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Human temperature regulation during exercise in the heat: effects of the menstrual cycle and ambient thermal profile

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ABSTRACT

Behavioural thermoregulation is the most effective means with which we regulate our body temperature at rest and during exercise. Yet, research into behavioural thermoregulation during exercise is still at an emergent stage, as it has not included females, or investigated different thermal profiles. In particular, limited studies are available to describe the behavioural and physiological differences between dry and humid heat for both sexes. Furthermore, it remains unknown whether ambient humidity or temperature alone contribute to the initiation of the behavioural responses during exercise in the heat. Therefore, the first part of this thesis investigated the effects of endogenous and exogenous female ovarian hormones on behavioural and autonomic responses, in both dry and humid heat environments matched according to the heat stress index, WBGT (**Chapter Five** and **Six**). The results from **Chapter Five** clearly show that behavioural and autonomic responses were less affected by menstrual phase, but were affected by the environmental conditions. In particular, trained women reduced their power output in order to nullify the autonomic strain from a humid heat environment. **Chapter Six** then extended this observation to (trained) women taking combined hormonal contraception, compared to eumenorrheic women in **Chapter Five**. The results from **Chapter Six** indicate that greater autonomic strain was observed in women with hormonal contraception, compared to eumenorrheic women, in both dry and humid heat, whilst the behavioural response was similar between those two groups. Furthermore, the behavioural response was different between dry and humid heat, with power output being lower in the humid heat environment compared to dry heat. The second part of this thesis investigated the effects of ambient temperature *per se* on the interaction of thermoregulatory, cardiovascular and perceptual responses to exercise (**Chapter Seven**), as well as assessing different exercise modalities (variable-intensity versus fixed-intensity exercise) and their effects on thermoregulation when the duration and average power output were matched (**Chapter Eight**). The results from **Chapter Seven** indicate that thermoregulatory and cardiovascular responses were not affected by ambient temperature but that perception was, when vapour pressure was matched between two different thermal profiles. The results from **Chapter Eight** indicate that self-pacing (behaviour) did not modulate thermoregulatory strain, when both self-paced and fixed-intensity were matched at the same exercise intensity and duration. In conclusion, this thesis extends the knowledge-base on behavioural

thermoregulation in trained women and also provides evidence that behavioural and autonomic thermoregulation is influenced more by vapour pressure than ambient temperature of the environment in men. Furthermore, the findings of this thesis confirm that behavioural thermoregulation is effective in modulating physiological strain only when there is a reduction in metabolic heat production.

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TABLE OF CONTENTS

ABSTRACT	II
ACKNOWLEDGEMENTS	IV
LIST OF ABBREVIATIONS.....	XII
LIST OF FIGURES	1
LIST OF TABLES	3
Chapter One	4
1.0: Introduction.....	4
Chapter Two	7
2.0: Review of Literature	7
2.1: Environmental changes and human behaviour	7
2.2: Human temperature regulation	8
2.2.1: Laws of thermodynamics	8
2.2.1.1: First law of thermal dynamics.....	9
2.2.1.2: Second law of thermal dynamics	9
2.2.2: Biophysics of heat transfer.....	9
2.2.2.1 The compartment model	11
2.2.3: Active and passive systems of heat transfer.....	13
.....	14
2.2.4: Autonomic regulation.....	14
2.2.4.1: Thermosensors	15
2.2.4.2: Thermoafferent pathways	17
2.2.4.3: The effector responses	17
2.2.4.3.1: The sudomotor response	18
2.2.4.3.2: Cutaneous blood flow	18
2.2.4.4: Reciprocal inhibition.....	20
2.2.4.5: Regulated variables	20
2.2.4.5.1: Core temperature.....	20
2.2.4.5.2: Skin temperature	21
2.3: Extents of heat stress.....	22
2.4: Human behavioural thermoregulation	24
2.4.1: Rest	24
2.4.2: Exercise.....	25
2.5: Acute exposures to dry heat	26
2.5.1: Core and skin temperature responses.....	26
2.5.2: Cardiovascular drift	26
2.5.3: The relationship between skeletal muscle blood flow and skin blood flow	28

2.5.4: Blood flow to the visceral organs	30
2.5.5: Sudomotor adjustment.....	30
2.5.6: Metabolic adjustments.....	30
2.5.7: Ventilation adjustments	31
2.5.8: Exercise performance in dry heat	33
2.6: Acute humid heat exposure	34
2.6.1: Core temperature differences	34
2.6.2: Cardiovascular adjustments.....	34
2.6.3: Sudomotor differences.....	35
2.6.4: Metabolic challenges	35
2.6.5: Ventilation and relationship between cerebral, cutaneous and muscle blood flow	35
2.6.6: Performance differences	36
2.6.7: Equalised heat strain from dry heat and humid heat environments.....	36
2.7: Female reproductive physiology	37
2.7.1: The ovarian cycle	37
2.7.2: The menstrual cycle.....	38
2.7.3: Hormone contraception	40
2.8: The menstrual cycle and acute heat exposure	40
2.8.1: Core temperature adjustments	41
2.8.2: Cutaneous adjustments	41
2.8.3: Sudomotor adjustments	42
2.8.4: Ventilation adjustments	43
2.8.5: Metabolic adjustments.....	43
2.8.6: Blood volume adjustments and haematological alternations	43
2.8.7: The menstrual cycle and exercise performance in dry heat.....	44
2.9: The OCP and exercise in the heat.....	45
2.9.1: Core temperature	45
2.9.2: Cutaneous vasodilation.....	45
2.9.3: Sudomotor adjustments	46
2.9.4: Blood volume adjustments	46
2.9.5: Performance differences	47
2.10: Summary of the literature.....	47
Chapter Three	48
3.0: Research Aims and Hypotheses	48
3.1: Aims.....	48
3.2: Hypotheses	50
Chapter Four	51

4.0: General Methodology	51
4.1: Participants.....	51
4.2: Experimental protocol.....	52
4.3: Seasonal control.....	52
4.4: Pre-experimental controls	52
4.5: Measurements	53
4.5.1: Anthropometric	53
4.5.2: Respiratory measurements	53
4.5.3: Submaximal and maximal oxygen consumption tests	53
4.5.4: Body temperature measurement	54
4.5.4.1: Validity of the measurements	54
4.5.5: Thermodynamics calculations.....	55
4.5.6: Cardiovascular measurements	56
4.5.6.1: Heart rate.....	56
4.5.6.2: Blood pressure measurement	56
4.5.6.3: Cardiac output and stroke volume	56
4.5.6.3.1: Golden standard for cardiac output measurement and validity for CO ₂ rebreathing	57
4.5.7: Blood flow measurement	57
4.5.7.1: Venous occlusion plethysmography.....	57
4.5.7.2: Laser Doppler flowmetry	58
4.5.7.3: Agreement between venous occlusion plethysmography and laser Doppler flowmetry	59
4.5.8: Sudomotor measurement	59
4.5.8.1: Whole body sweat rate.....	60
4.5.8.2: Local sweat rate	60
4.5.9: Perceptual measures.....	60
4.6: Statistical analysis	61
Chapter Five	62
5.0: Influence of menstrual phase and thermal profile on autonomic and behavioural thermoregulation during exercise in trained women.....	62
5.1: Introduction.....	63
5.2: Methods.....	66
5.2.1: Ethical approval	66
5.2.2: Participants.....	66
5.2.3: Experimental overview	66
5.2.4: Preliminary testing and familiarisation	66
5.2.5: Dietary and Exercise Control.....	67

5.2.6: Menstrual cycle and type of heat stress	67
5.2.7: Experimental procedure.....	68
5.2.8: Measurements.....	68
5.2.8.1: Hormonal analysis	68
5.2.9: Statistical analysis	70
5.3: Results	71
5.3.1: Ovarian Hormone concentrations.....	71
5.3.2: Exercise performance and behaviour	71
5.3.3: Thermoregulatory measures	73
5.3.3.1: Body temperature	73
5.3.3.2: Cardiovascular and thermoeffectors	75
5.3.3.3: Thermodynamics	77
5.3.3.4: Correlation and regression analyses	80
5.4: Discussion	81
Chapter Six	86
6.0: Influence of oral contraceptive pill and thermal profile on autonomic and behavioural thermoregulation during exercise in trained women	86
6.1: Introduction	87
6.2: Method.....	90
6.2.1: Ethical approval.....	90
6.2.2: Participants	90
6.2.3: Experimental Overview	90
6.2.4: Preliminary testing and familiarisation	90
6.2.5: Dietary and Exercise control	91
6.2.6: Hormone control and type of heat stress	91
6.2.7: Experimental procedure.....	91
6.2.8: Measurements.....	91
6.2.8.1: Hormonal analysis	91
6.2.9: Statistical analysis	92
6.3: Results	93
6.3.1: Hormone concentrations.....	93
6.3.2: Exercise performance and behaviour	95
6.3.3: Thermoregulatory measures	96
6.3.3.1: Body temperature	96
6.3.3.2: Cardiovascular and thermoeffectors	98
6.3.3.3: Thermodynamics	102
6.3.3.4:Respiratory	103

6.4: Discussion	105
Chapter Seven	112
7.0: Thermoregulatory, cardiovascular and perceptual responses in men during exercise in differing thermal profiles of heat matched for vapour pressure.....	112
7.1: Introduction.....	113
7.2: Methods.....	116
7.2.1: Ethical Approval	116
7.2.2: Participants.....	116
7.2.3: Experimental Overview	116
7.2.4: Preliminary Testing and Familiarisation	116
7.2.5: Experimental Procedure.....	117
7.2.6: Measurements	117
7.2.7: Statistical Analysis	117
7.3: Results.....	119
7.3.1: Exercise Performance and Behaviour	119
7.3.2: Thermoregulatory Measures	120
7.3.2.1: Body Temperature.....	120
.....	121
7.3.2.2: Cardiovascular and Thermoeffectors	122
7.3.3: Perceptual.....	125
7.4: Discussion	127
Chapter Eight	132
8.0: Autonomic and behavioural thermoregulation during exercise in different thermal profiles when matched for vapour pressure	132
8.1: Introduction.....	133
8.2: Methods.....	135
8.2.1: Ethical Approval	135
8.2.2: Participants.....	135
8.2.3: Experimental Overview	135
8.2.4: Preliminary Testing	137
8.2.5: Experimental procedure	137
8.2.6: Measurements	137
8.2.7: Statistical analysis.....	137
8.3: Results.....	139
8.3.1: Thermoregulatory Measures	139
8.3.1.1: Body temperature.....	139
8.3.1.2: Cardiovascular and thermoeffectors	141

8.3.1.3: Thermodynamics	146
8.4: Discussion	148
Chapter Nine.....	151
9.0: General Discussion.....	151
9.1: General aim I.....	151
9.2: General aim II.....	153
9.3: Hypotheses	154
9.4: Limitations and Future Direction	154
9.4.1: Special consideration of this thesis	156
9.5: Conclusions	157
References	158
APPENDIX 1: Ethical approval for Chapter Five and Six	175
APPENDIX 2: Ethical Approval for Chapter Six and Seven.....	176
APPENDIX 3: RPE Scale	177
APPENDIX 4: Thermal Discomfort Scale	178
APPENDIX 5: Thermal Sensation Scale.....	179
APPENDIX 6: Pleasant scale	180
APPENDIX 7: Skin Wetness Scale	181
APPENDIX 8: Publication for Chapter Five.....	182
APPENDIX 9: Publication for Chapter Five.....	183

LIST OF ABBREVIATIONS

A

ANOVA	Analysis of variance
A-VCO ₂	Arteriovenous carbon dioxide content difference
AVP	Arginine vasopressin
Ach	Acetylcholine
ATP	Adenosine triphosphate
ADP	Adenosine diphosphate
AMP	Adenosine monophosphate
au	arbitrary unit

B

BSA	Body surface area
BMI	Body mass index
BP	Blood pressure

C

\dot{C}	Convective heat lost
°C	Degree centigrade
\dot{C}_{res}	Respiratory conductive heat lost
CO ₂	Carbon dioxide
CNS	Central nervous system
Ca ²⁺	Calcium
Cl ⁻¹	Chloride
CVR	Cutaneous vascular resistance
CVC	Cutaneous vascular conductance

D

DBP	Diastolic blood pressure
DRY	Dry heat

E

\dot{E}	Evaporative heat lost
E _{max}	Maximal evaporative cooling capacity of the environment
E _{req}	Required evaporative cooling for heat balance

EF	Early follicular
eNOS	endothelial nitric oxide synthase

F

FSH	Follicle stimulating hormone
FBF	Forearm blood flow
FVR	Forearm vascular resistance

G

g	Gram
GnRH	Gonadotropin–releasing hormone

H

h	Hour
h_c	Convective heat transfer
HR	Heart rate
HSI	Heat strain index
HUM	Humid heat
HSP	Heat shock protein

K

Kg	Kilogram
K^+	Potassium
KJ	Kilojoule
Kpa	Kilopascal

L

L	Litre
LF	Linear factor
LR	Lewis relation
LSR	Local sweat rate

M

m	Metre
\dot{M}	Metabolic heat production
MAP	Mean arterial pressure
Min	Minute
ML	Mid luteal phase

mmHg	Millimeters of mercury
mmol	Millimole
N	
Na ⁺	Sodium
nmoll ⁻¹	Nanomole per litre
NO	Nitric oxide
NS	Nervous system
O	
O ₂	Oxygen
OCP	Oral contraception pill
OP	Oral contraception
P	
P _A	Ambient water vapour pressure
P _{Sk}	Saturated water vapour pressure at the skin
P _{ET} CO ₂	Partial pressure of end- tidal CO ₂
PL	Pleasant
PO	Power output
Q	
\dot{Q}	Cardiac output
qF	Quasi-follicular
qL	Quasi-luteal
R	
\dot{R}	Rate of heat exchange via radiation
RER	Respiratory exchange ratio
RPE	Rate of perceived exertion
rpm	Revolutions per minute
S	
S	Second
\dot{S}	Heat Storage
SD	Standard deviation
SBP	Systolic blood pressure
SEE	Standard error of mean
SKBF	Skin blood flow
T	

T_A	Ambient temperature
\bar{T}_b	Mean body temperature
TAN	Total adenine nucleotide pool
T_{core}	Core temperature
TD	Thermal discomfort
T_{rec}	Rectal temperature
TS	Thermal sensation
\bar{T}_{sk}	Mean skin temperature
TRP	Transient receptor potential
V	
v	Air velocity
VOP	Venous occlusion plethysmography
$\dot{V}\text{CO}_2$	Rate of carbon dioxide elimination
$\dot{V}\text{O}_2$	Rate of oxygen uptake
$\dot{V}\text{O}_{2\text{max}}$	Maximal oxygen uptake
W	
W	Watt
WBGT	Wet-bulb globe temperature
\dot{W}	Rate of heat exchange from external work
Y	
Y	Year

LIST OF PUBLICATIONS

Chapter Five

Lei TH, Stannard SR, Perry BG, Schlader ZJ, Cotter JD, Toby Mündel (2017). Influence of menstrual phase and arid vs. humid heat stress on autonomic and behavioural thermoregulation during exercise in trained but unacclimated women. J Physiol 595.9(2017): 2823-2837.

Chapter Five

Lei TH & Mündel T (2018). Humid heat stress affects trained female athletes more than does their menstrual phase. Temperature, DOI:10.1080/23328940.2018.1436394.

Chapter Six

Lei TH, Cotter JD, Schlader ZJ, Stannard SR, Perry BG, Barnes MJ , Mündel T (in revision). On exercise thermoregulation in females: interaction of endogenous and exogenous ovarian hormones. J Physiol.

LIST OF FIGURES

Figure 1: Heat dissipation during exercise in a dry heat environment (Armstrong et al., 1996)	10
Figure 2: Heat dissipation in a humid heat environment (Armstrong et al., 1996).....	11
Figure 3: Two node (core to shell) model of thermoregulation. Adapted from Gagge and Gonzalez (2011).....	12
Figure 5: Close-control loop from the active and passive systems (Werner, 2005)	
Figure 6: Core temperature is stable within the range of temperatures bound by the core temperature for shivering and sweating, defined as the interthreshold zone, retrieved from (Mekjavic and Eiken, 2006)	15
Figure 7: Schematic representation of the dependence of activity on cold-activated (Blue) and heat-activated (Red) thermo TRP channels in heterologous systems, adapted from (Romanovsky, 2007).....	17
Figure 8: Comparison of rectal temperatures during intermittent and continuous exercise undertaken in compensable and uncompensable heat stresses, adapted from (Kraning and Gonzalez, 1991a).....	23
Figure 9: Cardiovascular responses during sustained moderate intensity (70% of VO_{2max}) exercise in temperate and hot conditions, retrieved from Sawka et al (2011).....	27
Figure 10: Schematic comparison of the thermoregulatory control of skin blood flow at rest (passive heating) and during dynamic exercise, retrieved from González-Alonso et al. (2008).	29
Figure 11: Effects of limiting the rise in rectal temperature, in humans, on pulmonary ventilation and arterial CO_2 tension, during prolong submaximal work at 65% maximal oxygen uptake, retrieved from White (2006).	32
Figure 12: Hormonal fluctuations during the menstrual cycle and their relation to the ovarian cycle, retrieved from THE CONVERSATION.com.	39
Figure 13: Mean (SD) power output (n=10) and individual and mean (SD) work capacity (n=10) during exercise in dry (DRY) and humid (HUM) heat during the early follicular (EF) and mid-luteal (ML) phase.	72
Figure 14: Mean (SD) rectal temperature (T_{rec} , n = 10) and weighted mean skin temperature T_{sk} , n =10) during exercise in dry (DRY) and humid (HUM) heat during the early follicular (EF) and mid-luteal (ML) phase.....	74
Figure 15: Mean (SD) local sweat rate (LSR, n=9) and forearm blood flow (FBF, n=10) against time and mean body temperature(T_b) during exercise in dry (DRY) and humid(HUM) heat during the early follicular (EF) and mid-luteal (ML) phase	76
Figure 16: Mean (SD) rate of metabolic heat production (M, n = 9), rate of evaporative heat loss (E, n = 9), rate of heat storage (S, n = 9), maximal evaporative capacity of the environment (E_{max} , n = 9), required evaporative cooling for heat balance (E_{req} , n = 9) and heat strain index (HSI, n = 9) during exercise in dry (DRY) and humid (HUM) heat during the early follicular (EF) and mid-luteal (ML) phase	78
Figure 17: Mean (SD) power output (n = 10) and individual and mean (SD) work capacity (n	

= 10) during exercise in dry (DRY) and humid (HUM) heat during the quasi-follicular (qF) and quasi-luteal (qL) phase.	95
Figure 18: Mean (SD) rectal temperature (T_{rec} , $n = 10$) and weighted mean skin temperature (T_{sk} , $n = 10$) during exercise in dry (DRY) and humid (HUM) heat during the quasi-follicular (qF) and quasi-luteal (qL) phase.	97
Figure 19: Mean (SD) local sweat rate (LSR, $n = 9$) and forearm blood flow (FBF, $n = 8$) against time and mean body temperature (T_b) during exercise in dry (DRY) and humid (HUM) heat during the quasi-follicular (qF) and quasi-luteal (qL) phase.	101
Figure 20: Mean (SD) rate of metabolic heat production (M , $n = 10$), rate of evaporative heat loss (E , $n = 10$), rate of heat storage (S , $n = 10$), maximal evaporative capacity of the environment (E_{max} , $n = 10$), required evaporative cooling for heat balance (E_{req} , $n = 10$) and heat strain index (HSI, $n = 10$) during exercise in dry (DRY) and humid (HUM) heat during the quasi-follicular (qF) and quasi-luteal (qL) phase.	104
Figure 21: Individual and mean (SEE) work capacity ($n = 14$), and mean (SEE) power output ($n = 14$) during exercise in 35 °C and 29 °C.	119
Figure 22: Mean (SEE) rectal temperature (T_{rec} , $n = 14$) and weighted mean skin temperature (T_{sk} , $n = 14$) during exercise in 35 °C and in 29 °C environments.	
* significant difference between 35 °C and 29 °C environments.	
Figure 23: Mean (SEE) local sweat rate (LSR, $n = 14$) and skin blood flow (SKBF, $n = 14$) against time during exercise in 35 °C and 29 °C environments.	123
Figure 24: Mean (SEE) rate of perceived exertion (RPE, $n = 14$), thermal sensation (TS, $n = 14$), thermal discomfort (TD, $n = 14$), pleasantness (PL, $n = 14$) and skin wetness ($n = 14$).	126
Figure 25: Power output during fixed-intensity and self-paced exercise ($n = 13$) in both 35 °C and 29 °C environments.	136
Figure 26: Mean (SEE) rectal temperature (T_{rec} , $n = 13$) and weighted mean skin temperature (T_{sk} , $n = 13$) during self-paced (SP) and fixed-intensity exercises at 35 °C and 29 °C.	140
Figure 27: Mean (SEE) skin blood flow (SKBF, $n = 13$) against time and mean body temperature (T_b) during self-paced (SP) and fixed-intensity exercises in 35 °C and 29 °C environments.	143
Figure 28: Mean (SEE) Local sweat rate (LSR) against time and mean body temperature (T_b) during self-paced (SP) and fixed-intensity exercises at 35 °C and 29 °C.	145
Figure 29: Mean (SEE) rate of metabolic heat production (M , $n = 13$), rate of evaporative heat loss (E , $n = 13$) and rate of heat storage (S , $n = 13$) between self-paced (SP) and fixed-intensity at 35 °C and 29 °C.	147

LIST OF TABLES

Table 1: Participants' anthropometric characteristics. Data are expressed as mean \pm SD, The bioelectrical impedance machine was not available after the completion of subject number eight.	51
Table 2: Mean arterial pressure (MAP, n=10), cardiac output(\dot{Q} , n=8), forearm vascular resistance (FVR, n=10) and stroke volume (SV, n=8) at rest and during fixed-intensity exercise in dry(DRY) and humid(HUM) heat during the early follicular(EF) and mid-luteal(ML) Phase.....	79
Table 3: Individual and group progesterone and 17 β -oestradiol concentrations during the (quasi-) follicular (F) and luteal (L) phase for the matched eummenorrheic (Chapter 5) and oral contraceptive pill (OCP) groups.....	94
Table 4: Mean arterial pressure (MAP, n = 8), cardiac output (\dot{Q} , n = 6), forearm vascular resistance (FVR, n = 8) and stroke volume (SV, n = 6) at rest and during fixed-intensity exercise in dry (DRY) and humid (HUM) heat during the quasi-follicular (qF) and quasi-luteal (qL) phase. Values are mean (SD).....	99
Table 5: Mean arterial pressure (MAP, n = 13), cardiac output (\dot{Q} , n = 11), forearm vascular resistance (CVR, n = 13) and stroke volume (SV, n = 11) at rest, during warm up and 6 minutes after the start of the 30-minute time trial in both 35°C/29°C environments.....	124
Table 6: Mean arterial pressure (MAP, n = 12), cardiac output (n = 9), forearm vascular resistance (CVR, n = 12) and stroke volume (SV, n = 9) at rest, during warm up and the first 6 minutes off the 30-minute time trial in both 35°C/29°C environments.	144