UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Manipulating Mother Nature to Accelerate Physiological Adaptations to Exercise

by Erin McCleave

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of
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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Erin McCleave declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Sport, Exercise and Rehabilitation, Faculty of Health, at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

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PREFACE

This thesis for the degree of Doctor of Philosophy is in the format of Thesis by compilation and abides by the 'Procedures for Presentation and Submission of Theses for Higher Degrees – University of Technology Sydney; Policies and Directions of the University'.

From the research design and data collection by the candidate, three manuscripts have been accepted and published to peer reviewed journals, with a fourth paper submitted and under review. These papers are brought together by an introduction, which provides background information, research problem, as well as the purpose and significance of each of the four studies. A literature review provides an overview of how heat and hypoxia influence physiological and performance outcomes. The manuscripts are then presented in a logical sequence following the development of research ideas within this thesis. Each manuscript has a similar outline of introduction, methods, results, discussion, practical applications, and conclusion. All studies are combined into a discussion chapter, which integrates the collective findings and limitations. This thesis finishes with an overall conclusion, practical applications, an overview of the impact of thesis findings, and directions for future research.

PUBLICATIONS

List of Articles Accepted for Peer Review Publication

McCleave, E. L., Slattery, K. M., Duffield, R., Saunders, P. U., Sharma, A. P., Crowcroft, S. J., & Coutts, A. J. (2017). Temperate Performance Benefits after Heat, but Not Combined Heat and Hypoxic Training. *Medicine and science in sports and exercise*, *49*(3), 509–517. https://doi.org/10.1249/MSS.0000000000001138

McCleave, E. L., Slattery, K. M., Duffield, R., Saunders, P. U., Sharma, A. P., Crowcroft, S., & Coutts, A. J. (2019). Impaired Heat Adaptation from Combined Heat Training and "Live High, Train Low" Hypoxia. *International journal of sports physiology and performance*, *14*(5), 635–643. https://doi.org/10.1123/ijspp.2018-0399

McCleave, E. L., Slattery, K. M., Duffield, R., Crowcroft, S., Abbiss, C. R., Wallace, L. K., & Coutts, A. J. (2020). Concurrent Heat and Intermittent Hypoxic Training: No Additional Performance Benefit Over Temperate Training. *International journal of sports physiology and performance*, 1–12. Advance online publication. https://doi.org/10.1123/ijspp.2019-0277

Article Submitted for Peer Review Publication

McCleave, E. L., Slattery, K. M., Duffield, R., Crowcroft, S., Abbiss, C. R., & Coutts, A. J. (Under review). Heat Response Test Adaptations Following Concurrent Heat and Hypoxic Training.

Conference Communications

McCleave, E.L., Slattery, K.M., Duffield, R., Crowcroft, S.J., Wallace L.K., and Coutts, A.J. (2014) Effects of high intensity interval training in concurrent heat and normobaric hypoxia on physiological and performance adaptations. *Awarded Young Investigator Award to present at 2014 Training and Competing in the Heat Conference, Aspetar – Qatar Orthopaedic and Sports Medicine Hospital, Doha, Qatar.*

McCleave, E.L., Slattery, K.M., Duffield, R., Crowcroft, S.J., Wallace L.K., and Coutts, A.J. (2014) Effects of high intensity interval training in concurrent heat and normobaric hypoxia on physiological and performance adaptations. *Exercise and Sports Science Australia Conference, Adelaide, Australia.*

McCleave, E.L., Slattery, K.M., Saunders, P., Sharma, A.P., Garvican, L., Duffield, R., and Coutts, A.J. (2015) Effect of 3 weeks combined 'Live High-Train Low' exposure with heat interval training in trained runners. *European College of Sport Science Congress, Malmo, Sweden.*

ABSTRACT

Endurance athletes commonly incorporate repeated exposure to either heat or hypoxia into their training program, due to its ability to improve physiological and performance outcomes. However, there is limited understanding of whether the combined effects of both stimuli together can provide even further benefits above either environment alone. Accordingly, this thesis aimed to assess the effectiveness of incorporating heat and hypoxia across a training block to enhance physiological adaptations and performance in endurance athletes.

Study one assessed the temperate performance and physiological changes following a three-week overload period of combined heat and 'Live High, Train Low' (LHTL) hypoxia. While the combined stimuli induced physiological adaptations, it did not transfer to improved 3-km time-trial running performance with the only performance improvements observed following independent heat training.

Study two further investigated the physiological outcomes of combined heat and LHTL, and assessed multiple thermal, cardiovascular, cellular, and perceptual adaptations during submaximal exercise in the heat. Combined heat and LHTL impaired many heat related adaptations relative to the heat only group, indicating that the addition of LHTL provided no greater physiological benefit during exercise in a hot environment.

Following from the findings of study one and two, study three and four assessed the performance and physiological outcomes when heat was applied concurrently with IHT. Specifically, study three evaluated changes in 20-km cycling time-trial performance in both temperate and the participant's assigned environmental condition following three weeks of training in either concurrent heat and IHT, independent heat or a temperate environment. Performance was improved in all groups to a similar extent regardless of the type of environment.

In the fourth and final study, the thermal, cardiovascular, and selected cellular responses following three weeks of training in heat and IHT were assessed. When compared to completing the same training in either independent heat or temperate environments,

concurrent heat and IHT provided some advantages above temperate training, but no further benefit above heat training alone.

Taken collectively, the present findings show the additive stimuli of combining heat and hypoxia does not directly transfer to improved endurance performance. While physiological adaptations were induced when both LHTL and IHT were applied with heat training, it did not provide clear benefits above independent heat training alone.

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LIST OF ABBREVIATIONS

[Hb]	Haemoglobin concentration
[Na]sweat	Sweat sodium concentration
µL	Microlitre
AIS	Australian Institute of Sport
AU	Arbitrary units
BV	Blood volume
CL	Confidence limits
CO	Carbon monoxide
CV	Coefficient of variation
ECU	Edith Cowan University
EPO	Erythropoietin
ES	Effect size
F	Female
FiO_2	Fraction of inspired oxygen
H	Hours
Hbmass	Haemoglobin mass
Hct	Hematocrit
HIF-1α	Hypoxia inducible factor-1α
HR	Heart rate
HRmax	Maximal heart rate
HRT	Heat response test
HSP	Heat shock protein
IAAF	International Association of Athletics Federation
IHT	Intermittent Hypoxic Training
Kg	Kilogram
Km	Kilometre
$L{\cdot}min^{-1}$	Litres per minute
LHTH	'Live High, Train High' mode of hypoxic exposure
LHTL	'Live High, Train Low' mode of hypoxic exposure
M	Male
m	Metres
$m{\cdot}s^{-1}$	Metres per second

Mg	Milligram
Min	Minutes
$ml\cdot kg^{-1}\cdot min^{-1}$	Oxygen capacity in milliliters per kilogram per minute
Mm	Millimeter
MMP	Mean maximal power
mRNA	Messenger ribonucleic acid
n	Sample size
NSWIS	New South Wales Institute of Sport
^{o}C	Degrees Celsius
PV	Plasma volume
RBC	Red blood cell count
RE	Running economy
RH	Relative humidity
RPE	Rating of perceived exertion
s	Seconds
SaO_2	Arterial oxyhaemoglobin saturation
SD	Standard deviation
sRPE	Session RPE
Sum of 7	Total seven sites of skinfolds, measured in millimetres
TE	Technical error
TL	Training load
TT	Time-trial
$v4\ mmol\cdot L^{-1}$	Velocity corresponding to lactate at 4 mmol per litre
VEGF	Vascular endothelial growth factor
VO_2	Oxygen consumption
VO_2max	Maximal aerobic capacity
VO_2peak	Peak aerobic capacity
vVO_{2peak}	Velocity corresponding to VO_{2peak}
W	Watts
Y	Year