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Rate and Magnitude of Muscle Temperature Increase with Cycling at Various Intensities

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Abstract

Purpose: Anecdotally, athletic training clinicians often have patients "warm up" on a stationary cycle prior to rehabilitation. No previous studies have evaluated the rate or magnitude of muscle temperature increase during a cycling task. Our objective was to determine the rate and magnitude of muscle temperature increase in superficial (2cm) and deep (4cm) muscle during cycling at various intensities. **Methods:** Randomized, counter-balanced crossover trial conducted at a University research laboratory. Sixteen healthy participants (male=7, female=9; mean age 26±4 years; height 170±10 cm; weight 77±8 kg; adipose thickness 1.4±0.9 cm; muscle thickness 5.1±0.7 cm). Participants performed cycling under 3 intensity conditions: 50-80 Watts/gear 8-10 (light), 100-130 Watts/12-16 gear (moderate), 140+ Watts/16+ gear (strenuous). Main outcomes measured were muscle temperature at depths of 2cm and 4cm were measured via 17-gauge catheter thermocouple. Temperatures were recorded at baseline and during the 20-minute cycling task. **Results:** 2cm depth: moderate heating achieved; nonsignificant intensity-by-time interaction ($F_{(20,80)}$=1.225, p=0.257, observed power 0.877). Significant main effect for time ($F_{(20,80)}$=18.995, p(1,4)=4.435, p=0.103, observed power 0.365). 4cm depth: moderate heating achieved; nonsignificant intensity-by-time interaction ($F_{(20,100)}$=0.784, p=0.257, observed power 0.720). Significant main effect for time ($F_{(20,100)}$=62.102, p(1,5)=1.267, p=0.311, observed power 0.152). **Conclusions:** No cycling intensities were able to increase muscle temperature to the vigorous heating range (4°C increase) at either 2cm or 4cm depth. Moderate to high-intensity cycling warmup may increase local metabolic rate, decrease pain, and decrease muscle spasm via 1-2°C increase in muscle temperature.

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ABSTRACT
Purpose: Anecdotally, athletic training clinicians often have patients "warm up" on a stationary cycle prior to rehabilitation. No previous studies have evaluated the rate or magnitude of muscle temperature increase during a cycling task. Our objective was to determine the rate and magnitude of muscle temperature increase in superficial (2cm) and deep (4cm) muscle during cycling at various intensities. **Methods:** Randomized, counter-balanced crossover trial conducted at a University research laboratory. Sixteen healthy participants (male=7, female=9; mean age 26±4 years; height 170±10 cm; weight 77±8 kg; adipose thickness 1.4±0.9 cm; muscle thickness 5.1±0.7 cm). Participants performed cycling under 3 intensity conditions: 50-80 Watts/gear 8-10 (light), 100-130 Watts/12-16 gear (moderate), 140+ Watts/16+ gear (strenuous). Main outcomes measured were muscle temperature at depths of 2cm and 4cm were measured via 17-gauge catheter thermocouple. Temperatures were recorded at baseline and during the 20-minute cycling task. **Results:** 2cm depth: moderate heating achieved; nonsignificant intensity-by-time interaction ($F_{(20,80)}$=1.225, p=0.257, observed power 0.877). Significant main effect for time ($F_{(20,80)}$=18.995, p<.001), nonsignificant main effect for intensity ($F_{(1,4)}$=4.435, p=0.103, observed power 0.365). 4cm depth: moderate heating achieved; nonsignificant intensity-by-time interaction ($F_{(20,100)}$=0.784, p=0.257, observed power 0.720). Significant main effect for time ($F_{(20,100)}$=62.102, p<.001), nonsignificant main effect for intensity ($F_{(1,5)}$=1.267, p=0.311, observed power 0.152). **Conclusions:** No cycling intensities were able to increase muscle temperature to the vigorous heating range (4°C increase) at either 2cm or 4cm depth. Moderate to high-intensity cycling warmup may increase local metabolic rate, decrease pain, and decrease muscle spasm via 1-2°C increase in muscle temperature.

Keywords: warm-up, vigorous heat, active warmup

INTRODUCTION

Athletic training clinicians often desire to increase temperature in biological tissue. Depending on the thermal physiological responses desired, specific temperature increases are required. Specifically, tissue temperature increase of 1°C (mild heating) has been suggested to increase metabolic rate; an increase of 2-3°C (moderate heating) to decrease muscle spasm, pain, chronic inflammation, and increase blood flow; and an increase of 4°C (vigorous heating) to increase collagen extensibility.[1,2] The "stretching window" is defined as the amount of time tissue temperature remains in the vigorous heating range (>4°C increase from baseline) following a heating treatment.

Athletic training clinicians often have patients "warm up" on a stationary cycle prior to rehabilitation to decrease perceived pain and stiffness, or increase perceived readiness for rehabilitation, or increase muscle temperature prior to stretching or other manual therapy techniques. To-date, the evidence supporting the physiologic changes that occur during this type of warmup are unknown. Previous research has found that cycling is capable of increasing muscle temperature from 1-3°C (maximum temperatures reported range from 36.5-39.3°C) at tissue depths of 1-5cm (triceps surae, vastus lateralis, rectus femoris);[3-7] however, these studies have typically been related to increasing performance. Therefore, the rate of cycling was very fast or not reported. No previous studies have systematically evaluated the rate or magnitude of muscle temperature increase during a cycling task -- it remains unclear whether common intensities for warmup in rehabilitation (light, moderate, strenuous) would results in increased tissue temperature to clinically meaningful ranges.

If cyling is able to consistently produce muscle temperature increases in both superficial and deep tissue, it may prove to be an inexpensive and clinically beneficial option for clinicians. As a means of understanding the potential value of a cycling warmup prior to rehabilitation, we sought to investigate changes in superficial (2cm) and deep (4cm) quadriceps muscle temperature during cycling at various intensities. To determine a potentially meaningful change, we chose to grade temperature changes based on clinical recommendations: 1°C for increasing metabolic rate, 2-3°C for decreasing pain and spasm, and >4°C for increasing collagen extensibility. We hypothesized that all cycling intensities would produce vigorous (>4°C) heating, with maximum tissue temperature occurring fastest with strenuous intensity and slowest with light intensity.

METHODS

Experimental Design

Prospective data was collected via a repeated-measures counterbalanced design (crossover study). The independent variables were cycling intensity (light, moderate, strenuous) and time. The dependent variables were intramuscular temperature at 2cm and 4cm depth. Individuals participated in each intensity condition (light, moderate, strenuous) with a minimum of 72 hours between sessions to ensure no carryover effects. This study took place in a University Research Laboratory.

Participants

Sixteen healthy participants (male=7, female=9; mean age 26±4 years; height 170±10 cm; weight 77±8 kg; adipose thickness 1.4±0.9 cm; muscle thickness 5.1±0.7 cm) were included in this study. Sample size was based on an a priori power analysis performed using G*Power with desired power set at 0.80. Participants must have regularly completed a minimum of 20 minutes of aerobic exercise at least three times per week. Participants were excluded if they have any of the following: lower leg injury within 6 months, current pregnancy, infection / open wound, edema, ecchymosis, rash, fever within the past 48 hours, history of peripheral vascular disease, thrombophlebitis, blood-borne disease, cardiovascular disease (including pacemaker), compromised circulation, or compromised sensation to the area being treated. Participants were required to reschedule if they had exercised earlier in the day. This study was approved by our Institutional Review Board and participants provided informed consent.

Treatment Conditions

Specific cycling parameters were: 50-80 Watts/gear 8-10 (light), 100-130 Watts/12-16 gear (moderate), 140+ Watts/16+ gear (strenuous). The M3i Indoor Cycle Spinning Bike (Keiser, Fresno, CA) was used in this study.

Instrumentation

Intramuscular temperature was measured via 17-gauge multi-sensory probe with thermocouples spaced 2.0cm apart (IT-17-2 Physitemp Instruments, Inc, Clifton, NJ). The thermocouples were attached to approved extension cords and plugged into an electrothermometer (Iso-Thermex; Columbus Instruments, Columbus, OH). Validity and reliability of IT thermocouples have been studied previously, and it has been recommended that researchers test and report on the equipment utilized in the study.[8,9] The intramuscular thermocouples utilized in the study were pilot tested with the Iso-Thermex electrothermometer and a calibrated mercury thermometer. Thermocouples were found to be valid compared with a mercury thermometer and reliable within 0.08°C. Previous research has demonstrated that the use of an extension cord does not influence temperature measurement.[10]

Procedures

The tempearture of the lab was controlled at 20°C (±0.3°C) during all trials. Participants wore shorts and short-sleeve shirts, socks, and close-toed footwear of choice. Participants were asked to sit on the cycle when they arrived so that seat height and handlebar position could be customized; these parameters were recorded for subsequent trials. Participants were asked to pedal until they felt comfortable with the cycle. Following this familiarization period, each participant laid supine on the table and the vastus lateralis muscle on their dominant leg was measured to determine where the thermocouple was placed. A standardized measurement site of 1/3 of the distance from the anterior superior iliac spine to the distal femur was marked. The catheter needle was inserted vertically to a depth of 4cm. The thermocouple had 2 sensors and recorded muscle temperature at both 2cm and 4cm depth. Following thermocouple insertion, the patient remained stationary on the table until muscle temperature returned to baseline (determined when muscle temperature plateaued for at least 2 consecutive minutes). The patient was then transferred to the cycle and again muscle temperature was allowed to return to baseline. Once the cycling task began, intramuscular temperatures were recorded to the nearest tenth of a degree every 60 seconds for the duration of the experiment. Each cycling experiment continued until 1) an increase of 5°C was achieved, 2) until such time as the subject's muscle temperature plateaued or began to decrease for at least 2 consecutive minutes, or 3) for a maximum of 20 minutes. If conditions increased tissue temperature at least 4°C, time for temperature decay to <4°C was recorded. If the condition did not result in a 4°C increase during the experiment, temperature decay was not recorded.

Statistical Analysis

A two-factor within-subjects repeated measures analysis of variance (ANOVA) was used to test for differences in muscle temperature during the cycling task. The factors include cycling intensity (3 levels) and time. All statistics were two-tailed with the alpha-level set a priori at ≤.05 (SPSS version 26, SPSS Inc., Chicago, IL). All relevant statistical assumptions were checked and were met.

RESULTS

For the 2cm depth, tissue temperatures did not exceed a 2.5°C increase under any cycling condition (Table 1). There was a nonsignificant intensity-by-time interaction ($F_{(20,80)}$=1.225, p=0.257, observed power 0.877). There was a significant main effect for time ($F_{(20,80)}$=18.995, p<.001, observed power 1.000) with temperature increasing at each time point. There was a nonsignificant main effect for intensity ($F_{(1,4)}$=4.435, p=0.103, observed power 0.365). For the 4cm depth tissue temperatures did not exceed a 2.6°C increase under any cycling condition (Table 2). There was a nonsignificant intensity-by-time interaction ($F_{(20,100)}$=0.784, p=0.257, observed power 0.820). There was a significant main effect for time ($F_{(20,100)}$=62.102, p<.001, observed power 1.000) with temperature increasing at each time point. There was a nonsignificant main effect for intensity ($F_{(1,5)}$=1.267, p=0.311, observed power 0.152).

Table 1. Temperature Means and Standard Deviations at 2cm Depth

Group	Baseline	5-min	10-min	15-min	20-min	Change
Light	35.6 (0.1)	36.2 (0.2)	36.6 (0.4)	36.7 (0.8)	36.7 (0.9)	0.1 (1.1)
Moderate	35.5 (2.6)	36.3 (2.4)	37.0 (2.3)	37.3 (2.4)	37.1 (2.0)	1.6 (1.5)
Strenuous	36.0 (1.1)	37.1 (1.5)	37.7 (1.6)	38.1 (1.1)	38.5 (1.1)	2.5 (0.7)
All Intensities (pooled)	35.6 (1.9)	36.5 (2.1)*	37.0 (2.1)*	37.3 (2.1)*	37.3 (2.0)*	1.7 (1.0)

*indicates significant change (p<.05)

Table 2. Temperature Means and Standard Deviations at 4cm Depth

Group	Baseline	5-min	10-min	15-min	20-min	Change
Light	36.8 (0.1)	37.4 (0.1)	37.7 (0.2)	37.7 (0.3)	37.7 (0.3)	0.9 (0.4)
Moderate	36.7 (1.0)	37.8 (1.2)	38.4 (1.0)	38.5 (0.9)	38.7 (0.9)	2.0 (0.9)
Strenuous	36.7 (0.5)	38.0 (0.7)	38.6 (0.7)	39.0 (0.3)	39.3 (0.3)	2.6 (0.3)
All Intensities (pooled)	36.7 (0.8)	37.8 (1.0)*	38.4 (0.8)*	38.6 (0.8)*	38.7 (.8)*	2.0 (.8)

*indicates significant change (p<.05)

DISCUSSION

Our premise upon undertaking this study was that active movement of major muscle groups would result in increased muscle temperature.[11] Previous research suggests that muscle temperature rises rapidly within 3-5 minutes of moderate-intensity exercise and reaches a relative plateau after 10-20 minutes of exercise. This research also suggests that changes in muscle temperature are related to exercise intensity.[12] It has also been proposed that due to a more efficient thermoregulatory system, well-conditioned athletes may require a longer and/or more intense warm up to sufficiently increase muscle temperature.[6] For these reasons, we selected various cycling intensities (light, moderate, strenuous) and a maximum cycling time of 20 minutes. We hypothesized that different intensities would require different amounts of time to reach a 4°C increase but assumed that all intensities would ultimately produce vigorous heating within the muscle. This hypothesis was disproven since none of our intensities produced vigorous heating in muscles at either the 2cm or 4cm depth.

While previous research was undertaken with highly-conditioned cyclists, the average muscle temperatures produced in our study were comparable to those reported in previous studies. Specifically, our results at 2cm depth were similar to previous results reported for vastus lateralis at 3cm depth following two six-minute bouts of cycling at power output at 90% VO_{2peak} (increases of 37.3±0.6°C and 37.2±0.3°C).[4] Our results at both 2cm and 4cm were also similar to previous results reported for vastus lateral at 3cm depth following a 4km cycling time trial under both hot and cool ambient temperature conditions (2.5-2.6°C increase to 39.3±0.58°C and 2.6°C increase to 38.4±0.48°C),[5] to those reported for vastus lateralis at 1,2, and 3cm depth following a cycling sprint protocol (muscle temperature increased by 2.5°C at all depths),[3] and to those reported for vastus lateralis at 4cm depth during a cycling task at 40% peak oxygen uptake (1.41°C increase to 37.26°C).[13] Also similar to previous research, muscle temperatures in our study did not exceed 39°C (39.3±0.58°C, 38.4±0.48°C, and 37.36±1.08°C reported previously).[5,13]

We searched the literature for any articles related to muscle temperature and exercise and were unable to locate any studies where active exercise results in muscle temperature increase into the vigorous heating range. Outside of cycling, we located one article that examined vastus lateralis temperature during an incremental isotonic test on a Kin-Com isokinetic device. This study reported average temperature increases of 2.00°C, 2.37°C, and 3.20°C at 10, 25, and 40 minutes, respectively.[14] While no studies, previous or current, have demonstrated active warmup to be capable of producing vigorous heating (>4°C) in muscle tissue, these types of active warmups have produced tissue temperature increases that may result in increased metabolic rate, decreased pain, and decreased muscle spasm (1-2°C; mild to moderate heating). It is possible that these physiologic changes may result in increased ability of patients to tolerate more aggressive manual therapy strategies for increasing collagen extensibility. Additional research is needed to confirm these suggestions.

CONCLUSION

Moderate to high-intensity cycling results in a 1-2°C increase in muscle tissue temperature, which supports the use of active warmup to increase local metabolic rate, decrease pain, and decrease muscle spasm. If, however, the purpose of the cycling warmup is to increase muscle tissue temperature to vigorous heating (>4°C) to address local adhesions associated with decreased collagen extensibility, cycling is not effective at meeting this goal.

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