Acute Effects of Dietary Ginger on Quadriceps Muscle Pain During Moderate Intensity Cycling Exercise

Christopher D. Black and Patrick J. O’Connor
Department of Kinesiology, The University of Georgia

Running Title:
Effects of Ginger on Cycling Pain

Key Words: Oxygen consumption, Heart rate, Perceived Exertion, Spice, Zingiber officinale

Corresponding Author:
Christopher D. Black
Department of Kinesiology
CBX 065
Georgia College and State University
Milledgeville, GA 31061
Phone: 478-445-0848
chris.black@gcsu.edu
Abstract

Ginger has known hypoalgesic and anti-inflammatory properties. The effects of an oral dose of ginger on quadriceps muscle pain, perceived exertion, and recovery of oxygen consumption were examined during and following moderate intensity cycling exercise. Twenty-five college-aged participants ingested a 2-gram dose of ginger or placebo, in a double-blind, cross-over design, and 30 minutes later completed 30 minutes of cycling at 60% of VO$_2$ peak. Quadriceps muscle pain, perceived exertion (RPE), work rate, heart rate (HR), and oxygen uptake (VO$_2$) were recorded every 5 minutes during exercise, and HR and VO$_2$ were recorded for 20 minutes after exercise. Compared to placebo, ginger had no clinically meaningful or statistically significant effect on perceptions of muscle pain, RPE, work rate, HR, and VO$_2$ during exercise. Recovery of VO$_2$ and HR following the 30 minute exercise bout followed a similar time-course during both the ginger and placebo conditions. The results were consistent with related findings showing that ingestion of a large dose of aspirin does not acutely alter quadriceps muscle pain during cycling, and this suggests that prostaglandins do not play a large role in this type of exercise induced skeletal muscle pain. Ginger consumption has also been shown to improve VO$_2$ recovery in an equine exercise model, but our results show this is not the case in humans.
Introduction

Moderate-to-high intensity exercise transiently and reliably produces pain within the activated muscles (Cook, O'Connor, Eubanks, Smith, & Lee, 1997; Cook, O'Connor, Oliver, & Lee, 1998). This naturally occurring pain during exercise is likely caused by mechanical pressure acting on pressure-sensitive nociceptors as well as by the muscle contraction induced production of several biochemical substances that are known algesics such as bradykinin, serotonin, potassium, histamine, substance P, hydrogen ions, prostaglandins, and adenosine (O'Connor & Cook, 1999).

Ingestion of large (10 mg·kg\(^{-1}\)) and moderate (5 mg·kg\(^{-1}\)) doses of caffeine, an adenosine receptor antagonist, prior to exercise have been shown to significantly reduce quadriceps muscle pain during cycling exercise in both men and women (Motl, O'Connor P, Tubandt, Puetz, & Ely, 2006; O'Connor, Motl, Broglio, & Ely, 2004). However, ingestion of a large dose of aspirin prior to exercise, to reduce prostaglandin concentrations, did not reduce pain during cycling exercise (Cook et al., 1997). The effect of dual acting non-steroidal anti-inflammatory drugs that block both prostaglandins and leukotrienes on cycling induced muscle pain has not yet been investigated.

Zingiber officinale, commonly known as ginger, has been widely used in Ayurvedic and Chinese medicine to treat conditions such as asthma, diabetes, nausea, stroke, rheumatism, and toothache (Afzal, Al-Hadidi, Menon, Pesek, & Dhami, 2001; Ali, Blunden, Tanira, & Nemmar, 2008). Gingerols and shogaols, which are constituents of ginger, have been shown to inhibit cyclooxygenase (COX) 1 and 2 (Koo, Ammit, Tran, Duke, & Roufogalis, 2001; Lantz, Chen, Sarihan, Solyom, Jolad, & Timmermann, 2007; Nurtjahja-Tjendraputra, Ammit, Roufogalis, Tran, & Duke, 2003; Tjendraputra,
Tran, Liu-Brennan, Roufogalis, & Duke, 2001), leukotriene synthesis (Kiuchi, Iwakami, Shibuya, Hanaoka, & Sankawa, 1992), and production of pro-inflammatory cytokines (Grzanna, Phan, Polotsky, Lindmark, & Frondoza, 2004; Tripathi, Bruch, & Kittur, 2008) *in vitro*. Additionally, 6-gingerol and ginger extracts acutely (within 30 minutes) reduce paw edema (Ojewole, 2006; Young, Luo, Cheng, Hsieh, Liao, & Peng, 2005) and pain behaviors in rodents (Ojewole, 2006; Young et al., 2005). The mechanism of this hypoalgesia is uncertain, but ginger and/or its constituents are thought to act both peripherally, by inhibiting the release of prostaglandins and leukotrienes (Ojewole, 2006; Young et al., 2005), and centrally (Ojewole, 2006), potentially by interacting with the vanilloid receptor TRPV1 which is known to play a role in the processing of nociceptive signals (Cortright, Krause, & Broom, 2007).

Ginger may also exert effects on metabolism. Infusion of ginger extracts has been shown to increase oxygen consumption in the rat hindlimb (Eldershaw, Colquhoun, Dora, Peng, & Clark, 1992) potentially through increased epinephrine secretion via activation of the TRPV1 receptor (Iwasaki, Morita, Iwasawa, Kobata, Sekiwa, Morimitsu, Kubota, & Watanabe, 2006). Consumption of a 30 gram dose of ginger (approximating 67 mg·kg⁻¹ body weight) has also been shown to increase recovery of the fast-phase of oxygen consumption following a maximal exercise test in horses (Liburt, 2005). In humans, however, the addition of a 30 gram dose of ginger to a meal did not increase post-prandial oxygen consumption compared to meal consumption alone (Henry & Piggott, 1987). To our knowledge, no studies have tested the effects of ginger on metabolism during or after exercise in humans.
The purpose of the present study was two-fold. First, we sought to determine whether a 2-gram oral dose of ginger consumed prior to exercise would reduce naturally occurring quadriceps muscle pain during moderate intensity cycling exercise. Secondly, we sought to determine the effects of ginger on oxygen consumption, heart rate, and ratings of perceived exertion during and following moderate intensity cycling exercise. Additionally, mood measurements were included to indirectly assess whether ginger has an effect on improving mood state as has been suggested by traditional medical practices (e.g., Ayurvedic medicine).

**Methods**

Twenty-five college aged men (n = 10) and women (n = 15) volunteered to participate in the study. All participants were screened for medical and/or orthopedic conditions that would preclude performance of strenuous cycling exercise. Selected characteristics of the participants are provided in Table 1. A sample of 25 provided a statistical power to detect an effect of $\geq 0.24$ SD given the study design, an alpha error of 0.05, and a correlation between repeated trials of $\geq 0.90$ on the outcome measures (Park & Schutz, 1999). All experimental methods were approved by the University of Georgia Institutional Review Board, and all participants provided written informed consent prior to participation.

**Procedures**

Participants completed 1 day of preliminary testing and 2 days of experimental testing. At least 48 hours separated the preliminary testing day from the first experimental
day. Experimental testing was performed at roughly (within ~90 minutes) the same time of day within each participant. Participants were asked to refrain from consumption of pain medications, caffeine, alcohol, and exercise for 12 hours prior, and eating for 2 hours prior to testing.

**Preliminary Testing Day**

Potential participants were screened, consent was obtained, and mood was assessed using the Profile of Mood States (POMS) 30-item short form. Participants reported how they felt “right now.” The POMS questionnaires were scored for the 6 distinct mood states—tension, depression, anger, vigor, fatigue, and confusion. The criterion measure was total mood disturbance (TMD) which is the sum of the scores for tension, depression, anger, fatigue, and confusion minus the score for vigor. There is evidence that POMS total scores can be interpreted as a valid measure of overall mood state (McNair, Lorr, & Droppleman, 1992).

Participants then performed a maximal exercise test on an electrically braked, computer-driven cycle ergometer (Lode BV, Groningen, The Netherlands) to measure peak oxygen consumption (VO$_2$ peak). Participants were fitted to the ergometer and provided instructions for correctly rating leg muscle pain intensity (Cook et al., 1997) and overall perceived exertion (Borg, 1982). A mouthpiece was inserted for collection of expired gases. Participants then performed a 5 minute warm-up at 25 watts (W). The initial work rate was set between 50 W and 100 W, depending on the size of the subject, and work rate was continuously increased at 0.4 W·s$^{-1}$ until volitional fatigue was reached. Verbal encouragement was provided throughout the exercise test. Ventilation
Effects of Ginger on Cycling Pain

(Vₑ), oxygen consumption (VO₂), carbon dioxide production (VCO₂), and respiratory exchange ratio (RER) were measured every 15 seconds via open-circuit spirometry (Parvomedics; Sandy, UT, USA). Oxygen and carbon dioxide analyzers were calibrated prior to each measurement with known gas concentrations (calibration gas: 16% O₂ and 4% CO₂). VO₂ and VCO₂ were standardized to STPD. Heart rate was continuously measured using a heart rate monitor (Polar Electro Oy, Kempele, Finland). Work rate, heart rate, ratings of leg muscle pain, and ratings of perceived exertion (RPE) were recorded every minute during the test. Peak oxygen consumption was defined by the attainment of two of three criteria: 1) RER ≥ 1.1; 2) peak heart rate within 10 beats min⁻¹ of age-predicted maximum; or 3) peak RPE ≥ 18. Quadriceps muscle pain intensity was measured using a previously described and validated 0 to 10 category scale (Cook et al., 1997; Cook et al., 1998).

**Experimental Testing Days**

Participants reported to the lab, completed a mood questionnaire, 24-hour activity and diet questionnaire, and then consumed 6 capsules containing either 2 grams of ground or 2 grams of flour (placebo) with 250 mL of water and 1 tablespoon of olive oil (to aid in absorption). Each capsule was standardized to contain 0.33 g of ground ginger and chemical analysis revealed that the ground ginger capsules contained 8.81% moisture, 1.6% volatile oil, 4.82% total ash, 0.40 acid insoluble ash, and 0.43% 6-gingerol. The 2-gram dose was chosen because 1 to 2 gram doses have been shown to exhibit CNS effects (Ernst & Pittler, 2000; Lien, Sun, Chen, Kim, Hasler, & Owyang, 2003). Participants were blind-folded and wore a nose clip while consuming the capsules.
to minimize any taste, odor, or appearance differences in capsules. The capsules were administered in a double-blind cross-over manner to minimize participant and researcher expectancy effects. PJO placed the capsules in sealed, coded envelopes and CDB, who was unaware of the contents of each envelope, administered the capsules to the participants.

Participants then sat quietly and rested/read for 30 minutes in a thermoneutral environment. After completion of this period, mood was again assessed and participants then performed 30 minutes of cycling on an ergometer at an intensity of 60% of VO\_2 peak. This exercise intensity has been demonstrated to stimulate mild-to-moderate quadriceps muscle pain (Cook et al., 1997). Expired gases, work rate, heart rate, ratings of thigh muscle pain intensity, and ratings of perceived exertion were collected every 5 minutes during the exercise bout. Following collection of expired gases, the work rate was adjusted so that exercise intensity remained constant at approximately 60% of VO\_2 peak. After completion of 30 minutes of exercise, participants completed a 5 minute cool down on the ergometer. Initially work rate was reduced to 25 W and participants cycled at this intensity for 2 minutes. This was followed by 3 minutes of seated rest on the ergometer. Expired gases and heart rate were collected continuously over this 5 minute period and averaged into 15 second epochs. Following this cool down period, participants got off the ergometer, walked five feet, and sat and rested on a padded bench for an additional 15 minutes. A mood questionnaire was completed immediately after exiting the ergometer and at the end of the 15 minutes of rest. Expired gases and heart rate were collected for 60 seconds every 5th minute (5, 10, and 15) and averaged into 15 second epochs.

**Statistical Analysis**
Preliminary Analysis: Data were entered into a spreadsheet, checked for errors, and analyzed using SPSS version 15.0 (SPSS Inc., Chicago, IL, USA). Differences between men and women in leg muscle pain were analyzed using a 2 (men vs. women) x 2 (condition: ginger and placebo) x 6 (time 5, 10, 15, 20, 25, and 30 minute) mixed model repeated measures ANOVA. No differences were found between men and women (p = 0.42) so data were pooled for further analysis.

Primary Analysis: Heart rate, oxygen consumption, leg muscle pain, and ratings of perceived exertion collected during exercise were analyzed using a 2 (condition: ginger and placebo) x 6 (time: 5, 10, 15, 20, 25, and 30 minute) repeated measures ANOVAs. Data regarding recovery of oxygen consumption and heart rate were analyzed using a 2 (condition: ginger and placebo) x 23 (time: 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, 180, 195, 210, 225, 240, 255, 270, 285, 300, 600, 900, and 1200 seconds after exercise) repeated measures ANOVAs. Total mood disturbance was analyzed using a 2 (condition: ginger and placebo) x 4 (time: pre1, pre2, post1, and post2) repeated measures ANOVA. Effect sizes are reported as partial eta squared ($\eta^2_p$). Statistical significance was set a priori at an alpha of $\leq$0.05, and all data are presented as mean ± SD.

Results

Effects During Exercise

Work rate, oxygen consumption, and heart rate during each exercise bout are presented in Figure 1A, 1B, and 1C, respectively. A statistically significant main effect for condition (ginger vs. placebo) was not found for heart rate ($P = 0.956; \eta^2_p < 0.000$) and oxygen consumption ($\text{VO}_2; P = 0.312; \eta^2_p = 0.042$) during exercise and there was not
a significant condition x time interaction for either heart rate (P = 0.116; \( \eta^2_p = 0.08 \)) or oxygen consumption (\( \text{VO}_2 \); P = 0.466; \( \eta^2_p = 0.034 \)). Mean \( \text{VO}_2 \) values during exercise were \( 25.3 \pm 3.8 \text{ ml·kg}^{-1}·\text{min}^{-1} \) and \( 25.1 \pm 4.0 \text{ ml·kg}^{-1}·\text{min}^{-1} \) for the placebo and ginger days, respectively. These values represent relative exercise intensities of 60% and 59% of \( \text{VO}_2\text{peak} \), and indicate the exercise bouts were similar. Mean heart rate during exercise was \( 152 \pm 8 \) and \( 152 \pm 7 \) in the ginger and placebo conditions, respectively.

Ratings of quadriceps muscle pain and RPE during each exercise bout are presented in Figure 2A and 2B, respectively. No main effect for condition was observed for muscle pain (P = 0.768; \( \eta^2_p = 0.004 \)) or RPE (P = 0.979; \( \eta^2_p < 0.000 \)) and there was not a significant condition x time interactions for muscle pain (P = 0.427; \( \eta^2_p = 0.037 \)) and RPE (P = 0.551; \( \eta^2_p = 0.028 \)). Mean values for muscle pain during exercise were \( 2.3 \pm 1.5 \) and \( 2.4 \pm 1.7 \) (P = 0.76) for the placebo and ginger conditions, respectively.

The time-course of recovery of \( \text{VO}_2 \) and heart rate following exercise are shown in Figure 3A and 3B, respectively. No main effect for condition was observed for \( \text{VO}_2 \) recovery (P = 0.944; \( \eta^2_p < 0.000 \)) and heart rate recovery (P = 0.538; \( \eta^2_p = 0.03 \)) nor was there a significant condition by time interaction for \( \text{VO}_2 \) recovery (P = 0.588; \( \eta^2_p = 0.038 \)) and heart rate recovery (P = 0.657; \( \eta^2_p = 0.046 \)). A significant main effect for time was observed for both \( \text{VO}_2 \) (P < 0.000; \( \eta^2_p = 0.934 \)) and heart rate (P < 0.000; \( \eta^2_p = 0.941 \)) with values decreasing over time toward resting levels.

Mean values (± SD) for total mood disturbance during the ginger condition were 0.6 ± 9.2, 1.6 ± 9.1, 2.3 ± 7.7, and 1.8 ± 6.7 for pre1, pre2, post1, and post2 time points, respectively. Values from the placebo condition were 3.4 ± 11.6, 2.8 ± 11.4, 2.4 ± 9.7, and 1.3 ± 8.7 for pre1, pre2, post1, and post2 time points, respectively. No main effect for
Effects of Ginger on Cycling Pain

time (P = 0.608; \(\eta_p^2 = 0.016\)) or condition (P = 0.402; \(\eta_p^2 = 0.031\)) was found nor was there a significant condition x time interaction (P = 0.111; \(\eta_p^2 = 0.092\)).

Discussion

The purpose of the present experiment was to examine the acute effects of oral consumption of a 2 gram dose of ginger on naturally occurring quadriceps pain, ratings of perceived exertion, oxygen consumption, and heart rate during and following moderate intensity cycling exercise. Work rate, heart rate, and oxygen consumption during cycling exercise did not differ between ginger and placebo conditions, and furthermore ginger exhibited no hypoalgesic effect on quadriceps pain intensity compared to placebo. Additionally, ginger consumption did alter recovery of oxygen consumption or heart rate in the 20 minutes after cessation of exercise.

The finding that ginger did not acutely reduce muscle pain and perceived exertion during moderate intensity exercise is consistent with previous studies demonstrating that a large dose of aspirin did not reduce exercise-induced skeletal muscle pain (Cook et al., 1997; Posner, 1984). Like aspirin, ginger and its constituents have been shown to have anti-inflammatory effects in vitro (Grzanna et al., 2004; Kiuchi et al., 1992; Koo et al., 2001; Lantz et al., 2007; Nurtjahja-Tjendraputra et al., 2003; Tjendraputra et al., 2001; Tripathi et al., 2008), and to reduce pain behaviors in rodent models (Ojewole, 2006; Young et al., 2005) and pain in arthritis patients (Altman & Marcussen, 2001; Bliddal, Rosetzsky, Schlichting, Weidner, Andersen, Ibfelt, Christensen, Jensen, & Barslev, 2000; Wigler, Grotto, Caspi, & Yaron, 2003). The hyopalgesic effects of ginger are thought to occur through the inhibition of prostaglandin and leukotriene synthesis (Ojewole, 2006;
Effects of Ginger on Cycling Pain

Young et al., 2005), as well as modulation the TRPV1 vallinoid receptor (Cortright et al., 2007). Thus ginger could mimic dual-action anti-inflammatory drugs and have more potent effects than aspirin alone. The present findings suggest that prostaglandins and leukotrienes have little role in naturally occurring low-to-moderate intensity skeletal muscle pain induced by exercise.

It is possible that ginger did not exhibit hypoalgesic effects in the present study because the dose was insufficient and/or the acute nature of the assessment (30-60 minutes after ingestion) did not allow adequate time for the ginger to move to the CNS and/or periphery and act. The 2 grams of ginger consumed provided a mean dose of 29.3 ± 5.6 mg·kg⁻¹ (ranging from 20 to 43mg·kg⁻¹) relative to participants’ body weight. Hypoalgesic effects were unrelated to ginger dose expressed relative to body weight. Ginger has been shown to provide hypoalgesia in a dose-dependent manner in rodent models (Ojewole, 2006; Young et al., 2005), however the relative dose administered in the present study appears to be within the range that has been reported to reduce acetic acid induced writhing in mice (Young et al., 2005). Moreover, chronic administration of a much smaller dose (170-510 mg·day⁻¹) has been shown to reduce pain in osteoarthritis patients (Altman & Marcussen, 2001; Bliddal et al., 2000; Wigler et al., 2003), and a 1 to 2 gram dose has been shown to reduce nausea (Ernst & Pittler, 2000; Lien et al., 2003). The time-course of action of ginger and its constituents following oral administration in humans remains unclear. An oral dose similar to that administered in the present study was found to reduce nausea within 60 minutes (Ernst & Pittler, 2000; Lien et al., 2003). Animal models using intraperitoneal administration which should presumably lead to fast bioavailability have demonstrated acute analgesic and anit-inflammatory effects within
30 minutes (Ojewole, 2006; Young et al., 2005). Depending on the predominant site of hyoalgesia it is plausible that the 30 minute latency between the ingestion of ginger and the start of cycling exercise was not sufficient for the ginger to exert an anti-nociceptive effect.

A novel finding of the present study was that ginger did not alter oxygen consumption during or following exercise. Evidence from rodent models indicates ginger may alter metabolism. Intravenous administration has been shown to increase epinephrine secretion in rats (Iwasaki et al., 2006), and infusion of ginger extracts has been shown to increase oxygen consumption in the rat hindlimb (Eldershaw et al., 1992). In contrast to these findings, introperitoneal administration of 6-gingerol has also been shown to induce a dose-dependent drop in body temperature rats (Ueki, Miyoshi, Shido, Hasegawa, & Watanabe, 2008). In the present study ginger ingestion did not alter oxygen consumption compared to placebo during work-matched bouts of submaximal cycling. This finding is consistent with a previous study from our lab which demonstrated that a 2-gram dose of ginger did not alter resting metabolic rate (compared to placebo) within 30 minutes of ingestion (unpublished observations) as well as the finding that the addition of ginger to a meal did not increase post-prandial oxygen consumption compared to the meal alone (Henry & Piggott, 1987). Taken together these findings suggest oral ginger consumption exerts little effect on metabolism at rest or during exercise in humans. Data from the present study are in contrast to those of Liburt (2005) who found a 22% faster recovery of the fast-phase of oxygen consumption to after a maximal exercise test in horses following ginger ingestion compared to ingestion of water or cranberry extract. While the author does not comment on the mechanism underlying the
improvement in recovery time, the results were compelling enough for a patent
application to be submitted for the blend of ginger extract and water administered in the
study (McKeever, 2006). It remains unclear, especially in light of the findings of the
present study, as to how ginger might enhance recovery from a bout of exercise. Previous
research has clearly demonstrated that endurance training speeds the recovery of both
oxygen consumption and heart rate following exercise (Hagberg, Hickson, Ehsani, &
Holloszy, 1980). This is thought to be the result of increased mitochondrial density and
an increased ability of muscle to resynthesize ATP and PCr (phosphocreatine) stores and
replenish oxygen stores (i.e. myoglobin and hemoglobin). We are unaware of any
available data explaining how/why ginger could mimic the effects of endurance training.
The results from the present study cast doubts on the efficacy of ginger to improve
metabolic recovery following exercise.

In conclusion, the present study found that consumption of a 2-gram oral dose of
dietary ginger did not significantly alter naturally occurring quadriceps pain intensity and
perception of effort during submaximal cycling exercise compared to placebo. These
finding are potentially significant given that ginger has been previously been shown to
have anti-inflammatory and hyoalgesic effects. Additionally, oxygen consumption and
heart rate during and following exercise were not found to differ between ginger and
placebo conditions. These findings highlight the need for future study into the time-
course by which chronic ginger consumption produces the hyopalgesic effects observed
in previous studies (Altman & Marcussen, 2001; Bliddal et al., 2000; Wigler et al., 2003).
Acknowledgments

Funding for this study was provided by the McCormick Science Institute. We thank the participants for volunteering. We also thank Ashley Grove, John Heisler, and Matt Herring for assisting with data collection.
Figure Legends

Figure 1. Work rate (A), oxygen consumption (B), and heart rate (C) values during 30 minutes of moderate intensity cycling exercise (60% of VO_2peak). Values are mean ± SD.

Figure 2. Ratings of quadriceps muscle pain intensity (A) and ratings of perceived exertion (RPE) during 30 minutes of moderate intensity cycling exercise (60% of VO_2peak). Values are mean ± SD.

Figure 3.

Mean values for oxygen consumption (A) and heart rate (B) during 20 minutes of recovery from moderate intensity cycling exercise (60% of VO_2peak). Recovery is divided into 3 distinct periods—R1 = values during cycling at 25 watts for 2 minutes, R2 = values during resting on the cycle ergometer for 3 minutes, and R3 = values during resting on a padded bench for 15 minutes. Values are mean ± SD.
References


Effects of Ginger on Cycling Pain


Table 1. Selected characteristics of the 25 participants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>23.2 ± 4.2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.4 ± 9.6</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70.5 ± 12.8</td>
</tr>
<tr>
<td>Peak Power Output</td>
<td>250.6 ± 60.7</td>
</tr>
<tr>
<td>VO$<em>2$$</em>{peak}$ (ml·kg$^{-1}$·min$^{-1}$)</td>
<td>42.5 ± 7.2</td>
</tr>
<tr>
<td>VO$<em>2$$</em>{peak}$ (l·min$^{-1}$)</td>
<td>3.0 ± 0.8</td>
</tr>
<tr>
<td>Heart Rate$_{peak}$ (beats·min$^{-1}$)</td>
<td>187.8 ± 9.7</td>
</tr>
<tr>
<td>RER$_{peak}$</td>
<td>1.23 ± 0.06</td>
</tr>
<tr>
<td>RPE$_{peak}$</td>
<td>18.8 ± 0.6</td>
</tr>
<tr>
<td>Pain Intensity$_{peak}$</td>
<td>7.4 ± 2.1</td>
</tr>
</tbody>
</table>

SD: Standard Deviation
VO$_2$$_{peak}$: Peak oxygen consumption
Heart Rate$_{peak}$: Peak Heart Rate
RER$_{peak}$: Peak respiratory exchange ratio
RPE$_{peak}$: Peak rating of perceived exertion
Pain Intensity$_{peak}$: Pain rating of quadriceps muscle pain