Hyperthermia-induced fatigue - hypothesis-driven research

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Exercise in the heat – importance of CBF changes

Psychological factors
- Mood, focus, motivation
- Anxiety, fatigue, and perception of task demand

Neurological/CNS changes
- Reduced cerebral blood flow
- Decreased cerebral metabolic rate
- Alterations in regional neurotransmitter levels (serotonin, dopamine, glutamate)
- Ammonia, cytokines, endorphins
- Cerebral/hypothalamic temperature, oxygen delivery

Fatigue/Performance
- Reduced stroke volume – cardiac output (when increase in HR does not compensate)
- MAP
- Increased PaCO2
- Lowered heart rate
- Impaired muscle function
- Impaired oxygen delivery and perfusion

Peripheral/muscular factors
- Increased ventilation
- Increased work and temperature

Psychological factors
- "Will/motivation"
- Mood
- Pain tolerance
- Previous experiences and expectation of task demand

Respiration
- Increased ventilation
- Increased heart rate
- Increased metabolic rate
- Blood pH

Cardiovascular changes
- Reduced stroke volume – cardiac output
- MAP
- Increased PaCO2
- Increased heart rate

High Core Temperature (and its effects on CNS and muscle function)
- or CV-changes (arterial oxygen delivery) that limits performance??

Cardiovascular strain impairs prolonged self-paced exercise in the heat

Graphs showing changes in oxygen uptake and rectal temperature over time in both cool and hot conditions.
Cardiovascular Strain and limitation for arterial oxygen delivery

Unaltered kinetics at the on-set of exercise, but reduced VO$_2$max and consequently impaired maximal exercise capacity

Nybo et al., J App Physiol, 2001

Prolonged submaximal exercise

Galloway & Maughan 1997

Submaximal whole-body exercise with progressive hyperthermia

- Marked CV stress - reduced SV and near max HR – but unaltered VO$_2$
- Absence of peripheral/muscular changes that may explain fatigue – CENTRAL FATIGUE ??
- The development of fatigue apparently linked to increase in core/trunk temperature – BRAIN TEMPERATURE ??

Bodil Nielsen and co-workers

Hyperthermia and fatigue during submaximal exercise

Gonzalez-Alonso et al. JAP 1999 Nybo & Nielsen JAP 2001
Knee extensions following exercise with and without hyperthermia

CBF during prolonged submaximal exercise

Implications for cerebral function and metabolism?

Psychological factors

Fatigue/Performance

Peripheral/muscular factors

Psychological factors

Fatigue/Performance

Peripheral/muscular factors

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CBF during prolonged submaximal exercise

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Implications for cerebral function and metabolism?
Restoration of cerebral circulation

Filled symbols represent data obtained without ventilatory manipulation, while open symbols represent data obtained during ventilatory manipulation. † Difference from pre-ventilatory manipulation value P < 0.05.

Restoring heat stress-associated reduction in middle cerebral artery velocity does not reduce fatigue in the heat.

Voluntary suppression of hyperthermia-induced hyperventilation mitigates the reduction in cerebral blood flow velocity during exercise in the heat.
Neurobiological/CNS changes
- Cerebral metabolic changes: substrate depletion
- Alterations in regional neurotransmitter levels (serotonin; dopamine; glutamate)
- Ammonia; cytokines; endorphins
- Cerebral / hypothalamus temperature; oxygen delivery

FATIGUE/PERFORMANCE

Psychological factors
- "Will/motivation"; mood; pain tolerance
- Previous experiences and expectation of task demand

Respiration
- Increased ventilation
- Increased PaCO₂
- Increased pH
- Increased temperature

Cardiovascular changes
- Reduced stroke volume – cardiac output when increase in HR does not compensate – MAP
- Increased PaCO₂
- Increased skin perfusion and temperature

Peripheral/muscular factors
- Altered/impaired muscle function
- Impaired oxygen delivery/perfusion
- Accumulation of metabolites
- Direct effects of heat on peripheral tissue
- Afferent feedback from thermo- and metaboreceptors

Respiratory changes
- Increased ventilation
- Increased PaCO₂
- Increased pH
- Increased temperature

Conclusions:
- Central fatigue is involved in the aetiology of the hyperthermia-induced impairment of exercise performance
- The average brain temperature remains higher than that of the body core/trunk during exercise – i.e. selective brain cooling is not observed in humans (high CNS likely candidate for fatigue)
- CBF reduced -> lower CNS oxygenation but not likely to cause fatigue
- During dynamic exercise hyperthermia is associated with "cardiovascular stressing" (limits maximal exercise) – However, performance is also impaired when the overall taxation of the cardiac capacity is far from maximal