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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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 ± 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 ± 0.9 $mL \cdot kg^{-1} \cdot min^{-1}$ ($p < 0.001$), 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 $\dot{V}O_2$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.

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List of Abbreviations

A

ANOVA	Analysis of variance

B

BLa	Blood lactate
BMI	Body mass index
BSA	Body surface area
$b \cdot min^{-1}$	Beats per minute

C

CBF	Cerebral blood flow
cm	Centimetres
CO_2	Carbon dioxide

E

ECF	Extracellular fluid
EHS	Exertional heat stroke

F

FI	Fixed-intenstiy

H

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

I

ISF	Interstitial fluid

K

kg	Kilograms
$kg \cdot m^{-2}$	Kilogram per square metre
km	Kilometres
$km \cdot h^{-1}$	Kilometres per hour

L

L	Litres
$L \cdot min^{-1}$	Litres per minute
$L \cdot h^{-1}$	Litres per hour
LSR	Local sweat rate

M

m	Metres
$m \cdot s^{-1}$	Metres per second
$MCAv_{mean}$	Middle cerebral artery mean blood velocity
mL	Millilitres
$mL \cdot kg^{-1} \cdot min^{-1}$	Millilitres per kilogram per minute
min	Minute
mm	Millimetres
mm Hg	Millimetres of mercury
$mmol \cdot L^{-1}$	Millimoles per litre
µL	Microlitres

N

Na^+/K^+ ATPase	Sodium-potassium adenosine triphosphatase
NE	Norepinephrine
NO	Nitric oxide

O

O_2	Oxygen

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
$\overline{T}_{sk}$	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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