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**Adaptation to exercise for maximal aerobic capacity,  
submaximal aerobic efficiency, and cardiovascular  
adjustments: does the addition of heat stress induce greater  
improvements than exercise alone?**

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A thesis presented in partial fulfilment of the requirements for the degree of

Master of Science

in

Exercise and Sport Science

Massey University, Palmerston North, New Zealand

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2015

## Abstract

**Background:** Exercising in a hot environment often feels harder, and puts a greater amount of strain on the body than exercise in cooler temperatures. The extra strain caused by the heat has been utilised and explained extensively in the previous literature, by which training in the heat, and the concurrent physiological adaptations that arise (heat acclimation), has been shown to improve exercise performance in hot environments. It appears that the effect that heat acclimation can have on exercise performance in temperate environments, as opposed to hot, has been relatively overlooked in the literature. The physiological adaptations associated with the extra strain whilst exercising in the heat may not only induce performance benefits in temperate environments, but may also lead to positive resting cardiovascular adjustments.

**Aim:** The aim of this study was to determine what effect exercising with additional heat stress (35°C) has on maximal and submaximal aerobic capacity/performance in a moderate environment (18°C). The physiological adaptations obtained with exercise and additional heat stress was investigated, along with the impact they have on resting cardiovascular measures.

**Methodology:** In a randomised, matched control group study, eighteen moderately active males participated in a maximal and submaximal aerobic test, followed by an 11-day training protocol (five consecutive days, one day rest, six consecutive days) consisting of 60 minutes of incline walking each day on a treadmill at 50% of their  $\dot{V}O_{2\max}$  in either a hot (35°C, 45% RH) or moderate (18°C, 53% RH) environment. Within four  $\pm$  one day of completing the training protocol, the maximal and submaximal aerobic tests were repeated. Maximal aerobic capacity was measured in the maximal test; with submaximal  $\dot{V}O_2$ , heart rate and lactate measured to indicate changes during exercise. Core temperature, heart rate, plasma volume, forearm blood flow, whole body sweat rate, local sweat rate, and perceptual measures were taken throughout the 60 minutes of walking over the 11-day training period, in combination with resting heart rate and blood pressure measures to determine cardiovascular adjustments.

**Results:** Exercise, with or without heat stress improved maximal aerobic capacity by  $7.0 \pm 0.9 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  ( $p < 0.001$ ), although, additional heat stress did not improve maximal aerobic capacity above exercise alone. The exercise protocol, irrespective of whether in a hot or moderate environment, lowered submaximal heart rate ( $p = 0.008$ ) and relative  $\dot{V}O_2$  ( $p < 0.001$ ), but had no effect on submaximal blood lactate. The 11-day training protocol lowered resting heart rate ( $p < 0.001$ ), reduced core temperature ( $p = 0.039$ ), increased forearm blood flow ( $p = 0.046$ ), and lowered perceived exertion ( $p < 0.001$ ) for both groups. Additionally, the heat group had increased whole

body sweat rate ( $p = 0.01$ ), and improved thermal comfort ( $p = 0.024$ ). The exercise, regardless of environment, appeared to induce resting cardiovascular adjustments, although statistical significance was not reached.

**Conclusions:** Eleven days of exercise at 50% of  $\dot{V}O_2\text{max}$ , regardless of environment, can improve maximal and submaximal performance in a moderate environment and induce positive cardiovascular adjustments. Eleven days of exercise in 35°C can induce heat acclimation, illustrated through an increase in whole body sweat rate, and a reduction in exercising heart rate, core temperature and perceived exertion.

## **Acknowledgements**

Firstly, I would like to thank my supervisors; Dr Toby Mündel, and Dr Darryl Cochrane. Darryl, your support through not only this thesis, but through my two years as a post-graduate student has been outstanding and I could not have asked for more, thank you. Toby, where do I even start! The amount of support, knowledge, and enthusiasm you have offered from under-graduate through to post-graduate study has been second to none, and undoubtedly the reason I have progressed this far and developed a passion for research, I cannot thank you enough.

To Karl and Blake, thank you for all your support and assistance from pilot work and data collection, all the way to the completion of this thesis. Your help and knowledge in the lab was irreplaceable, and a special thank you must go to you both for constantly having to move “that bloody treadmill” for me.

To my participants, a massive thank you is in order for the time and effort you put into completing my study; I could not have done it without each one of you.

Finally, to my family; your support and interest in not only this thesis, but also everything else that I choose to take part in has been especially important to me. I would not be where I am today without the love and support you provide, and for that I thank you so very much.

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## List of Abbreviations

### A

ANOVA                      Analysis of variance

### B

BLa                         Blood lactate  
BMI                         Body mass index  
BSA                         Body surface area  
b·min<sup>-1</sup>                      Beats per minute

### C

CBF                         Cerebral blood flow  
cm                         Centimetres  
CO<sub>2</sub>                         Carbon dioxide

### E

ECF                         Extracellular fluid  
EHS                         Exertional heat stroke

### F

FI                         Fixed-intensity

### H

Hb                         Haemoglobin  
Hct                         Haematocrit  
HPL                         Human Performance Laboratory  
HSP                         Heat shock protein

### I

ISF                         Interstitial fluid

## K

kg	Kilograms
kg·m <sup>-2</sup>	Kilogram per square metre
km	Kilometres
km·h <sup>-1</sup>	Kilometres per hour

## L

L	Litres
L·min <sup>-1</sup>	Litres per minute
L·h <sup>-1</sup>	Litres per hour
LSR	Local sweat rate

## M

m	Metres
m·s <sup>-1</sup>	Metres per second
MCAv <sub>mean</sub>	Middle cerebral artery mean blood velocity
mL	Millilitres
mL·kg <sup>-1</sup> ·min <sup>-1</sup>	Millilitres per kilogram per minute
min	Minute
mm	Millimetres
mm Hg	Millimetres of mercury
mmol·L <sup>-1</sup>	Millimoles per litre
μL	Microlitres

## N

Na <sup>+</sup> /K <sup>+</sup> ATPase	Sodium-potassium adenosine triphosphatase
NE	Norepinephrine
NO	Nitric oxide

## O

O <sub>2</sub>	Oxygen
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**P**

PV Plasma volume

**R**

RER Respiratory exchange ratio

RH Relative humidity

RPE Rating of perceived exertion

**S**

SD Standard deviation

SE Standard error

SkBF Skin blood flow

SP Self-paced

STPD Standard temperature and pressure, dry

SWR Whole body sweat rate

**T**

$T_c$  Core temperature

ThC Thermal comfort

ThS Thermal sensation

$T_{sk}$  Skin temperature

$\bar{T}_{sk}$  Mean skin temperature

**U**

USG Urine specific gravity

**V**

$V_E$  Minute ventilation

$\dot{V}O_2$  Oxygen consumption

$\dot{V}O_{2max}$  Maximal oxygen uptake

VOP Venous occlusion plethysmography

**W**

WBGT

Wet-bulb globe temperature

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