heat illness prevention intervention, as elderly people could complete a longer period of acclimation in the spring, and re-acclimate within a few days of a heat wave, maybe with even greater adaptations then the original heat acclimation bout. As a consequence, future PHE strategy could be encouraging elderly people to exercise and take hot baths in the spring, then provide a warning before a heat wave to do the same. This allows for a cohesive message from PHE to maintain safe and effective exercise, whilst protecting the elderly from the harmful effects of the heat. As always when such advice is offered the health and safety of the prescription must be carefully considered.

This thesis can be considered the start of heat illness prevention research during activities of daily living during hot UK summer climatic conditions for the elderly population. Climate change and a sedentary ageing population will require heat illness prevention strategies in the near future. The suggested future research directions will add to the research in this thesis in the aim of minimising severe heat illness in our vulnerable elderly population.

Chapter 9 Conclusion

This thesis adds to the body of knowledge pertaining to how the elderly physiologically and perceptually respond to activities of daily living within UK summer climatic conditions. Furthermore, it provides age-specific practical recommendations for the prevention of heat illness for the elderly population. Study 2 (Chapter 5, p124) demonstrated that as environmental temperature and exercise intensity increased, physiological responses increased without a corresponding perceptual difference. This is a significant finding as the acute and chronic heat illness prevention strategies investigated in studies 3 and 4 (Chapter 6 and 7, p139 and p167) may require additional educational material to explain to the elderly population the benefits of such strategies even when they do not necessarily feel the need to implement them. Study 3 (Chapter 6, p139) found that drinking cold water periodically can reduce physiological strain during exercise-heat stress. Lastly, study 4 (Chapter 7, p167) indicated that phenotypic adaptations have the possibility to develop within the first few days of HA. Further research into time-course of elderly HA, decay and then re-acclimation is warranted to optimise the practicality of HA for the elderly.

The concluding message of this thesis is that acute and chronic heat illness prevention strategies are effective at reducing physiological strain during heat stress in the elderly population. The dissemination of the research in this thesis via a public health campaign is essential, so that the elderly can develop a better understanding of how age effects how they physiologically and perceptually respond to environments and exercise intensities that have meaning to their everyday lives. Further, the elderly population must continue exercising for long-term health benefits and should not fear completing activities of daily living under heat stress as long as they implement evidence-based heat illness prevention strategies.

Chapter 10 References

Ainsworth, B. E., Haskell, W. L., Herrman, S. D., Meckes, N., Bassett, D. R., Tudor-Locke, C., *et al.,* (2011). 2011 Compendium of Physical Activities. Medicine & Science in Sports & Exercise (on-line), 43: 1575–1581. https://insights.ovid.com/crossref?an=00005768-201108000-00025.

Anderson, R. K. and Kenney, W. L. (1987). Effect of age on heat-activated sweat gland density and flow during exercise in dry heat. J Appl Physiol (on-line), 63: 1089–1094. http://jap.physiology.org/content/63/3/1089.abstract. Accessed 29 April 2016.

Arbuthnott, K. G. and Hajat, S. (2017). The health effects of hotter summers and heat waves in the population of the United Kingdom: A review of the evidence. Environmental Health: A Global Access Science Source, 16: 1–13.

Arbuthnott, K., Hajat, S., Heaviside, C. and Vardoulakis, S. (2016). Changes in population susceptibility to heat and cold over time: assessing adaptation to climate change. Environmental Health (on-line), 15. http://dx.doi.org/10.1186/s12940-016-0102-7.

Armstrong, C. G. and Kenney, W. L. (1993). Effects of age and acclimation on responses to passive heat exposure. J Appl Physiol (on-line), 75: 2162–2167.

Armstrong, L. E. and Maresh, C. M. (1991). The Induction and Decay of Heat Acclimatisation in Trained Athletes. Sports Medicine (on-line), 12: 302–312.

Armstrong, L. E., Casa, D. J., Millard-Stafford, M., Moran, D. S., Pyne, S. W. and Roberts, W. O. (2007). Exertional heat illness during training and competition. Medicine and Science in Sports and Exercise, 39: 556–572.

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

Atkinson, G. (2003). What is this thing called measurement error? : 1–8.

Atkinson, G. and Nevill, A. (1998). Statistical Methods for Assssing Measurement Error (Reliability) in Variables Relevant to Sports Medicine. Sports Medicine (on-line), 26: 217–238. http://link.springer.com/article/10.2165/00007256-199826040-00002.

Bain, A.R., Lesperance, N.C. and Jay, O. (2012). Body heat storage during physical activity is lower with hot fluid ingestion under conditions that ermit full evapouration. 98-108.

Balmain, B. N., Sabapathy, S., Louis, M. and Morris, N. R. (2018). Aging and Thermoregulatory Control: The Clinical Implications of Exercising under Heat Stress in Older Individuals. BioMed Research International (on-line), 2018: 1–12. https://www.hindawi.com/journals/bmri/2018/8306154/.

Barwood, M. J., Corbett, J., Thomas, K. and Twentyman, P. (2015). Relieving thermal discomfort: Effects of sprayed L-menthol on perception, performance, and time trial cycling in the heat. Scandinavian Journal of Medicine and Science in Sports, 25: 211–218.

Barwood, M. J., Goodall, S. and Bateman, J. (2018b). The effect of hot and cold drinks on thermoregulation, perception, and performance: the role of the gut in thermoreception. European Journal of Applied Physiology (on-line), 0: 0. http://dx.doi.org/10.1007/s00421-018-3987-8.

Barwood, M. J., Kupusarevic, J. and Goodall, S. (2018a). Repeated menthol spray application enhances exercise capacity in the heat.

BBC (2013). 10 ways the UK is ill-prepared for a heatwave (on-line). https://www.bbc.co.uk/news/magazine-23341698.

BBC (2018b). California wildfires: ‘It was like an apocalyptic movie’ (on-line). https://www.bbc.co.uk/news/av/world-us-canada-46191761/california-wildfires-it-was-like-an-apocalyptic-movie

BBC (2018a). Regular heatwaves ‘will kill thousands’ (on-line). https://www.bbc.co.uk/news/science-environment-44956310.

Best, R., Payton, S., Spears, I., Riera, F. and Berger, N. (2018). Topical and Ingested Cooling Methodologies for Endurance Exercise Performance in the Heat. Sports (on-line), 6: 11. http://www.mdpi.com/2075-4663/6/1/11.

Best, S., Thompson, M., Caillaud, C., Holvik, L., Fatseas, G. and Tammam, A. (2014). Exercise-heat acclimation in young and older trained cyclists. Journal of Science and Medicine in Sport (on-line), 17: 677–682. http://dx.doi.org/10.1016/j.jsams.2013.10.243.

Bird, S. R. and Davison, R. (1997). Guidelines for the Physiological Testing of Atheletes. British Association of Sport and Exercise Sciences.

Bland, J. M. and Altman, D. G. (1999). Measuring agreement in method comparison studies. Statistical Methods in Medical Research (on-line), 8: 135–160. http://smm.sagepub.com/cgi/doi/10.1191/096228099673819272.

Bligh, J. and Johnson, K. G. (1973). Glossary of terms for thermal physiology. Journal of Applied Physiology, 35: 941–961.

Bongers, C. C. W. G., Thijssen, D. H. J., Veltmeijer, M. T. W., Hopman, M. T. E. and Eijsvogels, T. M. H. (2014). Precooling and percooling (cooling during exercise) both improve performance in the heat: a meta-analytical review. British journal of sports medicine (on-line): 377–384. http://www.ncbi.nlm.nih.gov/pubmed/24747298.

Borg, G. A. V (1982). Psychophysical bases of percieved exertion. Medecine and Science in Sports and Exercise.

Bouchama, A. and Knochel, J. P. (2002). Heat Stroke. New England Journal of Medicine (on-line), 346: 1978–1988. http://www.nejm.org/doi/abs/10.1056/NEJMra011089.

Brearley, M. and Walker, A. (2015). Water immersion for post incident cooling of fi re fi ghters ; a review of practical fi re ground cooling modalities. Extreme Physiology & Medicine: 1–13.

Bright, F. M., Chaseling, G. K., Jay, O. and Morris, N. B. (2019). Journal of Science and Medicine in Sport Self-paced exercise performance in the heat with neck cooling , menthol application , and abdominal cooling. Journal of Science and Medicine in Sport (on-line), 22: 371–377. https://doi.org/10.1016/j.jsams.2018.09.225.

Brignole, M., Elliott, P. M., Delgado, V., Rice, C. P., Mitro, P., Mabo, P., Zamorano, J. L., *et al.,* (2018). 2018 ESC Guidelines for the diagnosis and management of syncope. European Heart Journal, 39: 1883–1948.

British Heart Foundation (2010). Beating Heart Disease Together active for later life Promoting physical activity with older people. : 37.

British Heart Foundation National Centre (2012). Interpreting the UK physical activity guidelines for older adults (65+). Guidance for those who work with older adults described as actives. : 1–18.

Burt, S. (2004). The August 2003 heatwave in the United Kingdom: Part 1 –Maximum temperatures and historical precedents. Weather, 59: 199–208.

Carter, J. E. and Gisolfi, C. V (1989). Fluid replacement during and after exercise in the heat. Medicine & Science in Sports & Exercise.

Carter, J. E. and Gisolfi, C. V (1989). Fluid replacement during and after exercise in the heat. Medicine & Science in Sports & Exercise.

Casa, D.J., Millard-Stafford, M., Moran, D.S., Pyne, S.W. and Roberts, W.O. (2007). Exertional heat illness during training and competition. American College of Sports Medicine, 555-572.

Castle, P., Maxwell, N., Webborn, A. D. J., Watt, P. W. and Mackenzie, R. W. (2011). Heat acclimation improves intermittent sprinting in the heat but additional pre-cooling offers no further ergogenic effect. Journal of Sports Sciences, 29: 1125–1134.

CBS (2018). Northern California's Camp Fire death toll hits 83 as area prepares for heavy rain, possible mudslides (on-line). https://www.cbsnews.com/live-news/california-fires-containment-search-rescue-air-2018-11-21-camp-woolsey-paradise-live-updates/.

Chalmers, S., Esterman, A., Eston, R., Bowering, K. J. and Norton, K. (2014). Short-Term Heat Acclimation Training Improves Physical Performance: A Systematic Review, and Exploration of Physiological Adaptations and Application for Team Sports. Sports Medicine (on-line), 44: 971–988. http://link.springer.com/10.1007/s40279-014-0178-6.

Charkoudian, N. (2003). Skin blood flow in adult human thermoregulation: how it works, when it does not, and why. Mayo Clinic proceedings. Mayo Clinic (on-line), 78: 603–612. http://dx.doi.org/10.4065/78.5.603.

Charkoudian, N. (2016). Human thermoregulation from the autonomic perspective. Autonomic Neuroscience (on-line), 196: 1–2. http://dx.doi.org/10.1016/j.autneu.2016.02.007.

Chen, T.-I., Tsai, P.-H., Lin, J.-H., Lee, N.-Y. and Liang, M. T. C. (2013). Effect of short-term heat acclimation on endurance time and skin blood flow in trained athletes. Opem Access Journal of Sports Medicine (on-line), 4: 161–70. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3871901&tool=pmcentrez&rendertype=abstract.

Cheung, S. S., McLellan, T. M. and Tenaglia, S. (2000). The thermophysiology of uncompensable heat stress. Physiological manipulations and individual characteristics. Sports medicine (Auckland, N.Z.), 29: 329–359.

Cheuvront, S. N. and Haymes, E. M. (2001). Thermoregulation and Marathon Running. Sports Medicine (on-line), 31: 743–762. http://link.springer.com/10.2165/00007256-200131100-00004.

Cheuvront, S. N. and Kenefick, R. W. (2014). Dehydration: Physiology, Assessment, and Performance Effects. Comprehensive Physiology (on-line), 4: 257–285. http://doi.wiley.com/10.1002/cphy.c130017.

Cohen, J. D. (1988). Statistical power analysis for the behavioral sciences. Statistical Power Analysis for the Behavioral Sciences.

Conti, S., Meli, P., Minelli, G., Solimini, R., Toccaceli, V., Vichi, M., Beltrano, C. and Perini, L. (2005). Epidemiologic study of mortality during the Summer 2003 heat wave in Italy. Environmental Research, 98: 390–399.

Corbett, J., Rendell, R. A., Massey, H. C., Costello, J. T. and Tipton, M. J. (2018). Inter-individual variation in the adaptive response to heat acclimation. Journal of Thermal Biology (on-line), 74: 29–36. https://doi.org/10.1016/j.jtherbio.2018.03.002.

Coris, E. E., Ramirez, A. M. and Van Durme, D. J. (2004). Heat Illness in Athletes: The Dangerous Combination of Heat, Humidity and Exercise. Sports Medicine, 34: 9–16.

Coris, E. E., Walz, S. M., Duncanson, R., Ramirez, A. M. and Roetzheim, R. G. (2006). Heat illness symptom index (HISI): a novel instrument for the assessment of heat illness in athletes. Southern medical journal (on-line), 99: 340–5. http://www.ncbi.nlm.nih.gov/pubmed/16634241.

Costill, D. L. and Fink, W. J. (2017). Plasma volume changes following exercise and thermal dehydration. Journal of Applied Physiology, 37: 521–525.

Cramer, M. N. and Jay, O. (2014). Selecting the correct exercise intensity for unbiased comparisons of thermoregulatory responses between groups of different mass and surface area. Journal of applied physiology (Bethesda, Md. : 1985) (on-line), 116: 1123–32. http://jap.physiology.org/content/116/9/1123.full-text.pdf+html.

Crandall, C. G. and Wilson, T. E. (2015). Human Cardiovascular Responses to Passive Heat Stress. Comprehensive Physiology (on-line), 5: 17–43. http://www.ncbi.nlm.nih.gov/pubmed/24692134.

Crapo, R. O., Casaburi, R., Coates, A. L., Enright, P. L., MacIntyre, N. R., McKay, R. T., Johnson, D., Wanger, J. S., Zeballos, R. J., Bittner, V. and Mottram, C. (2002). ATS statement: Guidelines for the six-minute walk test. American Journal of Respiratory and Critical Care Medicine, 166: 111–117.

Cuddy, J. S., Hailes, W. S. and Ruby, B. C. (2014). A reduced core to skin temperature gradient, not a critical core temperature, affects aerobic capacity in the heat. Journal of Thermal Biology (on-line), 43: 7–12. http://dx.doi.org/10.1016/j.jtherbio.2014.04.002.

Currell, K. and Jeukendrup, A. E. (2008). Validity, reliability and sensitivity of measures of sporting performance. Sports medicine, 38: 297–316.

D'Ippoliti, D., Michelozzi, P., Marino, C., De'Donato, F., Menne, B., Katsouyanni, K., Kirchmayer, U., Analitis, A., Medina-Ramón, M., Paldy, A., Atkinson, R., Kovats, S., Bisanti, L., Schneider, A., Lefranc, A., Iñiguez, C. and Perucci, C. A. (2010). The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. Environmental Health (on-line), 9: 37. http://ehjournal.biomedcentral.com/articles/10.1186/1476-069X-9-37.

Daanen, H. A. M. and Herweijer, J. A. (2014). Effectiveness of an indoor preparation program to increase thermal resilience in elderly for heat waves. Building and Environment (on-line), 83: 115–119. http://dx.doi.org/10.1016/j.buildenv.2014.04.010.

Daanen, H. A. M., Jonkman, A. G., Layden, J. D., Linnane, D. M. and Weller, A. S. (2011). Optimising the Acquisition and Retention of Heat Acclimation. International Journal of Sports Medicine (on-line), 32: 822–828. http://www.thieme-connect.de/DOI/DOI?10.1055/s-0031-1279767.

Daanen, H. A. M., Racinais, S. and Périard, J. D. (2017). Heat Acclimation Decay and Re-Induction: A Systematic Review and Meta-Analysis. Sports Medicine: 1–22.

Davidson and Keating (2008). de Morton Mobility Index (DEMMI). Health and quality of life outcomes, 6.

Department of Health (2001). National service framework for older people. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/198033/National_Service_Framework_for_Older_People.pdf.

Dill, D.B., Costill, D.L., 1974. Calculation of percentage changes in volumes of blood, plasma, and red cells in dehydration. J. Appl. Physiol. 37, 247–8.

Drinkwater, B. and Horvath, S. (1979). Heat tolerance and aging. Medicine and science in sports, 11: 49–55.

Duffield, R., Bird, S. P. and Ballard, R. J. (2011). Field-based pre-cooling for on-court tennis conditioning training in the heat. Journal of Sports Science and Medicine, 10: 376–384.

Duffield, R., Steinbacher, G. and Fairchild, T. J. (2009). the Use of Mixed-Method, Part-Body Pre-Cooling Procedures for Team-Sport Athletes Training in the Heat. Journal of Strength and Conditioning Research, 23: 2524–2532.

Durnin, J. V and Womersley, J. (1974). 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 (on-line), 32: 77–97. http://journals.cambridge.org/download.php?file=/BJN/BJN32_01/S0007114574000614a.pdf&code=8a07417744bb817af111c69b82140018.

Ebi, L. K. and Meehl, A. G. (2007). Heatwaves and global climate change. The heat is on: climate change and heatwaves in the midwest.

Eccles, R., Griffiths, D. H. and Newton, C. G. (1988). The effects of D and L Isomers of menthol upon nasal sensation of airflow. , 102: 506–508.

El Helou, N., Tafflet, M., Berthelot, G., Tolaini, J., Marc, A., Guillaume, M., Hausswirth, C. and Toussaint, J. F. (2012). Impact of environmental parameters on Marathon running performance. PLoS ONE, 7: 1–9.

El-Sharkawy, A. M., Watson, P., Neal, K. R., Ljungqvist, O., Maughan, R. J., Sahota, O. and Lobo, D. N. (2015). Hydration and outcome in older patients admitted to hospital (The HOOP prospective cohort study). Age and Ageing, 44: 943–947.

Enright, P. L., McBurnie, M. A., Bittner, V., Tracy, R. P., McNamara, R., Arnold, A. and Newman, A. B. (2003). The 6-min walk test: A quick measure of functional status in elderly adults. Chest (on-line), 123: 387–398. http://dx.doi.org/10.1378/chest.123.2.387.

Farrokhyar, F., Reddy, D., Poolman, R. W. and Bhandari, M. (2013). Why perform a priori sample size calculation? Canadian Journal of Surgery, 56: 207–213.

Faulkner, S. H., Hupperets, M., Hodder, S. G. and Havenith, G. (2015). Conductive and evaporative precooling lowers mean skin temperature and improves time trial performance in the heat. Scandinavian Journal of Medicine and Science in Sports, 25: 183–189.

Ferry, M. (2005). Strategies for ensuring good hydration in the elderly. Nutrition reviews, 63: S22–S29.

Field, A. (2017). Discovering Statistics using IBM SPSS Statistics. Discovering Statistics using IBM SPSS Statistics.

Finucane, C., Soraghan, C. J., Kenny, R. A., Nolan, H., O’Connell, M. D. L., Fan, C. W., Cronin, H. and Savva, G. M. (2014). Age-Related Normative Changes in Phasic Orthostatic Blood Pressure in a Large Population Study. Circulation, 130: 1780–1789.

Flood, T. R., Waldron, M. and Jeffries, O. (2017). Oral l-menthol reduces thermal sensation, increases work-rate and extends time to exhaustion, in the heat at a fixed rating of perceived exertion. European Journal of Applied Physiology, 117: 1501–1512.

Flouris, A. D. (2011). Functional architecture of behavioural thermoregulation. European Journal of Applied Physiology, 111: 1–8.

Flouris, A. D. and Cheung, S. S. (2009). Human conscious response to thermal input is adjusted to changes in mean body temperature. British journal of sports medicine, 43: 199–203.

Flouris, A. D. and Schlader, Z. J. (2015). Human behavioral thermoregulation during exercise in the heat. Scandinavian Journal of Medicine and Science in Sports, 25: 52–64.

Flynn, A., McGreevy, C. and Mulkerrin, E. C. (2005). Why do older patients die in a heatwave? QJM - Monthly Journal of the Association of Physicians, 98: 227–229.

Fox, B. Y. R. H., Goldsmith, R., Kidd, D. J. and Lewis, H. E. (1963). ACCLIMATIZATION TO HEAT IN MAN BY CONTROLLED ELEVATION OF BODY TEMPERATURE From the Division of Human Physiology, National Institute for. : 530–547.

Fox, R. H., Goldsmith, R., Hampton, I. F. and Hunt, T. J. (1967). Heat acclimatization by controlled hyperthermia in hot-dry and hot-wet climates. Journal of Applied Physiology (on-line), 22: 39–46. http://www.scopus.com/inward/record.url?eid=2-s2.0-0014039892&partnerID=40&md5=a3318258dac6b5f012de61ff8d7ca63f.

Fox, R. H., Goldsmith, R., Kidd, D. J. and Lewis, H. E. (1963). Blood flow and other thermoregulatory changes with acclimatization to heat. The Journal of Physiology (on-line), 166: 548–562. http://doi.wiley.com/10.1113/jphysiol.1963.sp007122.

Frost, J, (2019) Nonparametric tests *vs.* parametric tests. https://statisticsbyjim.com/hypothesis-testing/nonparametric-parametric-tests/(assessed 21.06.2019).

Fujii, N., Paull, G., Meade, R. D., McGinn, R., Stapleton, J. M., Akbari, P. and Kenny, G. P. (2015). Do nitric oxide synthase and cyclooxygenase contribute to the heat loss responses in older males exercising in the heat? The Journal of Physiology (on-line), 593: 3169–3180. http://doi.wiley.com/10.1113/JP270330.

Gagge, A. P., Stolwijk, J. A. J. and Hardy, J. D. (1967). Comfort and thermal sensations and associated physiological responses at various ambient temperatures. Environmental Research (on-line), 1: 1–20. http://www.sciencedirect.com/science/article/pii/0013935167900023.

Gagnon, D. and Crandall, C. (2017). Electric fan use during heat waves: Turn off for the elderly? Temperature (on-line), 8940. http://www.tandfonline.com/doi/full/10.1080/23328940.2017.1295833

Gagnon , D., Lemire, B. B., Casa, D.J. and Kenny, G.P. (2010) Cold-Water immersion and the treatment of hyperthermia: using 38.6C as a safe rectal temperature cooling limit. Journal of Athletic training. 45(5) 439-44.

Gagnon, D., Romero, S. A., Cramer, M. N., Jay, O. and Crandall, C. G. (2016). Cardiac and Thermal Strain of Elderly Adults Exposed to Extreme Heat and Humidity With and Without Electric Fan Use. , 316: 989–991.

Garrett, A. T., Creasy, R., Rehrer, N. J., Patterson, M. J. and Cotter, J. D. (2012). Effectiveness of short-term heat acclimation for highly trained athletes. European Journal of Applied Physiology, 112: 1827–1837.

Garrett, A. T., Rehrer, N. J. and Patterson, M. J. (2011). Induction and decay of short-term heat acclimation in moderately and highly trained athletes. Sports Medicine, 41: 757–771.

Gibson, O. R., Mee, J. A., Taylor, L., Tuttle, J. A., Watt, P. W. and Maxwell, N. S. (2015a). Isothermic and fixed-intensity heat acclimation methods elicit equal increases in Hsp72 mRNA. Scandinavian Journal of Medicine and Science in Sports, 25: 259–268.

Gibson, O. R., Mee, J. A., Tuttle, J. A., Taylor, L., Watt, P. W. and Maxwell, N. S. (2015b). Isothermic and fixed intensity heat acclimation methods induce similar heat adaptation following short and long-term timescales. Journal of Thermal Biology (on-line), 49–50: 55–65. http://linkinghub.elsevier.com/retrieve/pii/S0306456515000236%5Cnhttp://www.sciencedirect.com/science/article/pii/S0306456515000236.

Gibson, O. R., Willmott, A. G. B., James, C., Hayes, M. and Maxwell, N. S. (2016). Power relative to body mass best predicts change in core temperature during exercise-heat stress. Journal of Strength and Conditioning Research (on-line): 1. http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00124278-900000000-96417.

Gibson, O. R., Wrightson, J. G. and Hayes, M. (2018). Intermittent sprint performance in the heat is not altered by augmenting thermal perception via L-menthol or capsaicin mouth rinses. European Journal of Applied Physiology (on-line), 0: 0. http://dx.doi.org/10.1007/s00421-018-4055-0.

Gillis, D. J., Barwood, M. J., Newton, P. S., House, J. R. and Tipton, M. J. (2016). The influence of a menthol and ethanol soaked garment on human temperature regulation and perception during exercise and rest in warm, humid conditions. Journal of Thermal Biology (on-line), 58: 99–105. http://linkinghub.elsevier.com/retrieve/pii/S0306456515301790.

Gillis, D. J., House, J. R. and Tipton, M. J. (2010). The influence of menthol on thermoregulation and perception during exercise in warm, humid conditions. European Journal of Applied Physiology, 110: 609–618.

Gomm, E., Grimaldi, R., Galloway, R., Sharma, S., Simpson, W. and Cottingham, R. (2016). Successful out-of-hospital therapy for heatstroke in three marathon runners with a novel core body cooling device: CAERvest®. Scandinavian Journal of Medicine and Science in Sports, 26: 854–855.

Gosling, C. M. R., Gabbe, B. J., McGivern, J. and Forbes, A. B. (2008). The incidence of heat casualties in sprint triathlon: The tale of two Melbourne race events. Journal of Science and Medicine in Sport, 11: 52–57.

Gostic, C. L. (2005). The crucial role of exercise and physical activity in weight management and functional improvement for seniors. Clinics in Geriatric Medicine, 21: 747–756.

Grogan, H. and Hopkins, P. M. (2002). Heat stroke: Implications for critical care and anaesthesia. British Journal of Anaesthesia, 88: 700–707.

Guéritée, J. and Tipton, M. J. (2015). The relationship between radiant heat, air temperature and thermal comfort at rest and exercise. Physiology & Behavior (on-line), 139: 378–385. http://linkinghub.elsevier.com/retrieve/pii/S0031938414005976.

Guo, Y., Gasparrini, A., Li, S., Sera, F., Vicedo-Cabrera, A. M., de Sousa Zanotti Stagliorio Coelho, M., Saldiva, P. H. N., *et al.,* (2018). Quantifying excess deaths related to heatwaves under climate change scenarios: A multicountry time series modelling study. PLoS Medicine, 15: 1–17.

Gupta, S., Carmichael, C., Simpson, C., Clarke, M. J., Allen, C., Gao, Y., Chan, E. Y. Y. and Murray, V. (2012). Electric fans for reducing adverse health impacts in heatwaves. The Cochrane database of systematic reviews (on-line), 7: CD009888. http://www.ncbi.nlm.nih.gov/pubmed/22786530.

Hajat, S., Kovats, R. S. and Lachowycz, K. (2007). Heat-related and cold-related deaths in England and Wales: who is at risk? Occupational and environmental medicine, 64: 93–100.

Hajat, S., Vardoulakis, S., Heaviside, C. and Eggen, B. (2014). Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. Journal of epidemiology and community health (on-line), 68: 1–8.

Haugen, H., Melanson, E., Tran, Z., Kearney, J. and Hill, J. (2003) Variability of measured resting metabolic rate. The American Journal of Clinical Nutrition. 78, 1141-1144.

Hayes, M., Castle, P. C., Ross, E. Z. and Maxwell, N. S. (2014). The influence of hot humid and hot dry environments on intermittent-sprint exercise performance. International Journal of Sports Physiology and Performance, 9: 387–396.

Heled, Y., Rav-Acha, M., Shani, Y., Epstein, Y. and Moran, D. S. (2004). The ‘golden hour’ for heatstroke treatment. Military medicine (on-line), 169: 184–6. http://www.ncbi.nlm.nih.gov/pubmed/15080235.

Holowatz, L. a, Thompson, C. S. and Kenney, W. L. (2006a). L-Arginine supplementation or arginase inhibition augments reflex cutaneous vasodilatation in aged human skin. The Journal of physiology, 574: 573–581.

Holowatz, L. a, Thompson-Torgerson, C. and Kenney, W. L. (2010). Aging and the control of human skin blood flow. Frontiers in bioscience (Landmark edition) (on-line), 15: 718–39. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3228253&tool=pmcentrez&rendertype=abstract.

Holowatz, L. A. and Kenney, W. L. (2010). Peripheral mechanisms of thermoregulatory control of skin blood flow in aged humans. Journal of Applied Physiology (on-line), 109: 1538–1544. http://www.physiology.org/doi/10.1152/japplphysiol.00338.2010.

Holowatz, L. A., Jennings, J. D., Lang, J. A. and Kenney, W. L. (2009). Ketorolac alters blood flow during normothermia but not during hyperthermia in middle-aged human skin. Journal of applied physiology (Bethesda, Md.: 1985), 107: 1121–1127.

Holowatz, L. A., Thompson, C. S., Kenney, W. L., Lacy, A., Thompson, C. S. and Ken-, W. L. (2006b). Acute ascorbate supplementation alone or combined with arginase inhibition augments reflex cutaneous vasodilation in aged human skin. , 16802: 2965–2970.

Hopkins, W. G. (2000). Measures of Reliability in Sports Medicine and Science. , 30: 1–15.

Horowitz , M. & Meiri , U. (2011). MECHANISM OF HEAT ACCLIMATION INDUCED BRADYCARDIA IN THE SAND RAT. Journal of Basic and Clinical Physiology and Pharmacology, 4(1-2), pp. 37-46. Retrieved 28 Mar. 2019, from doi:10.1515/JBCPP.1993.4.1-2.37

Horowitz, M. (2014). Heat acclimation, epigenetics, and cytoprotection memory. Comprehensive Physiology, 4: 199–230.

Howe, A. S. and Boden, B. P. (2007). Heat-related illness in athletes. The American journal of sports medicine, 35: 1384–1395.

Huggett, D. L., Connelly, D. M. and Overend, T. J. (2005). Maximal Aerobic Capacity Testing of Older Adults: A Critical Review. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences (on-line), 60: 57–66. http://biomedgerontology.oxfordjournals.org/cgi/doi/10.1093/gerona/60.1.57.

Hunt, A. P., Parker, A. W. and Stewart, I. B. (2013). Symptoms of heat illness in surface mine workers. International Archives of Occupational and Environmental Health, 86: 519–527.

Inoue, Y. (1996). Longitudinal effects of age on heat-activated sweat gland density and output in healthy active older men. European journal of applied physiology and occupational physiology, 74: 72–77.

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

Inoue, Y., Nakao, M., Okudaira, S., Ueda, H. and Araki, T. (1995). Seasonal variation in sweating responses of older and younger men. European Journal of Applied Physiology and Occupational Physiology.

Inoue, Y., Shibasaki, M., Ueda, H. and Ishizashi, H. (1999). Mechanisms underlying the age-related decrement in the human sweating response. European Journal of Applied Physiology and Occupational Physiology, 79: 121–126.

Intergovernmental Panel on Climate Change (2013). Long-term Climate Change: Projections, Commitments and Irreversibility.

James, C. A., Richardson, A. J., Watt, P. W., Gibson, O. R. and Maxwell, N. S. (2015). Physiological responses to incremental exercise in the heat following internal and external precooling. Scandinavian Journal of Medicine and Science in Sports, 25: 190–199.

James, C. A., Richardson, A. J., Watt, P. W., Willmott, A. G. B., Gibson, O. R. and Maxwell, N. S. (2017). Short-term heat acclimation improves the determinants of endurance performance and 5-km running performance in the heat. Applied Physiology, Nutrition, and Metabolism (on-line), 42: 285–294. http://www.nrcresearchpress.com/doi/10.1139/apnm-2016-0349.

Jay, O. and Brotherhood, J. R. (2016). Occupational heat stress in Australian workplaces. Temperature (on-line), 3: 394–411. http://dx.doi.org/10.1080/23328940.2016.1216256.

Jay, O. and Morris, N. B. (2018). Does Cold Water or Ice Slurry Ingestion During Exercise Elicit a Net Body Cooling Effect in the Heat? Sports Medicine (on-line), 48: 17–29. http://link.springer.com/10.1007/s40279-017-0842-8.

Jay, O., Bain, A., Cramer, M., Jay, O., Bain, A. R., Deren, T. M., Sacheli, M. and Cramer, M. N. (2011). Large differences in peak oxygen uptake do not independently alter changes in core temperature and ... in core temperature and sweating during exercise.

Jay, O., Cramer, M. N., Ravanelli, N. M. and Hodder, S. G. (2014). Should electric fans be used during a heat wave? Applied Ergonomics (on-line), 46: 137–143. http://dx.doi.org/10.1016/j.apergo.2014.07.013.

Jeffries, O., Goldsmith, M. and Waldron, M. (2018). l-Menthol mouth rinse or ice slurry ingestion during the latter stages of exercise in the heat provide a novel stimulus to enhance performance despite elevation in mean body temperature. European Journal of Applied Physiology (on-line), 0: 0. http://link.springer.com/10.1007/s00421-018-3970-4.

Jéquier, E. and Constant, F. (2010). Water as an essential nutrient: The physiological basis of hydration. European Journal of Clinical Nutrition, 64: 115–123.

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

Johnson, J. M. (2010). Exercise in a hot environment: the skin circulation. Scandinavian Journal of Medicine and Science in Sports, 20: 29–39.

Kenney, W. and Munce, T. (2003). Invited review: aging and human temperature regulation. Journal of Applied Physiology (on-line): 2598–2603. http://www.jappl.org/content/95/6/2598.short.

Kenney, W. L. (2017). Edward F. Adolph Distinguished Lecture: Skin-deep insights into vascular aging. Journal of Applied Physiology (on-line): jap.00589.2017. http://jap.physiology.org/lookup/doi/10.1152/japplphysiol.00589.2017.

Kenney, W. L. and Chiu, P. (2001). Influence of age on thirst and fluid intake. Medicine and science in sports and exercise, 33: 1524–1532.

Kenney, W. L. and Fowler, S. R. (1988). Methylcholine-activated eccrine sweat gland density and output as a function of age. Journal of applied physiology, 65: 1082–1086.

Kenney, W. L., Craighead, D. H. and Alexander, L. M. (2014). Heat waves, aging and human cardiovascular health. Medicine and Science in Sports and Exercise, 46: 1891–1899.

Kenney, W. L., Willmore, J. H and Costill, D. L. (2015) Physiology of Sport and Exercise, 6th edition, Human Kinetics.

Kenny, G. P. and Jay, O. (2013). Thermometry, calorimetry, and mean body temperature during heat stress. Comprehensive Physiology, 3: 1689–1719.

Kenny, G. P., Flouris, A. D., Yagouti, A. and Notley, S. R. (2018). Towards establishing evidence-based guidelines on maximum indoor temperatures during hot weather in temperate continental climates. Temperature (on-line), 8940: 1–26. https://www.tandfonline.com/doi/full/10.1080/23328940.2018.1456257.

Kenny, G. P., Notley, S. R. and Gagnon, D. (2017). Direct calorimetry : a brief historical review of its use in the study of human metabolism and thermoregulation. European Journal of Applied Physiology.

Kenny, G. P., Poirier, M. P., Metsios, G. S., Boulay, P., Dervis, S., Friesen, B. J., Malcolm, J., Sigal, R. J., Seely, A. J. E. and Flouris, A. D. (2016). Hyperthermia and cardiovascular strain during an extreme heat exposure in young versus older adults. Temperature (on-line), 4: 79–88. https://www.tandfonline.com/doi/full/10.1080/23328940.2016.1230171.

Kenny, G. P., Yardley, J., Brown, C., Sigal, R. J. and Jay, O. (2010). Heat stress in older individuals and patients with common chronic diseases. Canadian Medical Association Journal (on-line), 182: 1053–1060. http://www.cmaj.ca/cgi/doi/10.1503/cmaj.081050.

Kervio, G., Carre, F. and Ville, N. S. (2003). Reliability and intensity of the six-minute walk test in healthy elderly subjects. Med Sci Sports Exerc (on-line), 35: 169–174. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12544651.

Kohl, H. W., Craig, C. L., Lambert, E. V., Inoue, S., Alkandari, J. R., Leetongin, G., Kahlmeier, S., Andersen, L. B., *et al.,* (2012). The pandemic of physical inactivity: Global action for public health. The Lancet (on-line), 380: 294–305. http://dx.doi.org/10.1016/S0140-6736(12)60898-8.

Kolbe-Alexander, T. L., Lambert, E. V and Charlton, K. E. (2006). Effectiveness of a community based low intensity exercise program for older adults. The journal of nutrition, health & aging (on-line), 10: 21–9. http://www.ncbi.nlm.nih.gov/pubmed/16453054.

Koo, T. K. and Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. Journal of Chiropractic Medicine (on-line), 15: 155–163. http://dx.doi.org/10.1016/j.jcm.2016.02.012.

Kovats, R. S. and Ebi, L. K. (2006). Heatwaves and public health in Europe. European Journal of Public Health, 16: 592–599.

Kräuchi, K. and Wirz-Justice, A. (1994). Circadian rhythm of heat production, heart rate, and skin and core temperature under unmasking conditions in men. The American Journal of Physiology, 267: R819–R829.

Kwan, M., Woo, J. and Kwok, T. (2004). The standard oxygen consumption value eqivalent to one metabolic equivalent (3.5 ml/min/kg) is not appropriate for elderly people. International journal of food sciences and nutrition, 55: 179–182.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. Frontiers in Psychology, 4: 1–12.

Larose, J., Boulay, P., Sigal, R. J., Wright, H. E. and Kenny, G. P. (2013b). Age-related decrements in heat dissipation during physical activity occur as early as the age of 40. PLoS ONE, 8: 1–7.

Larose, J., Boulay, P., Wright-Beatty, H. E., Sigal, R. J., Hardcastle, S. and Kenny, G. P. (2014). Age-related differences in heat loss capacity occur under both dry and humid heat stress conditions. Journal of applied physiology (Bethesda, Md. : 1985) (on-line), 117: 69–79. http://www.ncbi.nlm.nih.gov/pubmed/24812643.

Larose, J., Wright, H. E., Sigal, R. J., Boulay, P., Hardcastle, S. and Kenny, G. P. (2013a). Do older females store more heat than younger females during exercise in the heat? Medicine and Science in Sports and Exercise, 45: 2265–2276.

Lee, J. K. W., Shirreffs, S. M. and Maughan, R. J. (2008). Cold drink ingestion improves exercise endurance capacity in the heat. Medicine and Science in Sports and Exercise, 40: 1637–1644.

Leon, A. S., Fleg, J., Simons-Morton, D. A., Chaitman, B., Froelicher, V. F., Rodney, R., Fletcher, G. F., Bazzarre, T., Amsterdam, E. A., Eckel, R., Williams, M. A., Balady, G. J. and Piña, I. L. (2013). Exercise Standards for Testing and Training. Circulation, 104: 1694–1740.

Lieberman, D. E. (2011). Human locomotion and heat loss: an evolutionary perspective. Comprehensive Physiology (on-line), 4: 33–89. http://www.ncbi.nlm.nih.gov/pubmed/24692134.

Locks, R., Costa, T. C., Koppe, S., Yamaguti, A. M., Locks, R. R., Garcia, M. C. and Gomes, A. R. S. (2012). Effects of strength and flexibility training on functional performance of healthy older people. Brazilian Journal of Physical Therapy, 16: 184–190.

Lorenzo S, Minson CT. Heat acclimation improves cutaneous vascular function and sweating in trained cyclists. J Appl Physiol (1985). 2010;109(6):1736–1743. doi:10.1152/japplphysiol.00725.2010

Lorenzo, S., Halliwill, J. R., Sawka, M. N. and Minson, C. T. (2010). Heat acclimation improves exercise performance. Journal of Applied Physiology (on-line), 109: 1140–1147.

Luber, G. and McGeehin, M. (2008). Climate Change and Extreme Heat Events. American Journal of Preventive Medicine, 35: 429–435.

M. Jones, Jonathan H. Doust, A. (1996). A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. Journal of Sports Sciences (on-line), 14: 321–327.

Maddocks, D. L. M. A., Dicker Ph.D., G. D. B. S. and Saling, M. M. P. D. (1995). The Assessment of Orientation Following Concussion in Athletes. Clinical Journal of Sport Medicine.

Mader, S. L. (1989). Aging and Postural Hypotension. Journal of the American Geriatrics Society, 37: 129–137.

Mangione, K. K., Gloviak, A. and Hofmann, M. (1999). The Effects of High-Intensity and Low-Intensity Cycle Ergometry in Older Adults With Knee Osteoarthritis. , 54.

Maughan,R.J.(2012). Hydration,horbidity, and mortality in Vaulnerable populations. *Nutrition Reviews*, 70.

McGinn, R., Poirier, M. P., Louie, J. C., Sigal, R. J., Boulay, P., Flouris, A. D. and Kenny, G. P. (2017). Increasing age is a major risk factor for susceptibility to heat stress during physical activity. Applied Physiology, Nutrition, and Metabolism (on-line): apnm-2017-0322.

Mee, J. A., Gibson, O. R., Doust, J. and Maxwell, N. S. (2015). A comparison of males and females' temporal patterning to short- and long-term heat acclimation. Scandinavian Journal of Medicine and Science in Sports, 25: 250–258.

Mee, J. A., Peters, S., Doust, J. H. and Maxwell, N. S. (2017). Sauna exposure immediately prior to short-term heat acclimation accelerates phenotypic adaptation in females. Journal of Science and Medicine in Sport (on-line): 6–11. http://dx.doi.org/10.1016/j.jsams.2017.06.024.

MET Office (2018a). 2017: warmest year on record without El Niño (on-line). https://beta.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2018/2017-temperature-announcement.

MET Office (2018b). Was summer 2018 the hottest on record? (on-line). https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2018/end-of-summer-stats.

MET Office (2018c). Heatwave (on-line). https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/temperature/heatwave.

MET Office (2018d). UK climate (on-line). https://www.metoffice.gov.uk/public/weather/climate.

MET Office (2018e). UKCP18 (on-line). https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Overview-report.pdf.

MET Office (2018f). Forecast accuracy (on-line).https://www.metoffice.gov.uk/about-us/who/accuracy/forecasts

Minett, G. M., Skein, M., Bieuzen, F., Stewart, I. B., Borg, D. N., Bach, A. J. E. and Costello, J. T. (2016). Heat acclimation for protection from exertional heat stress (Protocol). The Cochrane Collaboration.

Minson, C. T., Holowatz, L. A., Wong, B. J., Kenney, W. L. and Wilkins, B. W. (2002). Decreased nitric oxide- and axon reflex-mediated cutaneous vasodilation with age during local heating. Journal of applied physiology (Bethesda, Md. : 1985) (on-line), 93: 1644–9. http://jap.physiology.org.ezproxy.brighton.ac.uk/content/93/5/1644.full.pdf+html? Accessed 21 January 2016.

Minson, C. T., Wladkowski, S. L., Cardell, a F., Pawelczyk, J. a and Kenney, W. L. (1998). Age alters the cardiovascular response to direct passive heating. Journal of applied physiology (Bethesda, Md. : 1985), 84: 1323–1332.

Montain, S. J. and Coyle, E. F. (1992). Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. Journal of Applied Physiology (on-line), 73: 1340–1350. http://www.physiology.org/doi/10.1152/jappl.1992.73.4.1340.

Mora, C., Dousset, B., Caldwell, I. R., Powell, F. E., Geronimo, R. C., Bielecki, C. R., Counsell, C. W. W., Dietrich, B. S., Johnston, E. T., Louis, L. V., Lucas, M. P., McKenzie, M. M., Shea, A. G., Tseng, H., Giambelluca, T. W., Leon, L. R., Hawkins, E. and Trauernicht, C. (2017). Global risk of deadly heat. Nature Climate Change (on-line), 7: 501–506. http://www.nature.com/doifinder/10.1038/nclimate3322.

Morris, N.B., Coombs,G. And Jay, O.(2016). Ice slurry ingestion leads to a lower net heat loss during exercise in the heat. *Medicine and science in sports and exercise*, 48:114-122.

Mündel, T. and Jones, D. (2010) The effects of swilling an L(-)-menthol solution during exercise in the heat. European Journal of Applied Physiology, 109, 59-65.

Mündel, T., King, J., Collacott, E. and Jones, D. A. (2006). Drink temperature influences fluid intake and endurance capacity in men during exercise in a hot, dry environment. Experimental physiology, 91: 925–933.

Nadir, M. N., Kachela, B., Nadir, N. and Khan, Z. (2016). A detailed account of heat stroke. , 20: 1–4.

Nakagawa, S. and Cuthill, I. C. (2007). Effect size, confidence interval and statistical significance: A practical guide for biologists. Biological Reviews, 82: 591–605.

National Institute of Health (2016). The World report on ageing and health: A policy framework for healthy ageing. The Lancet (on-line), 387: 2145–2154. http://dx.doi.org/10.1016/S0140-6736(15)00516-4.

Neal, R. A., Corbett, J., Massey, H. C. and Tipton, M. J. (2016). Effect of short-term heat acclimation with permissive dehydration on thermoregulation and temperate exercise performance. Scandinavian Journal of Medicine and Science in Sports, 26: 875–884.

New Scientist. (2003). European Heatwave caused 35,000 deaths (on-line). https://www.newscientist.com/article/dn4259-european-heatwave-caused-35000-deaths/.

NHS (2009). Change 4 life (on-line). https://www.nhs.uk/change4life/ .

Nielsen, B. Y. B., Hales, J. R. S., Strange, S. and Juel, N. (1993). Thermoregulatory adaptations. The Journal of physiology, 460: 467–485.

Noakes, T. D. (1993). Fluid replacement during exercise. Exercise and sport sciences reviews (on-line), 21: 297–330. http://www.ncbi.nlm.nih.gov/pubmed/8504845.

Notley, S., Dervis, S., Poirier, M. and Kenny, G. (2018a) Menstrual cycle phase does not modulate whole-body heat loss during exercise in hot, dry conditions. Journal of Applied Physiology 126(2).

Notley, S. R., Meade, R. D., D'Souza, A. W., McGarr, G. W. and Kenny, G. P. (2018b). Cumulative effects of successive workdays in the heat on thermoregulatory function in the aging worker. Temperature (on-line), 5: 293–295. https://www.tandfonline.com/doi/full/10.1080/23328940.2018.1512830,

Notley, S. R., Poirier, M. P., Hardcastle, S. P., Flouris, A. D., Boulay, P., Sigal, R. J. and Kenny, G. P. (2017). Aging Impairs Whole-Body Heat Loss in Females under Both Dry and Humid Heat Stress. Medicine & Science in Sports & Exercise (on-line): 1. http://insights.ovid.com/crossref?an=00005768-900000000-97186.

Office for National Statistics (2014). National Population Projections: 2014-based Statistical Bulletin. https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/nationalpopulationprojections/2015-10-29.

Office for National Statistics (2017). Overview of the UK Population: July 2017. Office for National Statistics (on-line): 1–17. https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/articles/overviewoftheukpopulation/july2017.

Otto, F. E. L., Massey, N., Van Oldenborgh, G. J., Jones, R. G. and Allen, M. R. (2012). Reconciling two approaches to attribution of the 2010 Russian heat wave. Geophysical Research Letters, 39: 1–5.

Parsons, K. (2014). Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance, Third Edition - CRC Press Book (on-line). https://www.crcpress.com/Human-Thermal-Environments-The-Effects-of-Hot-Moderate-and-Cold-Environments/Parsons/9781466595996. Accessed 28 April 2016.

Patterson, M. J. (2004). Humid heat acclimation does not elicit a preferential sweat redistribution toward the limbs. AJP: Regulatory, Integrative and Comparative Physiology (on-line), 286: 512R–518. http://ajpregu.physiology.org/cgi/doi/10.1152/ajpregu.00359.2003.

Patterson, M. J., Stocks J. M. and Taylor N. A. S. (2014) Whole-body fluid distribution in humans during dehydration and recovery, before and after humid-heat acclimation induced using controlled hyperthermia. Acta Physiologica, 2010, 899-912.

Peier, A. M., Moqrich, A., Hergarden, A. C., Reeve, A. J., Andersson, D. A., Story, G. M., Earley, T. J., Dragoni, I., Mcintyre, P., Bevan, S., Patapoutian, A. and Diego, S. (2002). A TRP Channel that Senses Cold Stimuli and Menthol. , 108: 705–715.

Périard, J. D., Racinais, S. and Sawka, M. N. (2015). Adaptations and mechanisms of human heat acclimation: Applications for competitive athletes and sports. Scandinavian Journal of Medicine & Science in Sports (on-line), 25: 20–38. http://doi.wiley.com/10.1111/sms.12408.

Périard, J. D., Travers, G. J. S., Racinais, S. and Sawka, M. N. (2016). Cardiovascular adaptations supporting human exercise-heat acclimation. Autonomic Neuroscience (on-line). http://linkinghub.elsevier.com/retrieve/pii/S1566070216300078.

Perkins, S. E., Alexander, L. V. and Nairn, J. R. (2012). Increasing frequency, intensity and duration of observed global heatwaves and warm spells. Geophysical Research Letters, 39: 1–5.

Phillips, P. A., Rolls, B. J., Ledingham, J. G. G., Forsling, M. L., Morton, J. J., Crowe, M. J. and Wollner, L. (1984). Reduced Thirst after Water Deprivation in Healthy Elderly Men. New England Journal of Medicine (on-line), 311: 753–759. http://www.nejm.org/doi/abs/10.1056/NEJM198603063141003.

Porcari, J., Bryant, C. and Comana, F. (2015). Environmental Physiology. F.A.Davis Company.

Public Health England (2015). Heatwave Plan for England.

Public Health England (2016). One You (on-line). https://campaignresources.phe.gov.uk/resources/campaigns/44-one-you %0A%09%0A.

Public Health England (2017). One You (on-line).

Public Health England (2018). Beat the heat. , 9: 67–73.

Racinais, S., Alonso, J. M., Coutts, A. J., Flouris, A. D., Girard, O., González-Alonso, J., Hausswirth, C., Jay, O., Lee, J. K. W., Mitchell, N., Nassis, G. P., Nybo, L., Pluim, B. M., Roelands, B., Sawka, M. N., Wingo, J. and Périard, J. D. (2015). Consensus recommendations on training and competing in the heat. British Journal of Sports Medicine, 49: 1164–1173.

Racinais, S., Mohr, M., Buchheit, M., Voss, S. C., Gaoua, N., Grantham, J. and Nybo, L. (2012). Individual responses to short-term heat acclimatisation as predictors of football performance in a hot, dry environment. British Journal of Sports Medicine, 46: 810–815.

Racinais, S., Wilson, M. G., Gaoua, N. and Périard, J. D. (2017). Heat acclimation has a protective effect on the central but not peripheral nervous system. Journal of Applied Physiology (on-line): jap.00430.2017. http://jap.physiology.org/lookup/doi/10.1152/japplphysiol.00430.2017.

Ramanathan, N. L. (1964). A new weighting system for mean surface temperature of the human body. Journal of applied physiology.

Ravanelli, N. M., Hodder, S. G., Havenith, G. and Jay, O. (2015). Heart rate and body temperature responses to extreme heat and humidity with and without electric fans. Jama (on-line), 313: 724–5. http://jama.jamanetwork.com/article.aspx?articleid=2110959.

Reid, C. E.,O'Neill, M.S., Gronlund C. J., Brines S.J., Brown, D.G., Diez-Roux, A. V. and Schwartz J. (2009). Mapping community determinants of heat vulnerability. Environmental Health Perspectives 117(11): 1730-1736.

Relf, R., Willmott, A., Mee, J., Gibson, O., Saunders, A., Hayes, M. and Maxwell, N. (2017). Females exposed to 24 h of sleep deprivation do not experience greater physiological strain, but do perceive heat illness symptoms more severely, during exercise-heat stress. Journal of Sports Sciences (on-line), 0: 1–8.

Rida, M., Ghaddar, N., Ghali, K. and Hoballah, J. (2014). Elderly bioheat modeling: changes in physiology, thermoregulation, and blood flow circulation. International Journal of Biometeorology: 1–19.

Rikkert, M. G. M., Melis, R. J. F. and Claassen, J. A. H. R. (2009). Heat waves and dehydration in the elderly. BMJ (Online), 339: 119.

Roach, R. C., Bartsch, P., Hackett, P. H. and Oelz, O. (1993). The Lake Louise Acute Mountain Sickness Scoring System 272–274.

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

Robinson, J., Charlton, J., Seal, R., Spady, D. and Joffres, M. R. (1998). Oesophageal, rectal, axillary, tympanic and pulmonary artery temperatures during cardiac surgery. Canadian Journal of Anaesthesia, 45: 317–323.

Ross, M., Abbiss, C., Laursen, P., Martin, D. and Burke, L. (2013). Precooling methods and their effects on athletic performance: A systematic review and practical applications. Sports Medicine, 43: 207–225.

Rowell, L. B., Marx, H. J., Bruce, R. A., Conn, R. D. and Kusumi, F. (1966). Reductions in cardiac output, central blood volume, and stroke volume with thermal stress in normal men during exercise. The Journal of clinical investigation, 45: 1801–1816.

Ruddock, A., Robbins, B., Tew, G., Bourke, L. and Purvis, A. (2017). Practical Cooling Strategies During Continuous Exercise in Hot Environments: A Systematic Review and Meta-Analysis. Sports Medicine, 47: 517–532.

Ruijs ACJ, Jaquet JB, Daanen HAM, Hovius SER (2006) Cold Intolerance of the hand measured by the CISS questionnaire in a normative study population. Journal of Hand Surgery 31 (5):533-536. doi:10.1016/j.jhsb.2006.04.013

Rutherford, T. (2012). Population ageing: statistics. House of Commons library (Standard not. … (on-line): 1–8. http://www.parliament.uk/business/publications/research/briefing-papers/SN03228.pdf.

Sampson, J. B. and Kobrick, J. L. (1980). The environmental symptoms questionnaire: Revisions and new field data. Aviation Space and Environmental Medicine.

Sampson, J. B., Cymerman, A., Burse, R. L., Maher, J. T. and Rock, P. B. (1983). Procedures for the measurement of acute mountain sickness. Aviation Space and Environmental Medicine.

Sampson, N. R., Gronlund, C. J., Buxton, M. A., Catalano, L., White-Newsome, J. L., Conlon, K. C., O'Neill, M. S., McCormick, S. and Parker, E. A. (2013). Staying cool in a changing climate: Reaching vulnerable populations during heat events. Global Environmental Change (on-line), 23: 475–484. http://dx.doi.org/10.1016/j.gloenvcha.2012.12.011.

Sanderson, M., Arbuthnott, K., Kovats, S., Hajat, S. and Falloon, P. (2017). The use of climate information to estimate future mortality from high ambient temperature : A systematic literature review.

Sato, F., Owen, M., Matthes, R., Sato, K. and Gisolfi, C. V (1990). Functional and morphological gland with heat acclimation changes in the eccrine sweat. : 232–236.

Sato, K. and Sato, F. (1983). Individual variations in structure and function of human eccrine sweat gland. The American journal of physiology (on-line), 245: R203-8. http://ajpregu.physiology.org/content/245/2/R203.abstract. Accessed 28 April 2016.

Savourey, G., Guinet, A., Besnard, Y., Garcia, N., Hanniquet, A. M. and Bittel, J. (1995). Evaluation of the Lake Louise acute mountain sickness scoring system in a hypobaric chamber. Aviation Space and Environmental Medicine.

Sawka, M. N. and Young, A. J. (2000a). Exercise in hot and cold climates. In: G. WE & K. DT (eds) Exercise and Sport Science. Philadelphia: Lippincott Williams and Wilkins. pp.385–400.

Sawka, M. N. and Young, A. J. (2000b). Physical exercise in hot and cold climates. In: Exercise and Sport Science. pp.385–400.

Sawka, M. N. and Young, Y. J. (2006). Physiological Systems and Their Responses to Conditions of heat and cold. ACSM's Advanced Exercise Physiology: 535–563.

Sawka, M. N., Burke, L. M., Eichner, E. R., Maughan, R. J., Montain, S. J. and Stachenfeld, N. S. (2007). Exercise and fluid replacement. Medicine and Science in Sports and Exercise, 39: 377–390.

Sawka, M. N., Leon, L. R., Montain, S. J. and Sonna, L. A. (2011). Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. Comprehensive Physiology, 1: 1883–1928.

Sawka, M. N., Pandolf, K. B., Avellini, B. . and Shapiro, Y. (1983). Does heat acclimation lower the rate of metabolism elicited by muscular exercise? Aviat Space Environ Med., 54: 27–31.

Scarborough, P., Bhatnagar, P., Wickramasinghe, K. K., Allender, S., Foster, C. and Rayner, M. (2011). The economic burden of ill health due to diet, physical inactivity, smoking, alcohol and obesity in the UK: An update to 2006-07 NHS costs. Journal of Public Health, 33: 527–535.

Schlader, Z. (2014). The relative overlooking of human behavioral temperature regulation: An issue worth resolving. Temperature (on-line), 1: 20–21. http://www.tandfonline.com/doi/abs/10.4161/temp.29235.

Schlader, Z. J., Coleman, G. L., Sackett, J. R., Sarker, S., Chapman, C. L., Hostler, D. and Johnson, B. D. (2017). Behavioral thermoregulation in older adults with cardiovascular co-morbidities. Temperature (on-line), 8940: 1–16. https://www.tandfonline.com/doi/full/10.1080/23328940.2017.1379585.

Schlader, Z. J., Perry, B. G., Jusoh, M. R. C., Hodges, L. D., Stannard, S. R. and Mündel, T. (2013). Human temperature regulation when given the opportunity to behave. European Journal of Applied Physiology, 113: 1291–1301.

Schlader, Z. J., Prange, H. D., Mickleborough, T. D. and Stager, J. M. (2009). Characteristics of the control of human thermoregulatory behavior. Physiology & behavior (on-line), 98: 557–62. http://www.sciencedirect.com/science/article/pii/S0031938409003011.

Schlader, Z. J., Stannard, S. R. and Mündel, T. (2010). Human thermoregulatory behavior during rest and exercise - A prospective review. Physiology and Behavior, 99: 269–275.

Scoon, G. S. M., Hopkins, W. G., Mayhew, S. and Cotter, J. D. (2007). Effect of post-exercise sauna bathing on the endurance performance of competitive male runners. Journal of Science and Medicine in Sport, 10: 259–262.

Scott, A., Antonishen, K., Johnston, C., Pearce, T., Ryan, M., Sheel, A. W. and McKenzie, D. C. (2006). Effect of Semirecumbent and Upright Body Position on Maximal and Submaximal Exercise Testing. Measurement in Physical Education and Exercise Science (on-line), 10: 41–50. http://www.tandfonline.com/doi/abs/10.1207/s15327841mpee1001_3.

Semenza, J. C., Mccullough, J. E., Flanders, W. D., Mcgeehin, M. A. and Lumpkin, J. R. (1999). the July 1995 Heat Wave in Chicago. American Journal of Preventive Medicine (on-line), 16: 269–277. http://linkinghub.elsevier.com/retrieve/pii/s0749-3797(99)00025-2.

Settles, T. L. (2012). Federalism, law, and the ethics of disaster evacuations. Emerald Group Publishing Ltd. http://dx.doi.org/10.1108/S1521-6136(2012)0000017007.

Shanklin, J. and Colwell, S. (2005). Letters: The UK’s hottest day on record. Weather (on-line), 60: 25–25. http://doi.wiley.com/10.1256/wea.208.04.

Shapiro, Y., Hubbard, R. W., Kimbrough, C. M. and Pandolf, K. B. (1981). Physiological and hematologic responses to summer and winter dry-heat acclimation. Journal of applied physiology (Bethesda, Md. : 1985).

Shibasaki, M. and Crandall, C. G. (2011). Mechanisms and controllers of eccrine sweating in humans. European Economic Review, 2: 685–696.

Shibasaki, M., Wilson, T. E. and Crandall, C. G. (2006). Neural control and mechanisms of eccrine sweating during heat stress and exercise. Journal of applied physiology (Bethesda, Md. : 1985), 100: 1692–1701.

Shirreffs, S. M., Taylor, A., Leiper, J., Maughan, R., (1996). Post-exercise rehydration in man: effects of volume consumed and drink sodium content. Medicine and Science in Sports and Exercise, 28, 1260-1271.

Siegel, R., Maté, J., Brearley, M. B., Watson, G., Nosaka, K. and Laursen, P. B. (2010). Ice slurry ingestion increases core temperature capacity and running time in the heat. Medicine and Science in Sports and Exercise, 42: 717–725.

Siegel, R., Maté, J., Watson, G., Nosaka, K. and Laursen, P. B. (2012). Pre-cooling with ice slurry ingestion leads to similar run times to exhaustion in the heat as cold water immersion. Journal of Sports Sciences, 30: 155–165.

Siri, W. E. (1956). The Gross Composition of the Body. In: Advances in biological and medical physics. pp.239–280. http://linkinghub.elsevier.com/retrieve/pii/B978148323110550011X.

Smith, S., Elliot, A. J., Hajat, S., Bone, A., Smith, G. E. and Kovats, S. (2016). Estimating the burden of heat illness in England during the 2013 summer heatwave using syndromic surveillance. Journal of epidemiology and community health, 70: 459–465.

Smoyer-Tomic, K. E. and Rainham, D. G. C. (2001). Beating the Heat: Development and Evaluation of a Canadian Hot Weather Health-Response Plan. Environmental Health Perspectives (on-line), 109: 1241. http://www.ncbi.nlm.nih.gov/pubmed/1240506.

Snellen, J. W., Chang, K. S. and Smith, W. (1983). Technical description and performance characteristics of a human whole-body calorimeter. Medical & Biological Engineering & Computing, 21: 9–20.

Southard, A., Niermeyer, S. and Yaron, M. (2007). Language Used in Lake Louise Scoring System Underestimates Symptoms of Acute Mountain Sickness in 4- to 11-Year-Old Children. , 8: 124–130.

Speechley, M., & Tinetti, M.R. (1991). Falls and injuries in frail and vigorous community elderly persons. Journal of the American Geriatrics Society, 39, 46-52. Taylor-Davis

Stachenfeld, N. S., DiPietro, L., Nadel, E. R. and Mack, G. W. (1997). Mechanism of attenuated thirst in aging: role of central volume receptors. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology (on-line), 272: R148–R157. http://www.physiology.org/doi/10.1152/ajpregu.1997.272.1.R148.

Stachenfeld, N. S., Mack, G. W., Takamata, A., DiPietro, L. and Nadel, E. R. (1996). Thirst and fluid regulatory responses to hypertonicity in older adults. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology (on-line), 271: R757–R765. http://www.physiology.org/doi/10.1152/ajpregu.1996.271.3.R757.

Stanley, J., Halliday, A., Auria, S. D., Buchheit, M. and Leicht, A. S. (2015). Effect of sauna‐based heat acclimation on plasma volume and heart rate variability. European Journal of Applied Physiology: 785–794.

Stapleton, J. M., Fujii, N., Carter, M. and Kenny, G. P. (2014a). Diminished nitric oxide-dependent sweating in older males during intermittent exercise in the heat. Experimental Physiology (on-line), 99: 921–932. http://www.scopus.com/inward/record.url?eid=2-s2.0-84901482690&partnerID=40&md5=41f75a3cac811ef5a4b5aa7ef17d3914.

Stapleton, J. M., Larose, J., Simpson, C., Flouris, A. D., Sigal, R. J. and Kenny, G. P. (2014b). Do older adults experience greater thermal strain during heat waves? Applied physiology, nutrition, and metabolism (on-line), 39: 292–8. http://www.ncbi.nlm.nih.gov/pubmed/24552369.

Stapleton, J. M., Poirier, M. P., Flouris, A. D., Boulay, P., Sigal, R. J., Malcolm, J. and Kenny, G. P. (2014c). Aging impairs heat loss, but when does it matter? Journal of Applied Physiology (on-line), 118: 299–309. http://jap.physiology.org/lookup/doi/10.1152/japplphysiol.00722.2014.

Stapleton, J. M., Poirier, M. P., Flouris, A. D., Boulay, P., Sigal, R. J., Malcolm, J. and Kenny, G. P. (2015). At what level of heat load are age-related impairments in the ability to dissipate heat evident in females? PLoS ONE (on-line), 10: 1–17. http://dx.doi.org/10.1371/journal.pone.0119079.

Stevens, C. J. and Best, R. (2017). Menthol: A Fresh Ergogenic Aid for Athletic Performance. Sports Medicine, 47: 1035–1042.

Stevens, C. J., Taylor, L. and Dascombe, B. J. (2017). Cooling During Exercise: An Overlooked Strategy for Enhancing Endurance Performance in the Heat. Sports Medicine, 47: 829–841.

Stevens, C. J., Thoseby, B., Sculley, D. V., Callister, R., Taylor, L. and Dascombe, B. J. (2015). Running performance and thermal sensation in the heat are improved with menthol mouth rinse but not ice slurry ingestion. Scandinavian Journal of Medicine & Science in Sports (on-line), 26: 1209–1216. http://doi.wiley.com/10.1111/sms.12555.

Stotz, A., Rapp, K., Oksa, J., Skelton, D. A., Beye, N., Klenk, J., Becker, C. and Lindemann, U. (2014). Effect of a brief heat exposure on blood pressure and physical performance of older women living in the community???a pilot-study. International Journal of Environmental Research and Public Health, 11: 12623–12631.

Sun, F., Norman, I. J. and While, A. E. (2013). Physical activity in older people: A systematic review. BMC Public Health, 13.

Tansey, E. A. and Johnson, C. D. (2015). Recent advances in thermoregulation. Advances in Physiology Education (on-line), 39: 139–148. http://ajpadvan.physiology.org/lookup/doi/10.1152/advan.00126.2014.

Taylor, D. (2014b). Physical activity is medicine for older adults. Postgraduate medical journal (on-line), 90: 26–32. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3888599&tool=pmcentrez&rendertype=abstract.

Taylor, N. a S. (2006). Challenges to temperature regulation when working in hot environments. Industrial health, 44: 331–344.

Taylor, N. a S. (2014a). Human heat adaptation. Comprehensive Physiology, 4: 325–365.

Taylor, N. A. and Cotter, J. D. (2006). ISMJ International SportMed Journal Heat adaptation: Guidelines for the optimisation of human performance. International SportMed Journal Official Journal of FIMS (International Federation of Sports Medicine) International SportMed Journal (on-line), 77: 33–5732. http://www.ismj.com.

Taylor, N. A. S. (2000). Principles and practices of heat adaptation. Journal of the Human Environmental System, 4: 11–22.

Taylor, N. A. S., Allsopp, N. K. and Parkes, D. G. (1995). Preferred Room Temperature of Young vs Aged Males: The Influence of Thermal Sensation, Thermal Comfort, and Affect. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences (on-line), 50A: M216–M221. https://academic.oup.com/biomedgerontology/article-lookup/doi/10.1093/gerona/50A.4.M216.

Taylor, N. A. S., Allsopp, N. K. and Parkes, D. G. (1995). Preferred Room Temperature of Young vs Aged Males: The Influence of Thermal Sensation, Thermal Comfort, and Affect. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences (on-line), 50A: M216–M221. https://academic.oup.com/biomedgerontology/article-lookup/doi/10.1093/gerona/50A.4.M216.

Telegraph, T. (2017). Which islands have been worst hit by Hurricane Irma and what is the advice for travellers headed to Florida? (on-line). https://www.telegraph.co.uk/travel/destinations/caribbean/articles/hurricane-irma-hotels-open-island-damage/.

The Guardian (2017). They let people die': searching for justice after Florida's nursing home tragedy (on-line). https://www.theguardian.com/us-news/2017/nov/07/hurricane-irma-florida-nursing-home-deaths-lawsuit.

The New York Times (2017). Hurricane Irma in Florida (on-line). https://www.nytimes.com/2017/09/09/world/americas/hurricane-irma-photos.html.

Theocharis, G., Tansarli, G. S., Mavros, M. N., Spiropoulos, T., Barbas, S. G. and Falagas, M. E. (2013). Association between use of air-conditioning or fan and survival of elderly febrile patients: A prospective study. European Journal of Clinical Microbiology and Infectious Diseases, 32: 1143–1147.

Tipton, M. (2018). Humans: A homeothermic animal that need perturbation? Experimental Physiology.

Tipton, M. J., Pandolf, K. B., Sawka, M. N., Werner, J. and Taylor, N. A. S. (2002). Physiological adaptation to hot and cold environments. Physiological bases of human performance during work and exercise: 379–400.

Townsend, N., Wickramasinghe, K., Williams, J., Bhatnagar, P. and Rayner, M. (2015). Physical activity statistics. British Heart Foundation: 1–128.

Tyler, C. J., Reeve, T., Hodges, G. J. and Cheung, S. S. (2016). The Effects of Heat Adaptation on Physiology, Perception and Exercise Performance in the Heat: A Meta-Analysis. Sports Medicine (on-line). http://link.springer.com/10.1007/s40279-016-0538-5.

Tyler, C. J., Sunderland, C. and Cheung, S. S. (2015). The effect of cooling prior to and during exercise on exercise performance and capacity in the heat : a meta-analysis. : 7–13.

Tyler, C. J., Wild, P. and Sunderland, C.(2010). Practical neck cooling and time-trial running performance in a hot environment. European Journal of Applied Physiology, 110: 1063-1074.

Vargas, N. T., Slyer, J., Chapman, C. L., Johnson, B. D., Temple, J. L., Mietlicki-Baase, E. G. and Schlader, Z. J. (2018). The motivation to behaviorally thermoregulate during passive heat exposure in humans is dependent on the magnitude of increases in skin temperature. Physiology and Behavior (on-line), 194: 545–551. https://doi.org/10.1016/j.physbeh.2018.07.009.

United Nations, (2015). World population ageing. https://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2015_Report.pdf

Vincent, W. and Weir, J. (1994). Statistics in Kinesiology.

Waters, T. A. (2001). Heat illness: Tips for recognition and treatment. Cleveland Clinic Journal of Medicine, 68: 685–687.

Watkins, E. R., Hayes, M., Watt, P. and Richardson, A. J. (2018). Practical pre-cooling methods for occupational heat exposure. Applied Ergonomics (on-line), 70: 26–33. https://doi.org/10.1016/j.apergo.2018.01.011.

Webborn, N., Price, M. J., Castle, P. and Goosey-Tolfrey, V. L. (2010). Cooling strategies improve intermittent sprint performance in the heat of athletes with tetraplegia. British journal of sports medicine, 44: 455–460.

Wenger, C. B. (1972). Heat of evaporation of sweat: thermodynamic considerations. Journal of Applied Physiology, 32: 456–459.

Willmott, A. G. B., Gibson, O. R., Hayes, M. and Maxwell, N. S. (2016). The effects of single versus twice daily short term heat acclimation on heat strain and 3000m running performance in hot, humid conditions. Journal of Thermal Biology (on-line), 56: 59–67. http://linkinghub.elsevier.com/retrieve/pii/S0306456515301406.

Willmott, A. G. B., Gibson, O. R., Hayes, M. and Maxwell, N. S. (2016). The effects of single versus twice daily short term heat acclimation on heat strain and 3000m running performance in hot, humid conditions. Journal of Thermal Biology (on-line), 56: 59–67. http://linkinghub.elsevier.com/retrieve/pii/S0306456515301406.

Willmott, A. G. B., Hayes, M., James, C. A., Dekerle, J. and Gibson, O. R. (2018). Once- and twice-daily heat acclimation confer similar heat adaptations , inflammatory responses and exercise tolerance improvements Once- and twice-daily heat acclimation confer similar heat adaptations , inflammatory responses and exercise tolerance improvements.

Wilson, T. M. and Tanaka, H. (2000). Meta-analysis of the age-associated decline in maximal aerobic capacity in men: relation to training status. American journal of physiology. Heart and circulatory physiology, 278: H829–H834.

World Health Organisation (2011). Public health advice on preventing health effects of heat. New and updated information for different audiences (on-line). http://www.euro.who.int/en/what-we-do/health-topics/environment-and-health/Climate-change/publications/2011/public-health-advice-on-preventing-health-effects-of-heat.-new-and-updated-information-for-different-audiences.

World Health Organisation (2013). Declaration of Helsinki World Medical Association Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects. The Journal of the American Medical Association, 310: 2191–2194.

Wragg, C. B., Maxwell, N. S. and Doust, J. H. (2000). Evaluation of the reliability and validity of a soccer-specific field test of repeated sprint ability. European Journal of Applied Physiology, 83: 77–83.

Wright, A. D., Jones, G. T., Fletcher, R. F., Mackintosh, J. H. and Bradwell, A. R. (1985). The Environmental Symptoms Questionnaire in acute mountain sickness. Aviation Space and Environmental Medicine.

Young, A. J., Sawka, M. N., Epstein, Y., Decristofano, B. and Pandolf, K. B. (1987). Cooling different body surfaces during upper and lower body exercise. Journal of applied physiology.

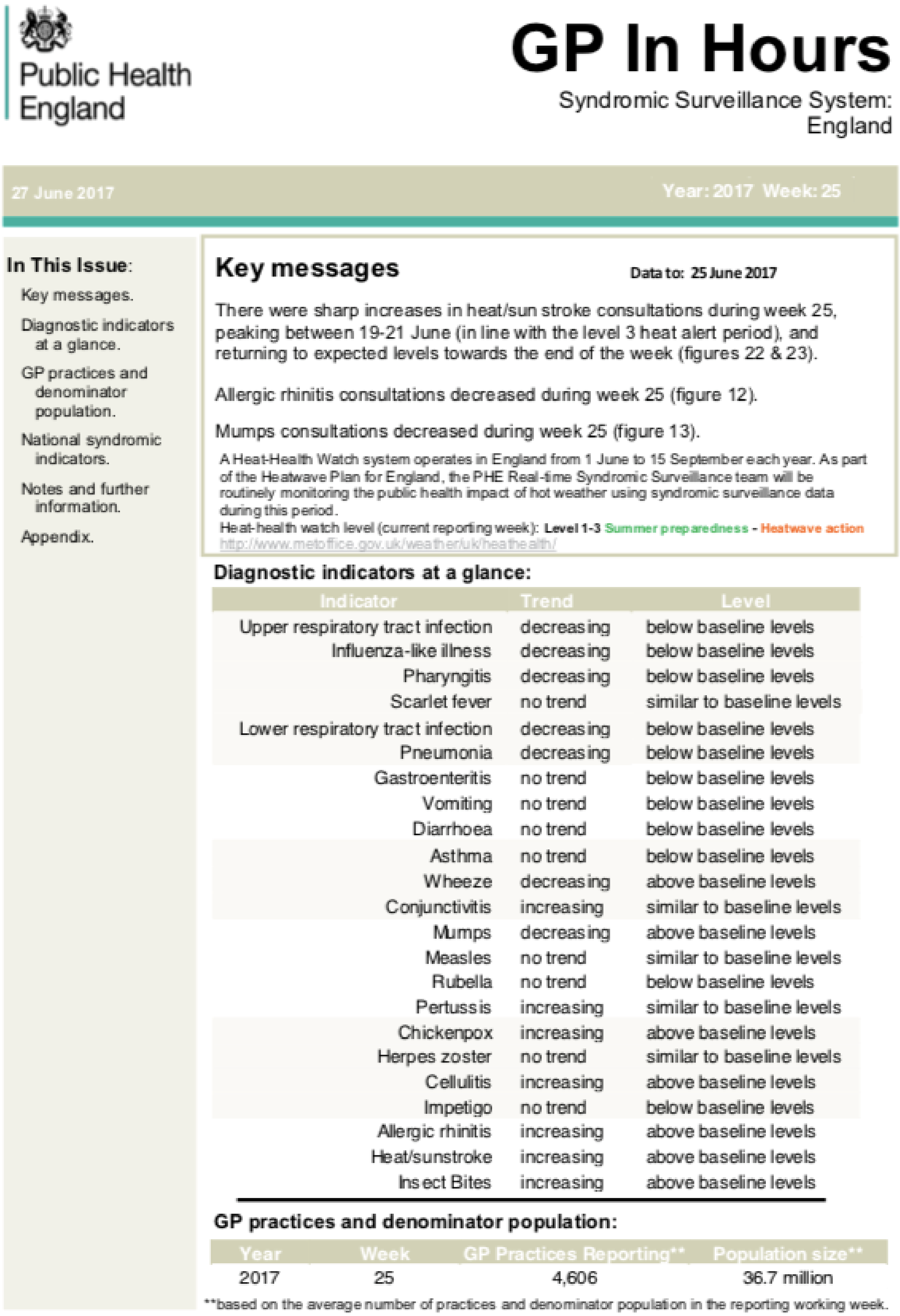
Younggren, B. N., Army, U. S., Program, A., Medicine, E., Program, R., Army, M., Lewis, F., Yao, C., Resident, S., Reviewers, P., Bowman, A. J., Care, P., Education, C., Hospital, H., Greater, C., Health, L. and Slovis, C. M. (2006). The Evaluation and Management of Heat Injuries in the Emergency Department. Emergency medicine practice, 8.

Zurawlew, M. J., Walsh, N. P., Fortes, M. B. and Potter, C. (2015). Post-exercise hot water immersion induces heat acclimation and improves endurance exercise performance in the heat. Scandinavian Journal of Medicine and Science in Sports.

Chapter 11 Appendices

List of Appendices

Appendix A: Example of the weekly report from Public Health England of the most prevalent reasons to visit the G.P.



Public Health England

GP In Hours

Syndromic Surveillance System: England

27 June 2017

Year: 2017 Week: 25

In This Issue:

- Key messages.
- Diagnostic indicators at a glance.
- GP practices and denominator population.
- National syndromic indicators.
- Notes and further information.
- Appendix.

Key messages

Data to: 25 June 2017

There were sharp increases in heat/sun stroke consultations during week 25, peaking between 19-21 June (in line with the level 3 heat alert period), and returning to expected levels towards the end of the week (figures 22 & 23).

Allergic rhinitis consultations decreased during week 25 (figure 12).

Mumps consultations decreased during week 25 (figure 13).

A Heat-Health Watch system operates in England from 1 June to 15 September each year. As part of the Heatwave Plan for England, the PHE Real-time Syndromic Surveillance team will be routinely monitoring the public health impact of hot weather using syndromic surveillance data during this period.

Heat-health watch level (current reporting week): **Level 1-3** Summer preparedness - Heatwave action

http://www.metoffice.gov.uk/weather/uk/heathealth/

Diagnostic indicators at a glance:

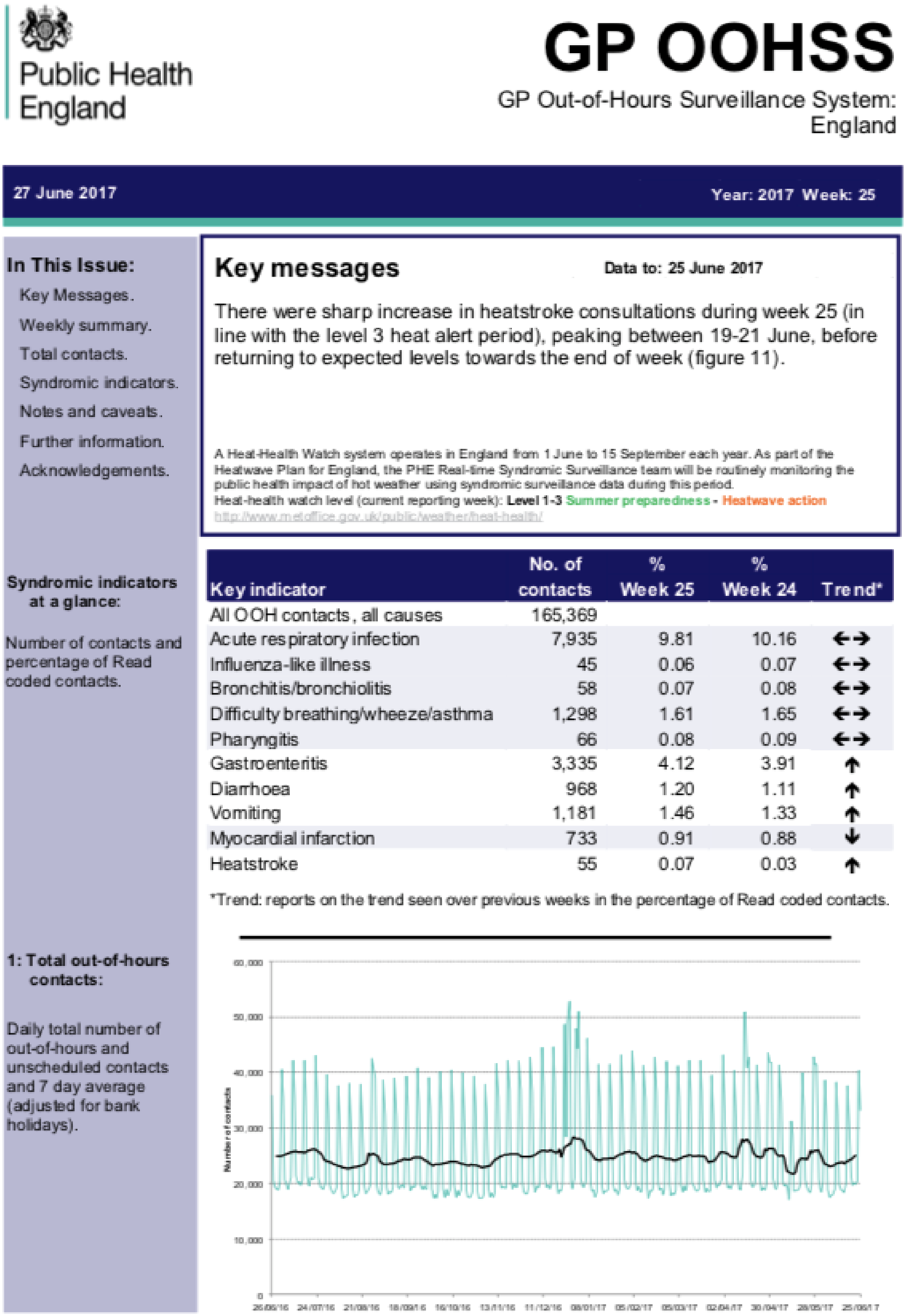
Indicator	Trend	Level
Upper respiratory tract infection	decreasing	below baseline levels
Influenza-like illness	decreasing	below baseline levels
Pharyngitis	decreasing	below baseline levels
Scarlet fever	no trend	similar to baseline levels
Lower respiratory tract infection	decreasing	below baseline levels
Pneumonia	decreasing	below baseline levels
Gastroenteritis	no trend	below baseline levels
Vomiting	no trend	below baseline levels
Diarrhoea	no trend	below baseline levels
Asthma	no trend	below baseline levels
Wheeze	decreasing	above baseline levels
Conjunctivitis	increasing	similar to baseline levels
Mumps	decreasing	above baseline levels
Measles	no trend	similar to baseline levels
Rubella	no trend	below baseline levels
Pertussis	increasing	similar to baseline levels
Chickenpox	increasing	above baseline levels
Herpes zoster	no trend	similar to baseline levels
Cellulitis	increasing	above baseline levels
Impetigo	no trend	below baseline levels
Allergic rhinitis	increasing	above baseline levels
Heat/sunstroke	increasing	above baseline levels
Insect Bites	increasing	above baseline levels

GP practices and denominator population:

Year	Week	GP Practices Reporting**	Population size**
2017	25	4,606	36.7 million

**based on the average number of practices and denominator population in the reporting working week.

Appendix B: Example of the weekly report from Public Health England of the most prevalent reasons to visit the out of hours G.P.



Public Health England

GP OOHSS

GP Out-of-Hours Surveillance System: England

27 June 2017 **Year: 2017 Week: 25**

In This Issue:

- Key Messages.
- Weekly summary.
- Total contacts.
- Syndromic indicators.
- Notes and caveats.
- Further information.
- Acknowledgements.

Key messages

Data to: 25 June 2017

There were sharp increase in heatstroke consultations during week 25 (in line with the level 3 heat alert period), peaking between 19-21 June, before returning to expected levels towards the end of week (figure 11).

A Heat-Health Watch system operates in England from 1 June to 15 September each year. As part of the Heatwave Plan for England, the PHE Real-time Syndromic Surveillance team will be routinely monitoring the public health impact of hot weather using syndromic surveillance data during this period.
Heat-health watch level (current reporting week): **Level 1-3** Summer preparedness - Heatwave action
http://www.metoffice.gov.uk/public/weather/heat-health/

Syndromic indicators at a glance:

Number of contacts and percentage of Read coded contacts.

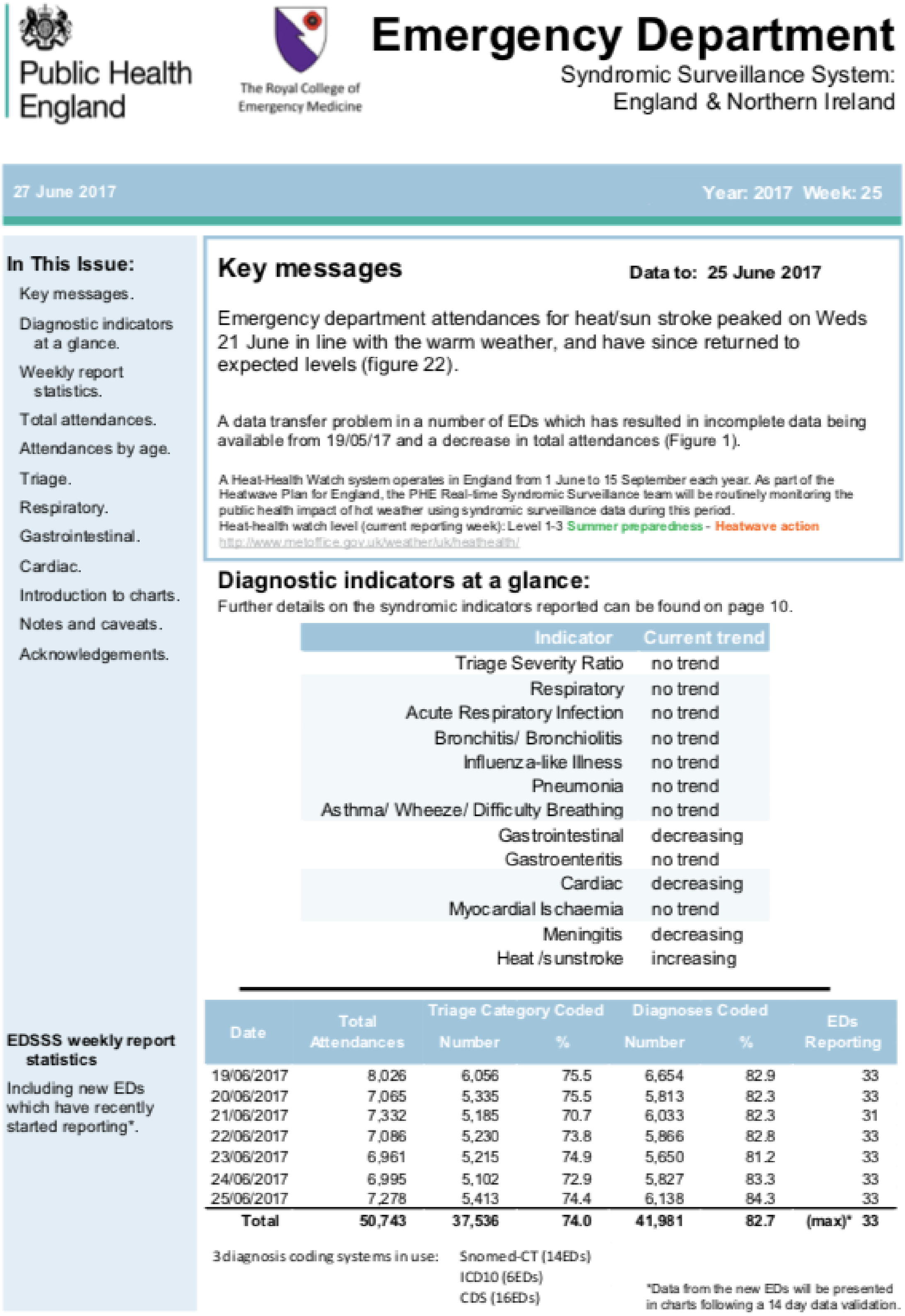
Key indicator	No. of contacts	% Week 25	% Week 24	Trend*
All OOH contacts, all causes	165,369			
Acute respiratory infection	7,935	9.81	10.16	↔
Influenza-like illness	45	0.06	0.07	↔
Bronchitis/bronchiolitis	58	0.07	0.08	↔
Difficulty breathing/wheeze/asthma	1,298	1.61	1.65	↔
Pharyngitis	66	0.08	0.09	↔
Gastroenteritis	3,335	4.12	3.91	↑
Diarrhoea	968	1.20	1.11	↑
Vomiting	1,181	1.46	1.33	↑
Myocardial infarction	733	0.91	0.88	↓
Heatstroke	55	0.07	0.03	↑

*Trend: reports on the trend seen over previous weeks in the percentage of Read coded contacts.

1: Total out-of-hours contacts:

Daily total number of out-of-hours and unscheduled contacts and 7 day average (adjusted for bank holidays).

Appendix C: Example of the weekly report from Public Health England of the most prevalent reasons to visit the emergency department.



Public Health England

The Royal College of Emergency Medicine

Emergency Department

Syndromic Surveillance System:
England & Northern Ireland

27 June 2017

Year: 2017 Week: 25

In This Issue:

- Key messages.
- Diagnostic indicators at a glance.
- Weekly report statistics.
- Total attendances.
- Attendances by age.
- Triage.
- Respiratory.
- Gastrointestinal.
- Cardiac.
- Introduction to charts.
- Notes and caveats.
- Acknowledgements.

Key messages

Data to: 25 June 2017

Emergency department attendances for heat/sun stroke peaked on Weds 21 June in line with the warm weather, and have since returned to expected levels (figure 22).

A data transfer problem in a number of EDs which has resulted in incomplete data being available from 19/05/17 and a decrease in total attendances (Figure 1).

A Heat-Health Watch system operates in England from 1 June to 15 September each year. As part of the Heatwave Plan for England, the PHE Real-time Syndromic Surveillance team will be routinely monitoring the public health impact of hot weather using syndromic surveillance data during this period.
Heat-health watch level (current reporting week): Level 1-3 Summer preparedness - Heatwave action
http://www.metoffice.gov.uk/weather/uk/heathealth/

Diagnostic indicators at a glance:

Further details on the syndromic indicators reported can be found on page 10.

Indicator	Current trend
Triage Severity Ratio	no trend
Respiratory	no trend
Acute Respiratory Infection	no trend
Bronchitis/ Bronchiolitis	no trend
Influenza-like Illness	no trend
Pneumonia	no trend
Asthma/ Wheeze/ Difficulty Breathing	no trend
Gastrointestinal	decreasing
Gastroenteritis	no trend
Cardiac	decreasing
Myocardial Ischaemia	no trend
Meningitis	decreasing
Heat /sunstroke	increasing

EDSSS weekly report statistics

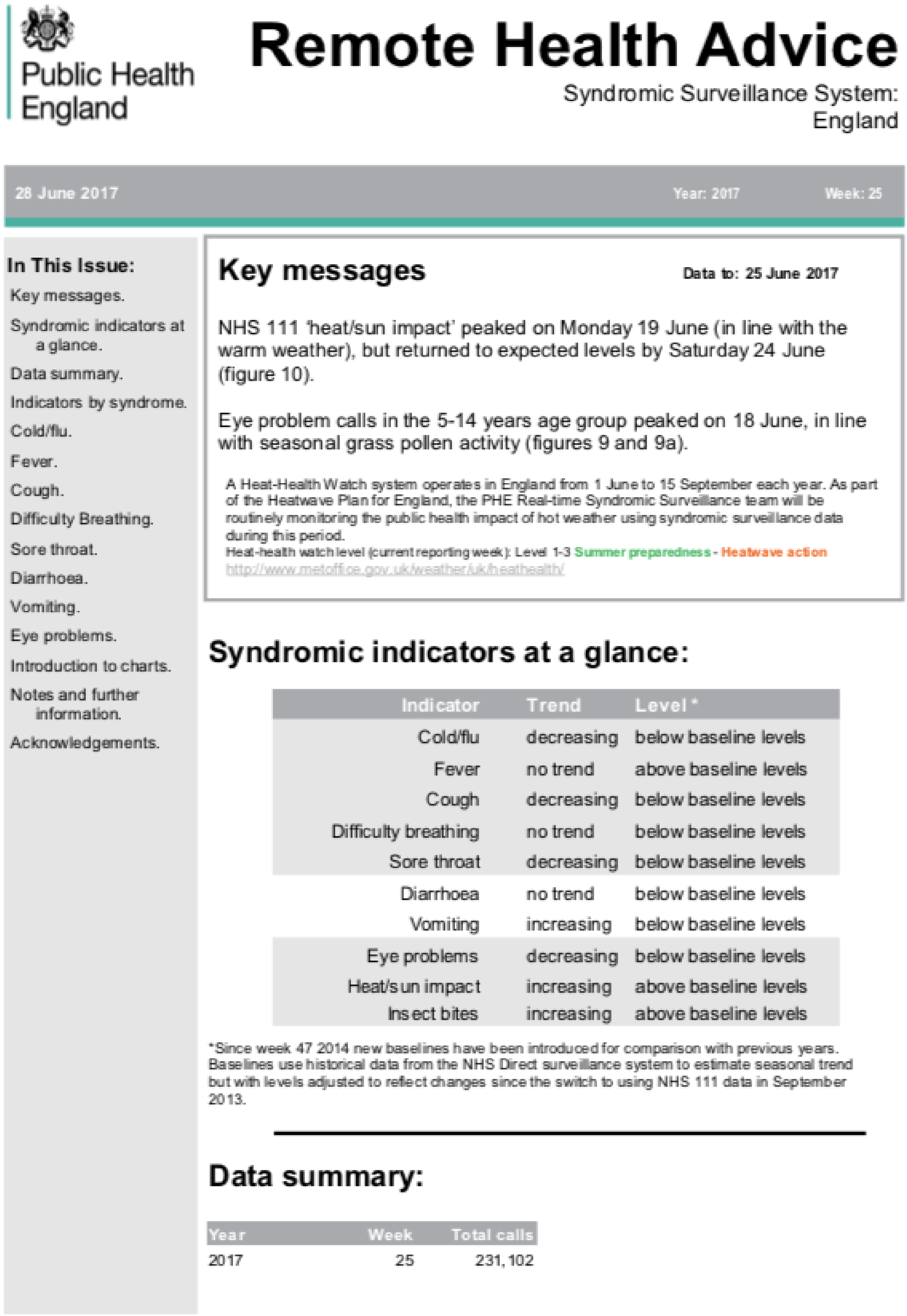
Including new EDs which have recently started reporting*.

Date	Total Attendances	Triage Category Coded		Diagnoses Coded		EDs Reporting
		Number	%	Number	%	
19/06/2017	8,026	6,056	75.5	6,654	82.9	33
20/06/2017	7,065	5,335	75.5	5,813	82.3	33
21/06/2017	7,332	5,185	70.7	6,033	82.3	31
22/06/2017	7,086	5,230	73.8	5,866	82.8	33
23/06/2017	6,961	5,215	74.9	5,650	81.2	33
24/06/2017	6,995	5,102	72.9	5,827	83.3	33
25/06/2017	7,278	5,413	74.4	6,138	84.3	33
Total	**50,743**	**37,536**	**74.0**	**41,981**	**82.7**	**(max)* 33**

3 diagnosis coding systems in use:
Snomed-CT (14EDs)
ICD10 (6EDs)
CDS (16EDs)

*Data from the new EDs will be presented in charts following a 14 day data validation.

Appendix D: Example of the weekly report from Public Health England of the most prevalent reasons to call NHS 111 service.



Public Health England

Remote Health Advice

Syndromic Surveillance System: England

28 June 2017 Year: 2017 Week: 25

In This Issue:

- Key messages.
- Syndromic indicators at a glance.
- Data summary.
- Indicators by syndrome.
- Cold/flu.
- Fever.
- Cough.
- Difficulty Breathing.
- Sore throat.
- Diarrhoea.
- Vomiting.
- Eye problems.
- Introduction to charts.
- Notes and further information.
- Acknowledgements.

Key messages

Data to: 25 June 2017

NHS 111 'heat/sun impact' peaked on Monday 19 June (in line with the warm weather), but returned to expected levels by Saturday 24 June (figure 10).

Eye problem calls in the 5-14 years age group peaked on 18 June, in line with seasonal grass pollen activity (figures 9 and 9a).

A Heat-Health Watch system operates in England from 1 June to 15 September each year. As part of the Heatwave Plan for England, the PHE Real-time Syndromic Surveillance team will be routinely monitoring the public health impact of hot weather using syndromic surveillance data during this period.
Heat-health watch level (current reporting week): Level 1-3 Summer preparedness - Heatwave action
http://www.metoffice.gov.uk/weather/uk/heathealth/

Syndromic indicators at a glance:

Indicator	Trend	Level *
Cold/flu	decreasing	below baseline levels
Fever	no trend	above baseline levels
Cough	decreasing	below baseline levels
Difficulty breathing	no trend	below baseline levels
Sore throat	decreasing	below baseline levels
Diarrhoea	no trend	below baseline levels
Vomiting	increasing	below baseline levels
Eye problems	decreasing	below baseline levels
Heat/sun impact	increasing	above baseline levels
Insect bites	increasing	above baseline levels

*Since week 47 2014 new baselines have been introduced for comparison with previous years. Baselines use historical data from the NHS Direct surveillance system to estimate seasonal trend but with levels adjusted to reflect changes since the switch to using NHS 111 data in September 2013.

Data summary:

Year	Week	Total calls
2017	25	231,102

Appendix E: First page of Public Health England's '*Beat the heat'* documentation.

Public Health England

NHS England

Beat the heat: staying safe in hot weather

Although most of us welcome the summer sun, high temperatures can be harmful to your health. In one hot spell in August 2003 in England and Wales there were over 2,000 extra deaths than would normally be expected. The heat can affect anyone, but some people run a greater risk of serious harm. As our climate changes, hot spells are expected to be more frequent and more intense.

This document will tell you how to stay safe in hot weather, including how to keep your home cool. It tells you who is at greatest risk of ill health from the heat, how to recognise when you or someone's health may be affected, and what to do if you or someone else becomes unwell as a result of the heat.

PHE publications gateway number: 2016071
Published: August 2018

Appendix F: Public Health England's *'Beat the heat'* campaign poster.

Public Health England

Beat the Heat

Keep in touch

Look after yourself, older people and the young

Listen to the weather forecast and the news

Plan ahead to avoid the heat

Keep well

Drink plenty of fluids and avoid excess alcohol

Dress appropriately for the weather

Slow down when it is hot

Find somewhere cool

Know how to keep your home cool

Go indoors or outdoors, whichever feels cooler

Cars get hot, avoid closed spaces

Watch out

Be on the lookout for signs of heat related illness

Cool your skin with water, slow down and drink water

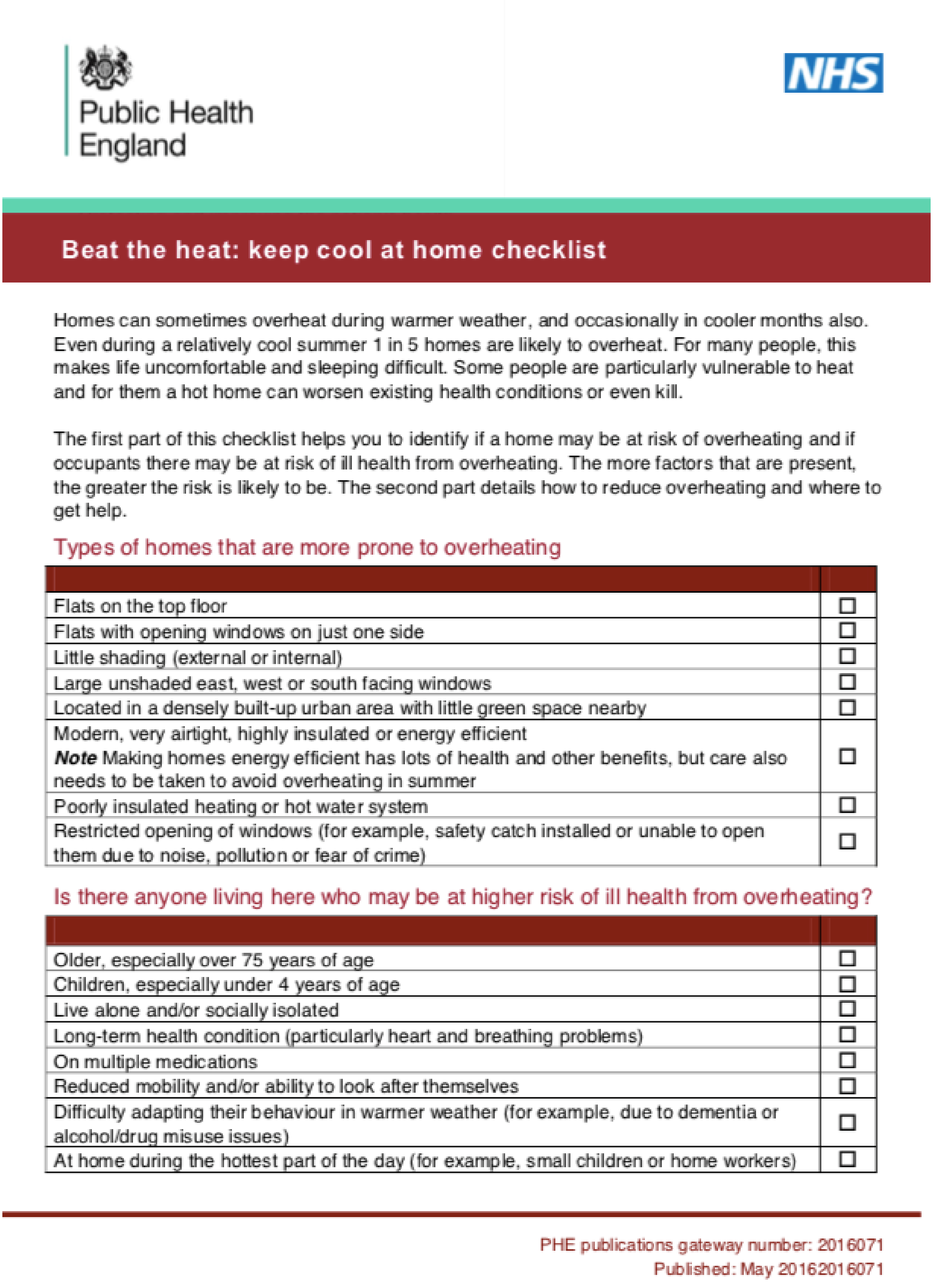
Stay safe when swimming

Get help. Call NHS 111 or in an emergency 999

For more information go to www.nhs.uk/heatwave

PHE publications gateway number: 2016071

Appendix G: Public Health England's ‘Beat the heat’ campaign checklist.



Public Health England

NHS

Beat the heat: keep cool at home checklist

Homes can sometimes overheat during warmer weather, and occasionally in cooler months also. Even during a relatively cool summer 1 in 5 homes are likely to overheat. For many people, this makes life uncomfortable and sleeping difficult. Some people are particularly vulnerable to heat and for them a hot home can worsen existing health conditions or even kill.

The first part of this checklist helps you to identify if a home may be at risk of overheating and if occupants there may be at risk of ill health from overheating. The more factors that are present, the greater the risk is likely to be. The second part details how to reduce overheating and where to get help.

Types of homes that are more prone to overheating

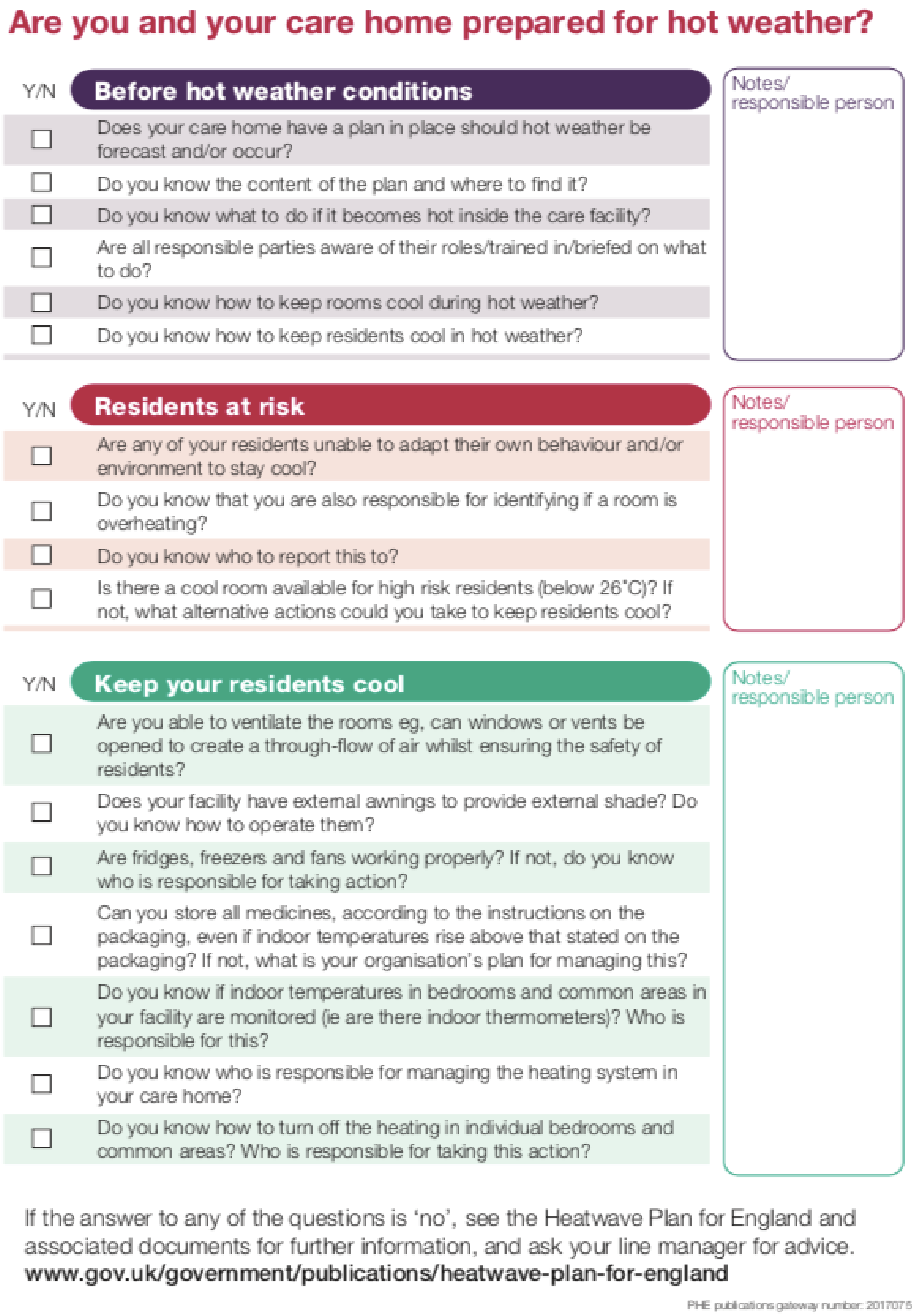
Flats on the top floor	☐
Flats with opening windows on just one side	☐
Little shading (external or internal)	☐
Large unshaded east, west or south facing windows	☐
Located in a densely built-up urban area with little green space nearby	☐
Modern, very airtight, highly insulated or energy efficient ***Note*** Making homes energy efficient has lots of health and other benefits, but care also needs to be taken to avoid overheating in summer	☐
Poorly insulated heating or hot water system	☐
Restricted opening of windows (for example, safety catch installed or unable to open them due to noise, pollution or fear of crime)	☐

Is there anyone living here who may be at higher risk of ill health from overheating?

Older, especially over 75 years of age	☐
Children, especially under 4 years of age	☐
Live alone and/or socially isolated	☐
Long-term health condition (particularly heart and breathing problems)	☐
On multiple medications	☐
Reduced mobility and/or ability to look after themselves	☐
Difficulty adapting their behaviour in warmer weather (for example, due to dementia or alcohol/drug misuse issues)	☐
At home during the hottest part of the day (for example, small children or home workers)	☐

PHE publications gateway number: 2016071
Published: May 20162016071

Appendix H: Public Health England's checklist for elderly care home providers.



Are you and your care home prepared for hot weather?

Y/N **Before hot weather conditions**

Notes/
responsible person

- ☐ Does your care home have a plan in place should hot weather be forecast and/or occur?
- ☐ Do you know the content of the plan and where to find it?
- ☐ Do you know what to do if it becomes hot inside the care facility?
- ☐ Are all responsible parties aware of their roles/trained in/briefed on what to do?
- ☐ Do you know how to keep rooms cool during hot weather?
- ☐ Do you know how to keep residents cool in hot weather?

Y/N **Residents at risk**

Notes/
responsible person

- ☐ Are any of your residents unable to adapt their own behaviour and/or environment to stay cool?
- ☐ Do you know that you are also responsible for identifying if a room is overheating?
- ☐ Do you know who to report this to?
- ☐ Is there a cool room available for high risk residents (below 26°C)? If not, what alternative actions could you take to keep residents cool?

Y/N **Keep your residents cool**

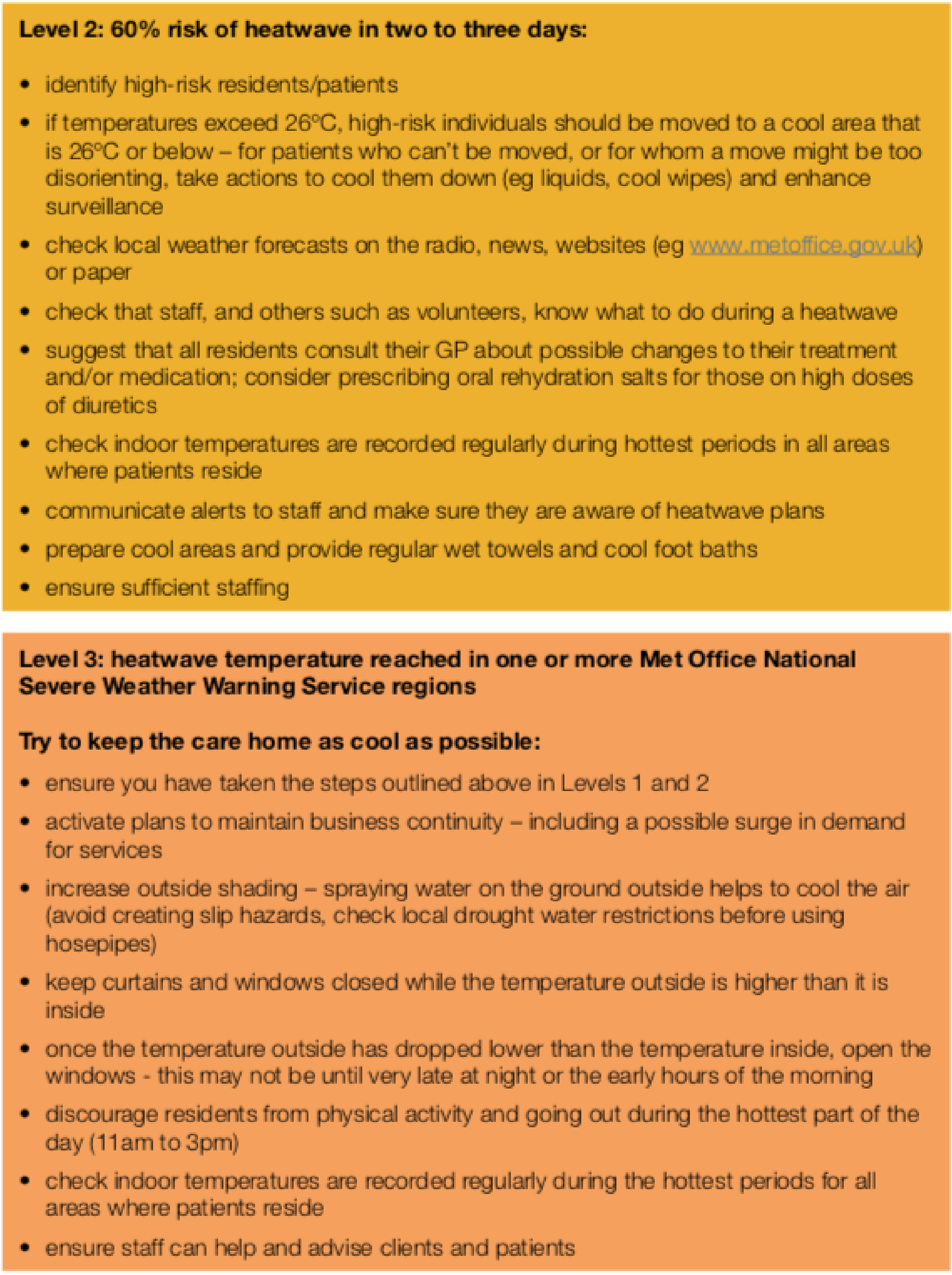
Notes/
responsible person

- ☐ Are you able to ventilate the rooms eg, can windows or vents be opened to create a through-flow of air whilst ensuring the safety of residents?
- ☐ Does your facility have external awnings to provide external shade? Do you know how to operate them?
- ☐ Are fridges, freezers and fans working properly? If not, do you know who is responsible for taking action?
- ☐ Can you store all medicines, according to the instructions on the packaging, even if indoor temperatures rise above that stated on the packaging? If not, what is your organisation's plan for managing this?
- ☐ Do you know if indoor temperatures in bedrooms and common areas in your facility are monitored (ie are there indoor thermometers)? Who is responsible for this?
- ☐ Do you know who is responsible for managing the heating system in your care home?
- ☐ Do you know how to turn off the heating in individual bedrooms and common areas? Who is responsible for taking this action?

If the answer to any of the questions is 'no', see the Heatwave Plan for England and associated documents for further information, and ask your line manager for advice.
www.gov.uk/government/publications/heatwave-plan-for-england

PHE publications gateway number: 2017075

Appendix I: Example of the advice Public Health England gives to care home providers at the different stages of the heatwave health watch system.



Level 2: 60% risk of heatwave in two to three days:

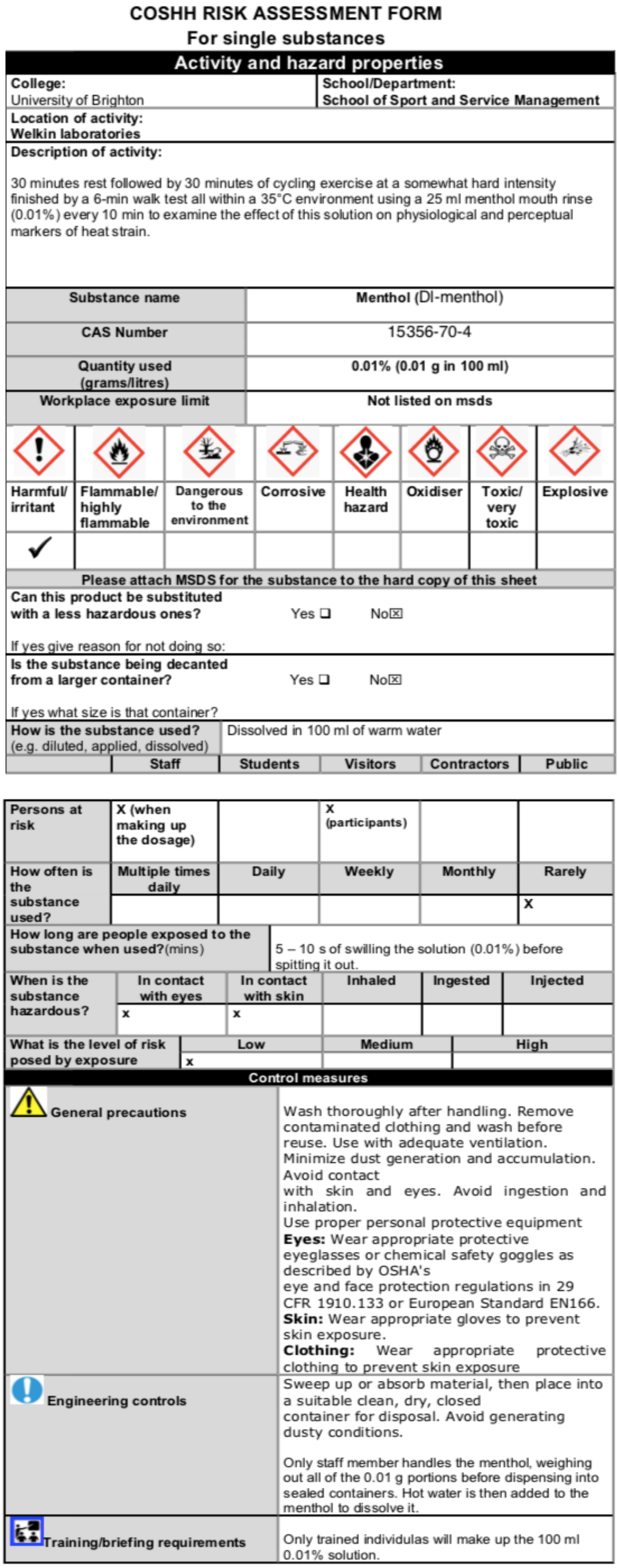
- identify high-risk residents/patients
- if temperatures exceed 26°C, high-risk individuals should be moved to a cool area that is 26°C or below – for patients who can't be moved, or for whom a move might be too disorienting, take actions to cool them down (eg liquids, cool wipes) and enhance surveillance
- check local weather forecasts on the radio, news, websites (eg www.metoffice.gov.uk) or paper
- check that staff, and others such as volunteers, know what to do during a heatwave
- suggest that all residents consult their GP about possible changes to their treatment and/or medication; consider prescribing oral rehydration salts for those on high doses of diuretics
- check indoor temperatures are recorded regularly during hottest periods in all areas where patients reside
- communicate alerts to staff and make sure they are aware of heatwave plans
- prepare cool areas and provide regular wet towels and cool foot baths
- ensure sufficient staffing

Level 3: heatwave temperature reached in one or more Met Office National Severe Weather Warning Service regions

Try to keep the care home as cool as possible:

- ensure you have taken the steps outlined above in Levels 1 and 2
- activate plans to maintain business continuity – including a possible surge in demand for services
- increase outside shading – spraying water on the ground outside helps to cool the air (avoid creating slip hazards, check local drought water restrictions before using hosepipes)
- keep curtains and windows closed while the temperature outside is higher than it is inside
- once the temperature outside has dropped lower than the temperature inside, open the windows - this may not be until very late at night or the early hours of the morning
- discourage residents from physical activity and going out during the hottest part of the day (11am to 3pm)
- check indoor temperatures are recorded regularly during the hottest periods for all areas where patients reside
- ensure staff can help and advise clients and patients

Appendix J: COSHH form the use of L-menthol in study 3 (Chapter 6, p139).



COSHH RISK ASSESSMENT FORM

For single substances

Activity and hazard properties

College: University of Brighton	**School/Department:** **School of Sport and Service Management**
Location of activity: **Welkin laboratories**	
Description of activity: 30 minutes rest followed by 30 minutes of cycling exercise at a somewhat hard intensity finished by a 6-min walk test all within a 35°C environment using a 25 ml menthol mouth rinse (0.01%) every 10 min to examine the effect of this solution on physiological and perceptual markers of heat strain.	

Substance name	**Menthol** (Dl-menthol)
CAS Number	15356-70-4
Quantity used (grams/litres)	**0.01% (0.01 g in 100 ml)**
Workplace exposure limit	**Not listed on msds**

Harmful/ irritant	**Flammable/ highly flammable**	**Dangerous to the environment**	**Corrosive**	**Health hazard**	**Oxidiser**	**Toxic/ very toxic**	**Explosive**
✓							

Please attach MSDS for the substance to the hard copy of this sheet

Can this product be substituted with a less hazardous ones? Yes ☐ No☒

If yes give reason for not doing so:

Is the substance being decanted from a larger container? Yes ☐ No☒

If yes what size is that container?

How is the substance used? (e.g. diluted, applied, dissolved)	Dissolved in 100 ml of warm water

	Staff	**Students**	**Visitors**	**Contractors**	**Public**
Persons at risk	**X (when making up the dosage)**		**x (participants)**		

How often is the substance used?	**Multiple times daily**	**Daily**	**Weekly**	**Monthly**	**Rarely**
					X

How long are people exposed to the substance when used?(mins)	5 – 10 s of swilling the solution (0.01%) before spitting it out.

When is the substance hazardous?	**In contact with eyes**	**In contact with skin**	**Inhaled**	**Ingested**	**Injected**
	x	x			

What is the level of risk posed by exposure	**Low**	**Medium**	**High**
	x		

Control measures

General precautions	Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Use with adequate ventilation. Minimize dust generation and accumulation. Avoid contact with skin and eyes. Avoid ingestion and inhalation. Use proper personal protective equipment **Eyes:** Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166. **Skin:** Wear appropriate gloves to prevent skin exposure. **Clothing:** Wear appropriate protective clothing to prevent skin exposure
Engineering controls	Sweep up or absorb material, then place into a suitable clean, dry, closed container for disposal. Avoid generating dusty conditions. Only staff member handles the menthol, weighing out all of the 0.01 g portions before dispensing into sealed containers. Hot water is then added to the menthol to dissolve it.
Training/briefing requirements	Only trained individulas will make up the 100 ml 0.01% solution.

Do the control measures reduce the risk to an acceptable level?	Yes
Are there any further control measures required?	No

Required PPE

						Other:	**Other:**
✓							
Type:	**Type:**	**Type:**	**Type:**	**Type:**	**Type:**	**Type:**	**Type:**

First aid procedure

Area exposed	Risk to health	First aid procedure
Skin	May cause skin irritation.	Get medical aid. Immediately flush skin with plenty of soap and water for at least 15 minutes while removing contaminated clothing and shoes.
Eyes	May cause severe eye irritation	Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid immediately.
Inhalation	May cause severe irritation	Get medical aid. Immediately flush skin with plenty of soap and water for at least 15 minutes while removing contaminated clothing and shoes.
Ingestion	May cause irritation of the digestive tract. The toxicological properties of this substance have not been fully investigated. May cause allergic reactions (urticaria).	If victim is conscious and alert, give 2-4 cupfuls of milk or water. Get medical aid immediately.

Waste and spillage procedures

Storage requirements	Store in a cool, dry, well-ventilated area away from incompatible substances
Spillage procedure	Sweep up or absorb material, then place into a suitable clean, dry, closed container for disposal. Avoid generating dusty conditions.
Ecological controls	**No data available**
Disposal procedure	Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.

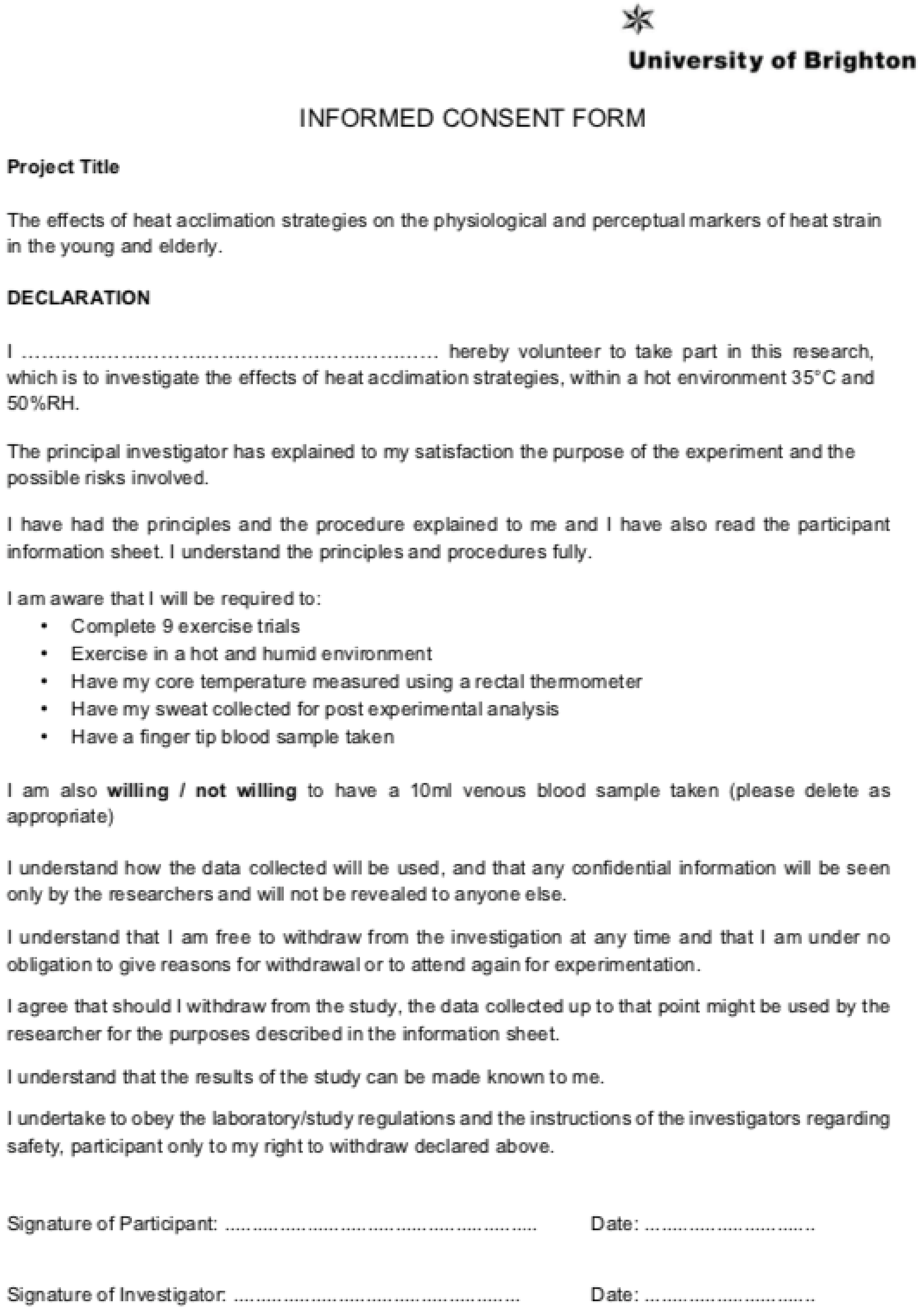
Fire controls

Water	Powder	Foam	CO2	Wet Chemical
✓				

Additional comments

Assessor:	**Mark Hayes**	**Date completed:**	**27 Jan 2017**
Manager's signature:		**Date:**	
Review date:			

Appendix K: Example of the informed consent form used in this thesis.



University of Brighton

INFORMED CONSENT FORM

Project Title

The effects of heat acclimation strategies on the physiological and perceptual markers of heat strain in the young and elderly.

DECLARATION

I ………………………………………………………… hereby volunteer to take part in this research, which is to investigate the effects of heat acclimation strategies, within a hot environment 35°C and 50%RH.

The principal investigator has explained to my satisfaction the purpose of the experiment and the possible risks involved.

I have had the principles and the procedure explained to me and I have also read the participant information sheet. I understand the principles and procedures fully.

I am aware that I will be required to:

- Complete 9 exercise trials
- Exercise in a hot and humid environment
- Have my core temperature measured using a rectal thermometer
- Have my sweat collected for post experimental analysis
- Have a finger tip blood sample taken

I am also **willing / not willing** to have a 10ml venous blood sample taken (please delete as appropriate)

I understand how the data collected will be used, and that any confidential information will be seen only by the researchers and will not be revealed to anyone else.

I understand that I am free to withdraw from the investigation at any time and that I am under no obligation to give reasons for withdrawal or to attend again for experimentation.

I agree that should I withdraw from the study, the data collected up to that point might be used by the researcher for the purposes described in the information sheet.

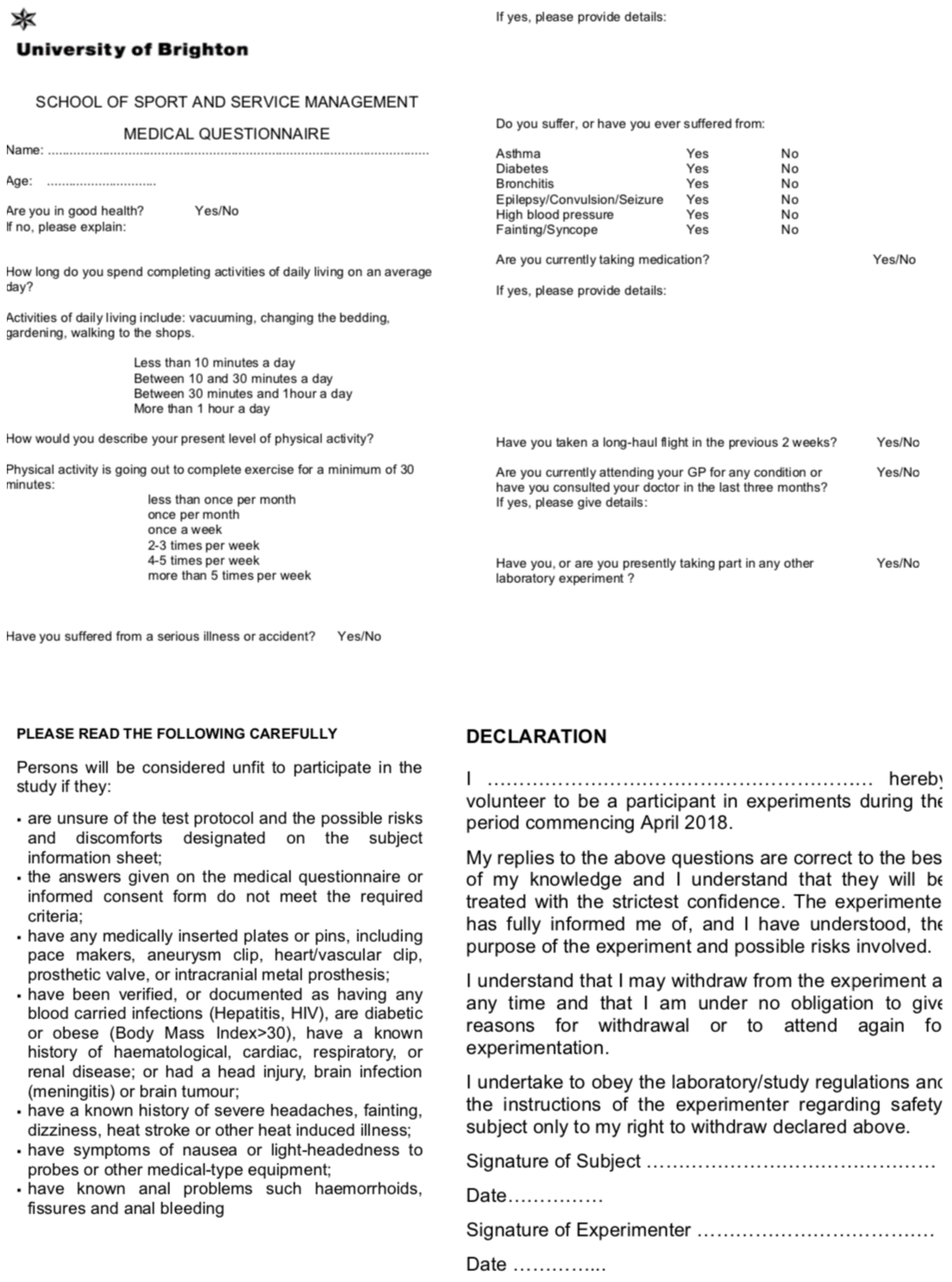
I understand that the results of the study can be made known to me.

I undertake to obey the laboratory/study regulations and the instructions of the investigators regarding safety, participant only to my right to withdraw declared above.

Signature of Participant: …………………………………………………… Date: …………………………

Signature of Investigator: ……………………………………………… Date: …………………………

Appendix L: Example of the participant medical questionnaire used in this thesis.



University of Brighton

SCHOOL OF SPORT AND SERVICE MANAGEMENT

MEDICAL QUESTIONNAIRE

Name: ……………………………………………………………………

Age: …………………………

Are you in good health? Yes/No
If no, please explain:

How long do you spend completing activities of daily living on an average day?

Activities of daily living include: vacuuming, changing the bedding, gardening, walking to the shops.

Less than 10 minutes a day
Between 10 and 30 minutes a day
Between 30 minutes and 1hour a day
More than 1 hour a day

How would you describe your present level of physical activity?

Physical activity is going out to complete exercise for a minimum of 30 minutes:

less than once per month
once per month
once a week
2-3 times per week
4-5 times per week
more than 5 times per week

Have you suffered from a serious illness or accident? Yes/No

If yes, please provide details:

Do you suffer, or have you ever suffered from:

Asthma	Yes	No
Diabetes	Yes	No
Bronchitis	Yes	No
Epilepsy/Convulsion/Seizure	Yes	No
High blood pressure	Yes	No
Fainting/Syncope	Yes	No

Are you currently taking medication? Yes/No

If yes, please provide details:

Have you taken a long-haul flight in the previous 2 weeks? Yes/No

Are you currently attending your GP for any condition or have you consulted your doctor in the last three months? Yes/No
If yes, please give details:

Have you, or are you presently taking part in any other laboratory experiment ? Yes/No

PLEASE READ THE FOLLOWING CAREFULLY

Persons will be considered unfit to participate in the study if they:

- are unsure of the test protocol and the possible risks and discomforts designated on the subject information sheet;
- the answers given on the medical questionnaire or informed consent form do not meet the required criteria;
- have any medically inserted plates or pins, including pace makers, aneurysm clip, heart/vascular clip, prosthetic valve, or intracranial metal prosthesis;
- have been verified, or documented as having any blood carried infections (Hepatitis, HIV), are diabetic or obese (Body Mass Index>30), have a known history of haematological, cardiac, respiratory, or renal disease; or had a head injury, brain infection (meningitis) or brain tumour;
- have a known history of severe headaches, fainting, dizziness, heat stroke or other heat induced illness;
- have symptoms of nausea or light-headedness to probes or other medical-type equipment;
- have known anal problems such haemorrhoids, fissures and anal bleeding

DECLARATION

I …………………………………………………… hereb volunteer to be a participant in experiments during th period commencing April 2018.

My replies to the above questions are correct to the bes of my knowledge and I understand that they will b treated with the strictest confidence. The experimente has fully informed me of, and I have understood, th purpose of the experiment and possible risks involved.

I understand that I may withdraw from the experiment a any time and that I am under no obligation to giv reasons for withdrawal or to attend again fo experimentation.

I undertake to obey the laboratory/study regulations an the instructions of the experimenter regarding safety subject only to my right to withdraw declared above.

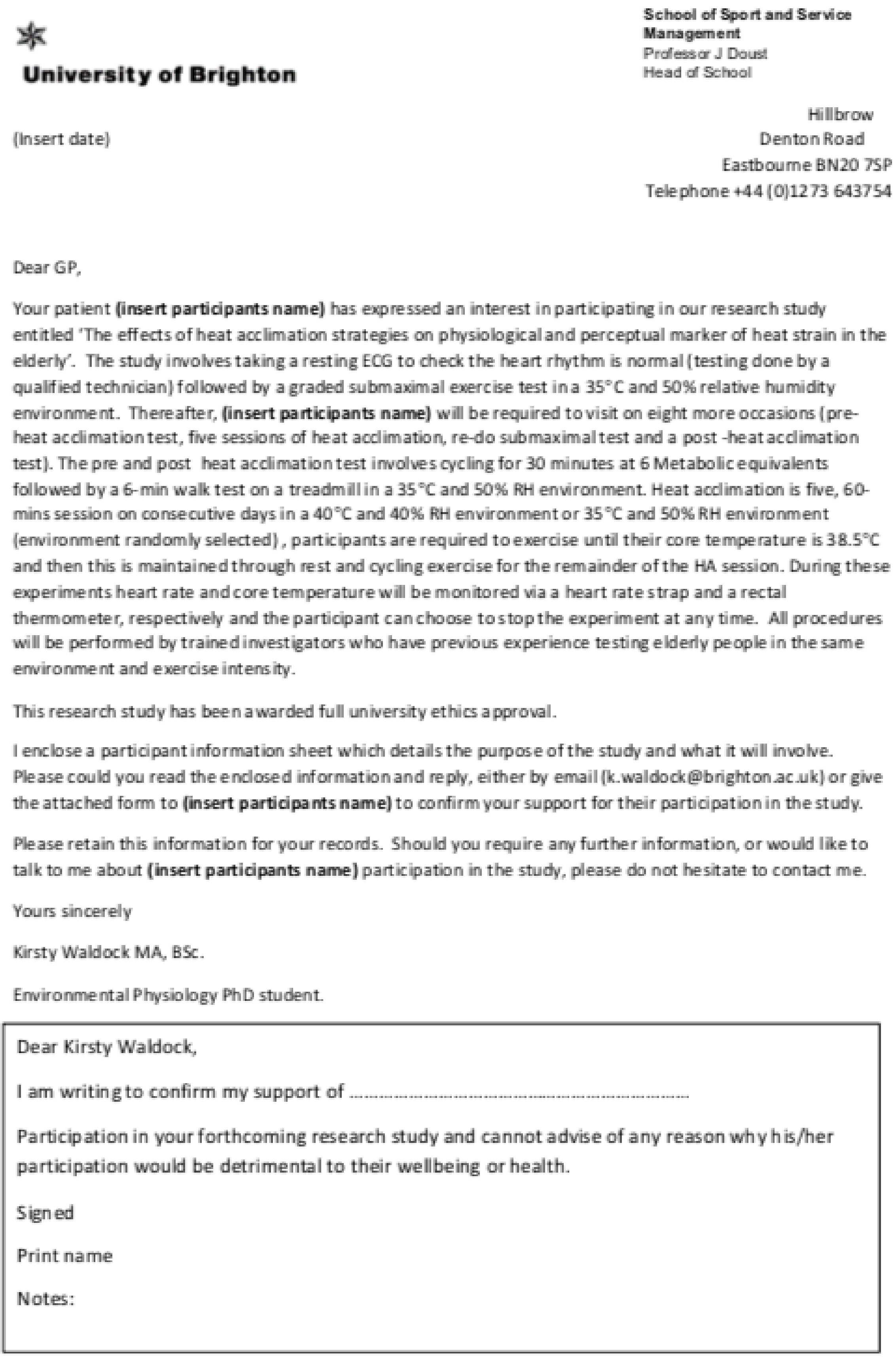
Signature of Subject ………………………………………

Date……………

Signature of Experimenter ………………………………

Date …………...

Appendix M: Example of the medical note given to the participants' G.P.to complete the research studies in this thesis.



University of Brighton

School of Sport and Service Management
Professor J Doust
Head of School

Hillbrow
Denton Road
Eastbourne BN20 7SP
Telephone +44 (0)1273 643754

(Insert date)

Dear GP,

Your patient **(insert participants name)** has expressed an interest in participating in our research study entitled 'The effects of heat acclimation strategies on physiological and perceptual marker of heat strain in the elderly'. The study involves taking a resting ECG to check the heart rhythm is normal (testing done by a qualified technician) followed by a graded submaximal exercise test in a 35°C and 50% relative humidity environment. Thereafter, **(insert participants name)** will be required to visit on eight more occasions (pre-heat acclimation test, five sessions of heat acclimation, re-do submaximal test and a post -heat acclimation test). The pre and post heat acclimation test involves cycling for 30 minutes at 6 Metabolic equivalents followed by a 6-min walk test on a treadmill in a 35°C and 50% RH environment. Heat acclimation is five, 60-mins session on consecutive days in a 40°C and 40% RH environment or 35°C and 50% RH environment (environment randomly selected) , participants are required to exercise until their core temperature is 38.5°C and then this is maintained through rest and cycling exercise for the remainder of the HA session. During these experiments heart rate and core temperature will be monitored via a heart rate strap and a rectal thermometer, respectively and the participant can choose to stop the experiment at any time. All procedures will be performed by trained investigators who have previous experience testing elderly people in the same environment and exercise intensity.

This research study has been awarded full university ethics approval.

I enclose a participant information sheet which details the purpose of the study and what it will involve. Please could you read the enclosed information and reply, either by email (k.waldock@brighton.ac.uk) or give the attached form to **(insert participants name)** to confirm your support for their participation in the study.

Please retain this information for your records. Should you require any further information, or would like to talk to me about **(insert participants name)** participation in the study, please do not hesitate to contact me.

Yours sincerely

Kirsty Waldock MA, BSc.

Environmental Physiology PhD student.

Dear Kirsty Waldock,

I am writing to confirm my support of ……………………………………………………………………

Participation in your forthcoming research study and cannot advise of any reason why his/her participation would be detrimental to their wellbeing or health.

Signed

Print name

Notes:

Appendix N: General methods equation list

Equation 1: Calculation for core-to-skin gradient (Cuddy *et al.,* 2014).

Core-to-skin gradient (°C) = core temperature (°C) – skin temperature (°C)

Equation 2: Calculation of body density for younger males (Durnin & Womersley, 1974).

Body density = 1.1610 – 0.0632 Log Σ bicep, triceps, subscapular and Iliac crest

Equation 3: Calculation of body density for younger females (Durnin & Womersley, 1974).

Body density = 1.1599 – 0.0717 Log Σ bicep, triceps, subscapular and Iliac crest

Equation 4: Calculation of body density for elderly males (Durnin & Womersley, 1974).

Body density = 1.1715 – 0.0779 Log Σ bicep, triceps, subscapular and Iliac crest

Equation 5: Calculation of body density for elderly females (Durnin & Womersley, 1987)

Body density = 1.1339 – 0.0645 Log Σ bicep, triceps, subscapular and Iliac crest

Equation 6: Calculation of body fat percentage (Siri, 1956).

Percentage body fat = ([4.95 / body density] - 4.5) x 100

Equation 7: Calculation for mean skin temperature (Ramanathan, 1964).

$$T_{skin} = 0.3 \cdot (T_{chest} + T_{arm}) + 0.2 \cdot (T_{upper\ leg} + T_{lower\ leg})$$

Equation 8: Calculation for whole body sweat rate

WBSR ($L.hr^{-1}$) = [pre-body mass (kg)-post-body mass (kg)]/exercise time (min)*60

Equation 9: Calculation for relative metabolic heat production (Cramer & Jay, 2014).

$\dot{H}_{prod}$ W·kg^{-1} = (M − W) / BM.

Where: M is metabolic energy expenditure, W is the external mechanical power output in Watts, and BM is body mass in kg.

Example:

$\dot{H}_{prod}$ W.kg^{-1} = (372-71 W) / 56.57 kg

$\dot{H}_{prod}$ W.kg^{-1} = 301 W / 56.57 kg

$\dot{H}_{prod}$ W.kg^{-1} = 3.5

Equation 10: Calculation for individual 1 MET value (Jetté *et al.,* 1990).

1 MET = ($\dot{V}O_2$ L.min^{-1}*1000) / BM

Where: this calculation, in this thesis, is made from a resting respiratory expired air sample.

Example:

1 MET = (0.146 $\dot{V}O_2$ L.min^{-1} * 1000) / 56.57 kg

1 MET = 146 $\dot{V}O_2$ ml.min^{-1} / 56.57 kg

1 MET = 2.58 $\dot{V}O_2$ ml.kg^{-1}.min^{-1}

Equation 11: Calculation for individual exercise MET value (Jetté *et al.,* 1990).

Exercise MET value = [($\dot{V}O_2$ L.min*1000) / BM] / individual 1 MET

Where: this calculation, in this thesis, is made from values calculated from exercise respiratory expired air analysis.

Example for 6 METs:

Exercise MET value = [(0.876 $\dot{V}O_2$ L.min^{-1} *1000)/ 56.57 kg]/ 2.58$\dot{V}O_2$ ml.kg^{-1}.min^{-1}

Exercise MET value = (876 $\dot{V}O_2$ ml.min^{-1} / 56.57 kg) / 2.58 $\dot{V}O_2$ ml.kg^{-1}.min^{-1}

Exercise MET value = 15.49 $\dot{V}O_2$ ml.kg^{-1}.min^{-1} / 2.58 $\dot{V}O_2$ ml.kg^{-1}.min^{-1}

Exercise MET value = 6

Equation 12: Calculation for change in plasma volume (Dill & Costill, 1974).

$\Delta PV\% = 100\ (HbA\ [1 - HctB * 10^{-2}])\ /\ (HbB\ [1 - HctA * 10^{-2}]) - 100$

Where: A in this study represents the pre heat acclimation blood sample and B represents the post heat acclimation blood sample.

Equation 13: Calculation for mean arterial pressure (Minson *et al.,* 1998).

MAP = (Systolic blood pressure + (2 * diastolic blood pressure))/3

Equation 14: Calculation for cutaneous vascular conductance (Holowatz *et al.,* 2006)

CVC = $\overline{X}$ flux / MAP

Where: $\overline{X}$ is the mean flux; MAP is mean arterial pressure

Equation 15: Calculation for the typical error of measurement (Hopkins, 2000).

$TEM = SD_{diff} / \sqrt{2}$

Where: SD_{diff} is the standard deviation of the difference between the repeated measures; $\sqrt{2}$ is the square root of 2.

Equation 16: Calculation for the coefficient of variation (Hopkins, 2000).

TEM (CV%) = (TEM / $\overline{X}$)*100

Where: the $\overline{X}$ is the mean of the paired samples.

Equation 17: Calculation for intraclass correlation coefficient (Atkinson, 2003).

ICC = (between-subject SD^2 – within-subject SD^2) / between-subject SD^2

Equation 18: Calculation for mean bias (Bland & Altman, 1999).

Mean bias = the mean of the difference between the two samples

Equation 19: Calculation for the lower 95% limit of agreement (Bland & Altman, 1999).

Lower 95% LoA = mean bias - (1.96*SD)

Where SD is the standard deviation of the mean difference of the two samples

Equation 20: Calculation for the lower 95% limit of agreement. (Bland & Altman, 1999).

Upper 95% LoA = mean bias + (1.96*SD)

Where SD is the standard deviation of the mean difference of the two samples

Equation 21: Calculation for mean bias (Bland & Altman, 1999).

Mean bias = the mean of the difference between the two samples

Equation 22: Calculation for the lower 95% limit of agreement (Bland & Altman, 1999).

Lower 95% LoA = mean bias - (1.96*SD)

Where SD is the standard deviation of the mean difference of the two samples

Equation 23: Calculation for the lower 95% limit of agreement. (Bland & Altman, 1999).

Upper 95% LoA = mean bias + (1.96*SD)

Where SD is the standard deviation of the mean difference of the two samples

Appendix O: Heat illness susceptibility- questionnaire (HIS-Q).

Heat Illness Susceptibility-Questionnaire (HIS-Q)

The purpose of this questionnaire is to assess your susceptibility of developing a heat illness. It is divided into two sections. The first section requires you to self-report on your symptoms and provide a score for your symptoms out of a maximum score of 18. The second section requires an observer to report on your heat illness signs, and carries a maximum score of 6. Both sections of the questionnaire should be completed and you should provide a score out of a total score of 24.

Part 1- Self Report

Select the statement that best describes how you are currently feeling by circling the number beside it.

Heat Rash	I do not have a rash, itching or burning sensation of the skin	**0**
	I have a small rash, or patch of itchy skin and/or burning sensation	**1**
	The rash is getting bigger or is in more than one place on the skin, it is itchy and or causing a burning sensation	**2**
	I have a large rash that seems to be spreading, it is itchy and is causing a burning sensation	**3**
Muscle Cramps	I do not have muscle cramps or twinges	**0**
	I have felt my muscles twinge occasionally	**1**
	I can continue completing the task however, I feel my muscles continuously twinging and I may get muscle cramps that will cause me to stop	**2**
	I have to stop due to the severity of muscle cramps	**3**
Dizziness	I am not dizzy	**0**
	I am feeling slightly dizzy	**1**
	I feel very dizzy and may have to stop soon	**2**
	I have to stop and lie down due to the dizziness	**3**
Nausea or Vomiting	I do not feel sick	**0**
	I feel slightly sick	**1**
	I feel very sick and may need to stop to be sick	**2**
	I need to stop to be sick	**3**
Excessive Fatigue and/or Weakness	I do not feel fatigued and /or weak	**0**
	I feel slightly fatigued and /or weak	**1**
	I am feeling very fatigued and /or weak and want to stop but can continue what I am doing	**2**
	I am feeling extremely fatigued and/or weak, causing me to stop	**3**

Headache	I do not have a headache	**0**
	I have a mild headache	**1**
	I have a headache and want to stop but feel I can continue	**2**
	I have a persistent painful headache and need to stop	**3**
	Total Score:	**/18**

Part 2- Observer Assessment

This part is completed by the person observing the completion of this questionnaire. Circle the appropriate number based on your assessment of these questions.

Part 2A- Questions			
In your opinion can the individual answer the questions below?		YES	NO
1.	Where are you?	0	1
2.	What are you doing?	0	1
3.	Do you know why you are doing the task at hand?	0	1
4.	How long have you been doing the task for today?	0	1
Part 2B- Observations			
5.	Is the persons' skin both hot and dry to the touch?	1	0
6.	Does the person seem confused and/or disorientated and/or ataxic? *Disorientated: The lack of personal identity, location, date, time and present situation* *Ataxic: lack of voluntary coordination of muscle movements*	1	0
	Part 2A and Part 2B Total Score:		/6

Part 1 Total	/18
Part 2A + 2B Total	/6
Part 1 and Part 2 Total	/24

If available record the individual's core temperature at time of assessment