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Original Research

The effect of local skin cooling before a sustained, submaximal isometric contraction on fatigue and isometric quadriceps femoris performance: A randomized controlled trial☆

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ABSTRACT

The central- and peripheral mechanisms by which heat strain limits physical performance are not fully elucidated. Nevertheless, pre-cooling is often used in an attempt to improve subsequent performance. This study compared the effects of pre-cooling vs. a pre-thermoneutral application on central- and peripheral fatigue during 60% of isometric maximum voluntary contraction (MVC) of the right quadriceps femoris muscle. Furthermore, the effects between a pre-cooling and a pre-thermoneutral application on isometric MVC of the right quadriceps femoris muscle and subjective ratings of perceived exertion (RPE) were investigated. In this randomized controlled trial, 18 healthy adults voluntarily participated. The participants received either a cold (experimental) application (+8 °C) or a thermoneutral (control) application (+32 °C) for 20 min on their right thigh (one cuff). After the application, central (fractal dimension – FD) and peripheral (muscle fiber conduction velocity – CV) fatigue was estimated using sEMG parameters during 60% of isometric MVC. Surface EMG signals were detected from the vastus medialis and lateralis using bidimensional arrays. Immediately after the submaximal contraction, isometric MVC and RPE were assessed. Participants receiving the cold application were able to maintain a 60% isometric MVC significantly longer when compared to the thermoneutral group (mean time: 78 vs. 46 s; $p=0.04$). The thermoneutral application had no significant impact on central fatigue ($p > 0.05$) compared to the cold application ($p=0.03$). However, signs of peripheral fatigue were significantly higher in the cold group compared to the thermoneutral group ($p=0.008$). Pre-cooling had no effect on isometric MVC of the right quadriceps muscle and ratings of perceived exertion. Pre-cooling attenuated central fatigue and led to significantly longer submaximal contraction times compared to the pre-thermoneutral application. These findings support the use of pre-cooling procedures prior to submaximal exercises of the quadriceps muscle compared to pre-thermoneutral applications.

1. Introduction

Pre-cooling strategies are frequently used for the purpose of reducing body temperature prior to exercise, decreasing heat strain and improving performance (Cotter et al., 2001; Duffield et al., 2010). A recently published meta-analytical review showed that the positive effects of pre-cooling could be most beneficial before endurance exercises (Wegmann et al., 2012). In a heat-gaining environment, whole-body pre-cooling methods can be used to combat the debilitating effects of heat-stress-induced fatigue in order to increase heat storage capacity and improve exercise tolerance (Ross et al., 2013). High environmental heat stress may lead to several exertional heat-related illness types (Nichols, 2014). The most serious form is exertional heat stroke, characterized by a core temperature >40 °C and is associated with central nervous system disturbance, hot skin and sweating (Howe and Boden, 2007). It has been demonstrated that exhaustion and high ratings of perceived exertion (RPE) are reached at muscle temperatures of 40 °C (Gonzalez-Alonso et al., 1999). Hyperthermia-induced fatigue

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during prolonged exercise is mainly due to perturbations in the brain's ability to sustain sufficient activation of the skeletal muscles. It has been assumed that the elevated brain temperature itself, which increases parallel with that of the body core, is the main factor affecting motor activation, but feedback from the skeletal muscles and activity of the dopaminergic system also seem to be important (Nybo, 2008, 2012). However, the absence of irreversible damage to the human brain during and after hyperthermia may indicate that these mechanisms have not yet been clearly understood (Robertson and Marino, 2017). It has also been shown that lower ambient heat stress and auxiliary cooling of the skin improves endurance exercise performance (Gonzales et al., 2014; Uckert and Joch, 2007). However, excessive external cooling strategies have been shown to reduce muscular performance as a result of reductions in muscle/nerve conduction velocity (Ranalli et al., 2010).

It has been demonstrated that exhaustive exercises do not only cause peripheral but also central fatigue, leading to decreased muscle contractility (Bigland-Ritchie et al., 1978). Two main physiological factors can explain the different myoelectric manifestations of peripheral- and central fatigue: (1) the slowing of motor-unit action potentials due to reduced conduction velocity and (2) the synchronization of motor-units by the central nervous system to increase the mechanical output when the whole motor-unit pool is recruited (Merletti and Parker, 2004).

During submaximal and sustained maximum voluntary contraction (MVC), healthy subjects developed both central- and peripheral fatigue, leading to reduced performance output (Schillings et al., 2003). Numerous researchers, with conflicting results, have investigated the effects of local thigh water-perfused or ice-cuff cooling on strength parameters, such as isometric muscle contractions of the quadriceps femoris muscles (Cotter et al., 2001; Pointon et al., 2011). One study investigated the effects of a 20 min cold application (10 °C water temperature) on isometric MVC of the lower leg and found that isometric force was reduced in the tibialis anterior muscle (Halder et al., 2014). Another study showed that local ice bag cooling (approximately 20–35 min) led to significant lower MVC values of the quadriceps muscle in young (mean ± SD age: 22 ± 2 years) individuals (Dewhurst et al., 2010). However, the largest efficacy for pre-cooling strategies can be observed for endurance tasks, whereas the effects on short active muscle contractions is considerably smaller (Wegmann et al., 2012). It has been demonstrated that a 20-min local ice-pack application leads to significantly higher peak power output during a 40-min intermittent cycle sprint performance when compared to non-cooling techniques (Castle et al., 2006). The use of cold water immersions is becoming very popular as a standard technique for lowering tissue temperature (McDermott et al., 2009). However, the practical execution of such cold water immersions is not possible everywhere (water access, cooling a full team) (Marino, 2002; Minett et al., 2011). Moreover, results that question the effects of cooling have been reported. A recently published study showed that cooling can have a negative impact on strength training adaptions in well trained students (Frohlich et al., 2014). It has also been demonstrated that pre-cooling can have a detrimental effect on short active muscle contractions (Schniepp et al., 2002). Studies using local cooling devices for investigating thermal effects on submaximal MVC and central vs. peripheral fatigue are limited.

It has been suggested that central- and peripheral fatigue are related to changes in fractal dimension (FD) and muscle fiber conduction velocity (CV) during submaximal isometric contractions (Mesin et al., 2009). One study suggested that FD analyses can be used as an indicator for central fatigue mechanisms with respect to CV in fatiguing contractions (Boccia et al., 2016). Another study evaluated FD and CV slopes as indexes of central- and peripheral fatigue during isometric contractions in humans (Beretta-Piccoli et al., 2015). The authors of this study pointed out that further studies are needed to investigate FD and CV as indexes of central- and peripheral fatigue. There is, to our knowledge, no published study that has investigated the effect of pre-cooling on central- and peripheral fatigue using these parameters. Athletes, patients and researchers might profit from these further investigations.

Therefore, the aim of this randomized controlled trial was to compare the effects of a single pre-cooling application vs. a pre-thermoneutral application on both central- and peripheral fatigue, using FD and CV, during a 60% of isometric MVC contraction of the right quadriceps femoris muscle till exhaustion. Furthermore, the effects between pre-cooling and a pre-thermoneutral application after the exhaustive 60% of isometric MVC task on isometric MVC of the right quadriceps femoris muscle and RPE were investigated. We hypothesized that local skin pre-cooling would have a positive effect on peripheral fatigue and lead to longer submaximal contraction times but not on isometric MVC after the exhaustive exercise when compared to a pre-thermoneutral application. To our knowledge, this is the first study that compares these parameters in this specific experimental set-up.

2. Methods

2.1. Design and participants

In this randomized controlled trial, 18 young, healthy adults (11 female and 7 male), regularly involved in moderate physical endurance activity voluntarily participated in this study. Four female and 5 male participants were randomly assigned to the cold group (experimental) and the remaining 9 (7 females and 2 males) were assigned to the thermoneutral (control) group. Randomization was ensured by drawing lots. Mixed gender population has already been used in the field of cryotherapy studies (Costello et al., 2012; Crowe et al., 2007). The participants completed a pre-test questionnaire and were excluded if they had a history of lower limb injuries in the past twelve months, current pain symptoms, cardiovascular diseases or any contraindication for cryotherapy including Raynaud's disease or if they were not between the age of 18 and 30 years. The participants were fully informed about the risks and discomforts before signing an informed-consent form. The Swiss ethical committee of Zurich (KEK-ZH.Nr. 2015-0113) approved this study in accordance with the declaration of Helsinki (ICH-GCP). The participants had to appear in a healthy and in a fully recovered state at the beginning of the study – without any symptoms of exhaustion (rated on a 6–20 BORG scale). Finally, participants were instructed to refrain from alcohol and other beverages that might influence the results such as caffeinated soft drinks, coffee and isotonic drinks at least 24 h prior to the start of the experiment.

2.2. Baseline measurements

After randomization, the participants' anthropometric data were collected. Standing body height was measured to the nearest 0.1 cm, using a GPM stadiometer (Zurich, Switzerland). Body weight and estimated lower body fat percentage were measured using the athlete modus of the TANITA-TBF 611 scale (Tokyo, Japan). The isometric MVC of the right quadriceps femoris muscle was determined using a custom-made (Cor 1-V1.0) ergometer chair for biomechanical measurements (OT Bioelettronica, Torino, Italy). The maximum force of the knee extensors was determined with a force meter operating linearly in the range of 0–1000 N. The signal was amplified with the MISO II (OT Bioelettronica, Torino, Italy). The participants' force was displayed on a monitor, providing real-time feedback. All measurements on the ergometer chair were conducted in a seated position and at a knee angle of 120° and a hip angle of 100° as previously conducted (Beretta-Piccoli et al., 2015). The participants' right leg was attached to the ergometer chair with a strap above the right malleoli lateralis and medialis, ensuring an isometric maximum performance. The partici-