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Dynamics of thermographic skin temperature response during squat exercise at two different speeds

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ABSTRACT

Low intensity resistance training with slow movement and tonic force generation has been shown to create blood flow restriction within muscles that may affect thermoregulation through the skin. We aimed to investigate the influence of two speeds of exercise execution on skin temperature dynamics using infrared thermography. Thirteen active males performed randomly two sessions of squat exercise (normal speed, 1 s eccentric/1 s concentric phase, 1 s; slow speed, 5 s eccentric/5 s concentric phase, 5 s), using ~50% of 1 maximal repetition. Thermal images of ST above muscles quadriceps were recorded at a rate of 0.05 Hz before the exercise (to determine basal ST) and for 480 s following the initiation of the exercise (to determine the nonsteady-state time course of ST). Results showed that ST changed more slowly during the 5 s exercise ($p = 0.002$), whereas the delta (with respect to basal) excursions were similar for the two exercises ($p > 0.05$). In summary, our data provided a detailed nonsteady-state portrait of ST changes following squat exercises executed at two different speeds. These results lay the basis for further investigations entailing the joint use of infrared thermography and Doppler flowmetry to study the events taking place both at the skin and the muscle level during exercises executed at slow speed.

1. Introduction

The control of heat exchange between the human body and the external environmental is crucial for the regulation of body temperature during exercise. To this aim, the skin promotes heat exchange through conduction, convection, radiation and evaporation (Gisolfi and Wenger, 1984). Skin temperature is well correlated with skin blood flow (Schlager et al., 2010; Swain and Grant, 1989) which, in turn, is the result of the interplay between cutaneous vasodilation and vasoconstriction. Cutaneous vasoconstriction accompanies the onset of dynamic exercise, after which cutaneous vasodilation begins (Kellogg, 2006; Kenney and Johnson, 1992).

Skin temperature during exercise can be assessed by Infrared thermography (IRT). IRT is a non-invasive technique that yields a two-dimensional map of the temperature on a well-defined skin area. IRT has been increasingly adopted for evaluating skin temperature variations associated to physical exercise (Abate et al., 2013; Arfaoui et al., 2014; Ferreira et al., 2008; Formenti et al., 2013, 2013; Ludwig et al., 2012; Merla et al., 2010; Zontak et al., 1998). Using IRT, cycling and running exercises have been extensively studied (Abate et al., 2013; Arfaoui et al., 2014; Balci et al., 2016; Merla et al., 2010; Priego Quesada et al., 2015a, 2015b; Torii et al., 1992; Zontak et al., 1998). whereas resistance exercise has received increase research attention only in the very recent years (Ferreira et al., 2008; Formenti et al., 2013; Neves et al., 2015; Sanz-López et al., 2016).

There is an increasing interest in proposing low-intensity resistance training to diminish both the mechanical stress on joints and the risk of injuries in sedentary, active subjects and athletes (Alberti et al., 2013). Several studies have addressed the effects of low-intensity resistance training with slow movement and tonic force generation (LST). Such modality of training has been shown to promote muscular hypertrophy and strength gain that well compare with those obtained with high-intensity training at a normal speed (Tanimoto and Ishii, 2006; Tanimoto et al., 2008, 2009). It has been purported that the effectiveness of LST is related with its ability to generate a moderate vascular occlusion, resulting in muscle ischemia (Tanimoto and Ishii, 2006). Indeed, continuous muscular contractions at moderate intensity (about 50% of

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1 maximal repetition (1RM)) with slow movement has been shown to suppress both inflow and outflow from the muscle (Tanimoto et al., 2009). It stands to reason that the blood flow restriction generated by LST may impact on skin blood flow, thus influencing the time course of skin temperature during exercise.

The aim of the study was to investigate the influence of two different speeds of execution of squat exercise on the dynamics of skin temperature. Using a within-subjects experimental design, we used IRT to measure the time course of skin temperature in the area of the quadriceps femoris (i. e., the muscles directly involved in squat exercise) during low-intensity resistance training with either normal speed (1 s for eccentric and 1 s for concentric phase) or slow speed (5 s for eccentric and 5 s for concentric phase). Our hypothesis was that normal- and slow-speed exercises could have different impacts on the dynamic features of the skin temperature response. We were particularly interested in comparing the rates of change and the excursions of skin temperature following the two types of exercise.

2. Material and methods

2.1. Participants

Thirteen male active subjects volunteered to take part in this study. They belonged to the student population of the School of Exercise Sciences of the local University. Their mean age, body mass, height and body mass index were 24.5 ± 2.0 yrs, 70.1 ± 6.3 kg, 179.1 ± 8.3 cm and 22.3 ± 2.1 kg m^{-2} (Mean ± SD), respectively. They were habitually physically active, but none of them was used to resistance training. All participants were non-smokers, and without cardiovascular or pulmonary diseases. They had not assumed drugs or medications with a potential effect on cardiovascular and thermoregulatory functions during the two months before the tests.

The Ethical Committee of the local University approved this study. After a thorough explanation of the protocol that was going to be used, the subjects accepted informed written consent to participate in this study.

2.2. Experimental protocol

We used a within-subjects design so that each subject served as his own control. The experiment comprised three different sessions, each one separated by five days with the following one. After a preliminary session, the two experimental sessions – denoted as 1 s exercise and 5 s exercise - were randomized. The subjects were instructed to refrain from strenuous physical activity the two days before the trials and abstained from assuming alcoholic or caffeine-containing products for a 4 – h period before the start of the experiment. All sessions were scheduled in late morning to mitigate possible effects due to circadian rhythm variations.

2.2.1. Preliminary session

The preliminary session was aimed to collect anthropometric measurements, to find out the load of maximum repetition (1RM) in parallel squat exercise and to familiarize the subject with the 1 s and 5 s exercises. Body mass and composition, and body mass index (BMI) were measured using an impedance analyser (Body composition analyser BC-418AM, TanitaCorporation, Tokio, Japan). As the subject became familiar with the proper lifting technique, the 1RM test was carried out. The 1RM test was performed accordingly to the guidelines established by the National Strength and Conditioning Association (O'Shea, 1985).

The day before the experimental sessions, subjects observed a standard protocol for preparing the skin of the thighs to infrared thermal imaging measurements (Ammer, 2008; Fernández-Cuevas et al., 2015). They removed body hair on legs that were clean and without cosmetics products.

2.2.2. 1 s and 5 s squat exercise sessions

Before the trials, subjects performed a standardized warm-up, i.e., 5 min of walking on a treadmill and 2 min of squat exercise without overload. After that, and before starting the exercise, subjects acclimated to the room climate conditions (temperature 22–24 °C; relative humidity 50 ± 5%; no direct ventilation and constant intensity of light) for 15 min at rest condition. Then, subjects underwent either the 1 s or 5 s exercise (the two exercises were randomized and separated by at least 5 days). The 1 s exercise was a squat exercise (with intensity of ~50% of 1RM) executed with 1 s for eccentric (lowering phase) and 1 s for concentric (lifting phase) actions. The 5 s exercise was a squat exercise (with intensity of ~50% of 1RM) executed with 5 s for eccentric (lowering phase) and 5 s for concentric (lifting phase) actions. In either session, subjects repeated the movement until exhaustion (repetition maximum; RM) following the 1 s/5 s pace with the aid of a metronome. The 1 s and 5 s exercise lasted (on average) 55 s and 100 s, respectively.

2.3. Thermographic analysis

A 14-bit digital infrared thermal camera a (AVIO, TVS-700, 320 × 240 pixels, Microbolometric Array; 8–14 μm spectral range; 0.07 °C thermal resolution; and 35 mm lens) provided thermal image sequences of the subject's thighs during the 1 s and 5 s exercises. The subjects were swimsuit dressed to permit the complete exposure of the anterior region of the thighs and were placed at 3 m from the infrared camera. A uniform background with a constant temperature (T = 24.86 ± 0.20 °C) was placed behind the subjects to permit the calibration procedure and the emissivity value was set to 0.98 (Bernard et al., 2013). Thermal images were recorded for 120 s prior to the exercise to determine basal skin temperature and for 480 s after the beginning of the exercise to determine the time course of skin temperature response. Recordings were made using a digital frame grabber with a rate of one image per 20 s (the frame rate was thus 0.05 Hz). All thermal images were recorded at the same instant during the exercise (i.e., when the subjects re-achieved the starting position at the end of the concentric action). Sweat production during exercises was negligible, and therefore it did not affect skin temperature. The images of the sequence were analyzed with a specific software for thermal imaging (GRAYESS® IRT Analyser, Version 4.8), using the Tmax method previously described (Formenti et al., 2013; Ludwig et al., 2014). The operator selected a ROI including the totality of the thigh surface. Second, the software selected automatically the five warmest pixels within the ROI, with at least a minimum distance of five pixels between each other. Third, the software selected an area of 5 × 5 pixels around each of the five pixels previously selected. In this way, the temperature value representative of the body area was calculated as the mean of the temperatures of such 125 pixels (Ludwig et al., 2014). Thus, a representative value of the skin temperature of each thigh was extracted. Finally, the skin temperature values of left and right thighs were averaged, yielding one representative temperature value at each time point.

2.4. Data analysis

Data analysis had the purpose to derive key parameters summarizing the skin temperature time course during three phases (i.e., basal steady state, execution of the exercise, post-exercise recovery phase). Fig. 1 shows the time courses of skin temperature during 1 s