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Doctoral thesis abstract

The Effect of Temperature Manipulation on Skeletal Muscle Function and Thermal Stress Responses in Young Males

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ABSTRACT

BACKGROUND AND OBJECTIVES

Temperature manipulation, through heating and cooling strategies such as hot or cold water immersion (HWI, CWI) or exertional heating, alters body temperature and can influence muscle function, metabolic activity, recovery, and thermal stress responses (Cramer et al., 2022; Rodrigues et al., 2022; Versey et al., 2013). These interventions can elevate or reduce core and muscle temperature (T_{mu}), leading to distinct effects on muscle contractility, fatigue, recovery, and endocrine responses (Bergh & Ekblom, 1979; Cheng et al., 2017; Morton et al., 2007; Mündel et al., 2006). Prolactin is often used as an indirect marker of central fatigue and heat-related stress (Mündel et al., 2006), however, it is unclear whether endocrine responses differ when core temperature increases are closely matched but skin temperature varies between active (exercise-induced, Exer-H) and passive (exogenous, Exo-H) heating. The mechanisms underlying neuromuscular and thermal stress responses remain unclear, particularly regarding the influence of exposure duration and differences between active and passive heating modalities. The general aim of the dissertation was to determine the effects of heating and cooling of varying durations on skeletal muscle function and thermal stress responses in recreationally active young males.

METHODS

Four studies were conducted. In *Study I*, a randomised crossover design was used, in which participants completed both active (exercise-induced) heating (cycling at 60% $\dot{V}O_2max$ until rectal temperature (T_{rec}) reached 39°C) and passive (exogenous) heating (lower-body immersion in hot water until T_{rec} reached 39°C). *Study II* comprised four randomised cross-over experimental trials across two phases: a single exposure phase (SP) for 45 min and an intermittent/prolonged exposure phase (IPP) for 300 min, each including control sitting (CON) and hot water immersion (HWI at 44–45°C up to the waist) performed in random order and separated by at least one week, with muscle force and contractile properties assessed during the experiments. *Study III* followed the same design as *Study II*, but used cold water immersion (CWI at 10°C up to the waist) instead of HWI. *Study IV* combined the protocols of *Studies II and III*, with participants completing six experimental trials: acute (CON, HWI, CWI) and intermittent/prolonged (CON, HWI, CWI), along with additional assessments of muscle force recovery.

- **Study I (subjects: young healthy males (n = 14, age: 23.5 ± 4.1 years):** measurements were taken at 0.5°C increase in T_{rec} up to 39°C and during the subsequent decrease down to 37.5°C, including muscle temperature, skin temperature (T_{sk}), rectal temperature, blood samples for prolactin concentration assessment, and thermal perceptions.

- **Studies II and III (subjects: recreationally active males (n = 12, age: 27.2 ± 6.6 years).** Single (SP) and intermittent/prolonged (IPP) hot water (HWI) or cold water (CWI) immersion. During intermittent/prolonged CWI phase, two additional 15 min immersions were added at 165 min and 255 min, while during intermittent/prolonged HWI, eight additional bouts of HWI were added after 75, 105, 135, 165, 195, 225, 255, and 285 min. Participants underwent measurements of body composition, cardiovascular parameters (heart rate, blood pressure), rectal (T_{rec}) and muscle (T_{mu}) temperature, and neuromuscular function (P20, P100, TT, maximal voluntary isometric contraction (MVIC), dynamic knee exercises) at baseline and multiple time points during single and intermittent/prolonged immersion. Both phases concluded with a fatiguing protocol of 100 electrical stimulation trains to the knee extensors.
- **Study IV (subjects: recreationally active males (n = 10, age: 27.1 ± 6.8 years).** The participants for Study IV are a subset from studies II and III. Assessed the effects of acute and prolonged temperature exposure on muscle recovery, including neuromuscular testing 3 min after fatiguing exercise.

RESULTS

In *Study I*, the Δ changes in prolactin concentration were larger in Exo-H compared to Exer-H during both the heating phase (P = 0.011) and post-heating (P = 0.009) phases. The increase in T_{sk} Calf and T_{sk} Thigh was larger in Exo-H compared to Exer-H during the heating phase (P < 0.001) and smaller but significant differences were observed in T_{sk} Shoulder and Forehead (P < 0.01). In *Study II* (HWI), muscle temperature increased at all depths (~38–38.5°C) and remained elevated during SP and IPP (condition effect, P < 0.001). P100 torque was not affected by single and intermittent/prolonged condition, while half-relaxation time (HRT) decreased compared to control at the end of the single phase (P < 0.008) and over the intermittent/prolonged phase (group effect: P = 0.002) with no differences in Δ changes between single and intermittent/prolonged conditions (P ≤ 0.008). In *Study III* (CWI), T_{mu} (at the three depths) were similarly reduced in CWI compared with CON at the end of the single phase and at 60 min during the intermittent/prolonged phase (P < 0.05), remaining reduced until the end of the intermittent/prolonged phase (P < 0.05). P100 was lower in CWI than in CON at the end of the single phase (P < 0.01) and only at 60 min during the intermittent/prolonged phase (P < 0.05), with larger Δ changes reductions in SP-CWI compared to IPP-CWI (P = 0.02). HRT was higher in CWI than CON at the end of the single phase (P < 0.01) and showed a significant group effect over the intermittent/prolonged protocol (P = 0.03), with Δ changes smaller in IPP-CWI than SP-CWI (P < 0.05). In *Study IV*, MVIC remained significantly lower after 3 min in single CON and HWI, and in all intermittent/prolonged protocol groups (P < 0.05). Central activation ratio (CAR) remained significantly reduced in HWI during the intermittent/prolonged phase at the end of the bath and after 3 min of recovery (P < 0.05).

CONCLUSIONS

The findings indicate that Exo-H elicits greater prolactin responses than Exer-H, despite a similarly matched elevation of T_{rec}, likely due to larger lower-limb skin temperature elevations, while thermal perceptions remain similar between conditions. Single or intermittent/prolonged HWI enhances muscle contractile properties and relaxation in the unfatigued state without impairing muscle force, and prolonged exposure does not further augment these effects under moderate thermal stress. In contrast, intermittent/prolonged CWI produces a less pronounced fast-to-slow contractile transition than single immersion, likely due to reduced vasoconstriction and maintained superficial muscle perfusion. Although HWI effectively increases body temperature, it may significantly impair neuromuscular recovery compared with CWI or passive rest.

Keywords: hot-water immersion, cold-water immersion, temperature, thermal stress, neuromuscular function

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