International Journal of Sport Nutrition and Exercise Metabolism, 2008, 18, 653-664

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

Christopher D. Black and Patrick J. O'Connor

Ginger has known hypoalgesic and anti-inflammatory properties. The effects of an oral dose of ginger on quadriceps muscle pain, rating of perceived exertion (RPE), and recovery of oxygen consumption were examined during and after moderate-intensity cycling exercise. Twenty-five college-age participants ingested a 2-g dose of ginger or placebo in a double-blind, crossover design and 30 min later completed 30 min of cycling at 60% of VO_{2peak}. Quadriceps muscle pain, RPE, work rate, heart rate (HR), and oxygen uptake (VO_2) were recorded every 5 min during exercise, and HR and VO_2 were recorded for 20 min after exercise. Compared with placebo, ginger had no clinically meaningful or statistically significant effect on perceptions of muscle pain, RPE, work rate, HR, or VO_2 during exercise. Recovery of VO_2 and HR after the 30-min exercise bout followed a similar time course in the ginger and placebo conditions. The results were consistent with related findings showing that ingesting 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 these results show that this is not the case in humans.

Keywords: oxygen consumption, heart rate, perceived exertion, spice, *Zingiber officinale*

Moderate- to high-intensity exercise transiently and reliably produces pain in 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).

Ingesting large (10 mg/kg) and moderate (5 mg/kg) doses of caffeine, an adenosine-receptor antagonist, before exercise has been shown to significantly

Black is with the Dept. of Kinesiology, Georgia College and State University, Milledgeville, GA 31061. O'Connor is with the Dept. of Kinesiology, University of Georgia, Athens, GA 30602.

reduce quadriceps muscle pain during cycling exercise in both men and women (Motl, O'Connor, Tubandt, Puetz, & Ely, 2006; O'Connor, Motl, Broglio, & Ely, 2004). Ingesting a large dose of aspirin before exercise to reduce prostaglandin concentrations, however, did not reduce pain during cycling exercise (Cook et al., 1997). The effect of dual-acting nonsteroidal anti-inflammatory drugs that block both prostaglandins and leukotrines 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 proinflammatory cytokines (Grzanna, Phan, Polotsky, Lindmark, & Frondoza, 2004; Tripathi, Bruch, & Kittur, 2008) in vitro. In addition, 6-gingerol and ginger extracts acutely (within 30 min) 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; Young et al.), and centrally (Ojewole), potentially by interacting with the vanilloid receptor TRPV1, which is known to play a role in processing nociceptive signals (Cortright, Krause, & Broom, 2007).

Ginger might also exert effects on metabolism. Infusion of ginger extracts has been shown to increase oxygen consumption in rat hind limb (Eldershaw, Colquhoun, Dora, Peng, & Clark, 1992), potentially through increased epinephrine secretion via activation of the TRPV1 receptor (Iwasaki et al., 2006). Consuming a 30-g dose of ginger (approximating 67 mg/kg body weight) has also been shown to increase recovery of the fast phase of oxygen consumption after a maximal exercise test in horses (Liburt, 2005). In humans, however, the addition of a 30-g dose of ginger to a meal did not increase postprandial oxygen consumption compared with 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 current study was twofold. First, we sought to determine whether a 2-g oral dose of ginger consumed before exercise would reduce naturally occurring quadriceps muscle pain during moderate-intensity cycling exercise. Second, we sought to determine the effects of ginger on oxygen consumption, heart rate, and ratings of perceived exertion during and after moderate-intensity cycling exercise. In addition, mood measurements were included to indirectly assess whether ginger improves mood state, as has been suggested by traditional medical practices (e.g., Ayurvedic medicine).

Methods

Twenty-five college-age men (n = 10) and women (n = 15) volunteered to participate in the study. All participants were screened for medical and 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 ≥0.24 *SD* given the study design, an alpha error of .05, and a correlation between repeated trials of ≥.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 before participation.

Procedures

Participants completed 1 day of preliminary testing and 2 days of experimental testing. At least 48 hr separated the preliminary-testing day from the first experimental day. Experimental testing was performed at roughly (within ~90 min) the same time of day with each participant. Participants were asked to refrain from pain medications, caffeine, alcohol, and exercise for 12 hr and eating for 2 hr before 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 six distinct mood states—tension, depression, anger, vigor, fatigue, and confusion. The criterion measure was total mood disturbance, 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 are a valid measure of overall mood state (McNair, Lorr, & Droppleman, 1992).

Table 1 Characteristics of 15 Female and 10 Male Participants

Characteristic	*M* ± *SD*
Age (years)	23.2 ± 4.2
Height (cm)	174.4 ± 9.6
Weight (kg)	70.5 ± 12.8
Peak power output	250.6 ± 60.7
Peak oxygen consumption (ml · kg^{-1} · min^{-1})	42.5 ± 7.2
Peak oxygen consumption (L/min)	3.0 ± 0.8
Peak heart rate (beats/min)	187.8 ± 9.7
Peak respiratory-exchange ratio	1.23 ± 0.06
Peak rating of perceived exertion	18.8 ± 0.6
Rating of quadriceps muscle pain	7.4 ± 2.1

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_{2peak}). They 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-min warm-up at 25 W. The initial work rate was set between 50 W and 100 W, depending on the size of the participant, and work rate was continuously increased at 0.4 W/s until volitional fatigue was reached. Verbal encouragement was provided throughout the exercise test. Ventilation, oxygen consumption (VO_2), carbon dioxide production (VCO_2), and respiratory-exchange ratio (RER) were measured every 15 s via open-circuit spirometry (Parvomedics, Sandy, UT, USA). Oxygen and carbon dioxide analyzers were calibrated before each measurement with known gas concentrations (calibration gas: 16% O_2 and 4% CO_2). VO_2 and VCO_2 were standardized to standard temperature and pressure, dry. 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: RER ≥1.1, peak heart rate within 10 beats/min of age-predicted maximum, or peak RPE ≥18. Quadriceps muscle-pain intensity was measured using a previously described and validated 0- to 10-category scale (Cook et al., 1997, 1998).

Experimental-Testing Days

Participants reported to the laboratory, completed a mood questionnaire and 24-hr activity and diet questionnaire, and then consumed six capsules containing either 2 g of ground ginger or 2 g 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-g dose was chosen because 1- to 2-g doses have been shown to induce central nervous system effects (Ernst & Pittler, 2000; Lien, Sun, Chen, Kim, Hasler, & Owyang, 2003). Participants were blindfolded 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 crossover manner to minimize participant and researcher expectancy effects. P.J.O. placed the capsules in sealed, coded envelopes, and C.D.B., who was unaware of the contents of each envelope, administered the capsules to the participants.

Participants then sat quietly and rested or read for 30 min in a thermoneutral environment. After this period, mood was again assessed and participants then performed 30 min of cycling on an ergometer at an intensity of 60% of VO_{2peak}. 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 RPEs were collected every 5 min during the exercise bout. After collection of expired gases, the work rate was adjusted so that exercise intensity remained constant at approximately 60% of VO_{2peak}. After

30 min of exercise, participants completed a 5-min cool-down on the ergometer. Initially work rate was reduced to 25 W and participants cycled at this intensity for 2 min. This was followed by 3 min of seated rest on the ergometer. Expired gases and heart rate were collected continuously over this 5-min period and averaged into 15-s epochs. After the cool-down, participants got off the ergometer, walked 1.5 m (5 ft), and sat and rested on a padded bench for an additional 15 min. A mood questionnaire was completed immediately after getting off the ergometer and at the end of the 15 min of rest. Expired gases and heart rate were collected for 60 s every 5 minutes (5, 10, and 15) and averaged into 15-s 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) × 2 (condition: ginger and placebo) × 6 (time 5, 10, 15, 20, 25, and 30 min) mixed-model repeated-measures ANOVA. No differences were found between men and women ($p = .42$), so data were pooled for further analysis.

Primary Analysis. Heart rate, oxygen consumption, leg muscle pain, and RPE collected during exercise were analyzed using a 2 (condition: ginger and placebo) × 6 (time: 5, 10, 15, 20, 25, and 30 min) repeated-measures ANOVA. Data regarding recovery of oxygen consumption and heart rate were analyzed using a 2 (condition: ginger and placebo) × 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 1,200 s after exercise) repeated-measures ANOVA. Total mood disturbance was analyzed using a 2 (condition: ginger and placebo) × 4 (time: pre1, pre2, post1, and post2) repeated-measures ANOVA. Effect sizes are reported as partial eta squared (η^2_p). Statistical significance was set a priori at an alpha level of ≤.05, and all data are presented as $M \pm SD$.

Results

Effects During Exercise

Work rate, oxygen consumption, and heart rate during each exercise bout are presented in Figure 1. A statistically significant main effect for condition (ginger vs. placebo) was not found for heart rate ($p = .956$, $\eta_p^2 < .000$) or oxygen consumption ($p = .312$, $\eta_p^2 = .042$) during exercise, and there was not a significant Condition × Time interaction for either heart rate ($p = .116$, $\eta_p^2 = .08$) or oxygen consumption ($p = .466$, $\eta_p^2 = .034$). Mean VO_2 values during exercise were 25.3 ± 3.8 ml · kg^{-1} · min^{-1} and 25.1 ± 4.0 ml · kg^{-1} · min^{-1} for the placebo and ginger days, respectively. These values represent relative exercise intensities of 60% and 59% of VO_{2peak} and indicate that the exercise bouts were similar. Mean heart rate during exercise was 152 ± 8 and 152 ± 7 in the ginger and placebo conditions, respectively.

Ratings of quadriceps muscle pain and perceived exertion during each exercise bout are presented in Figure 2. No main effect for condition was observed for

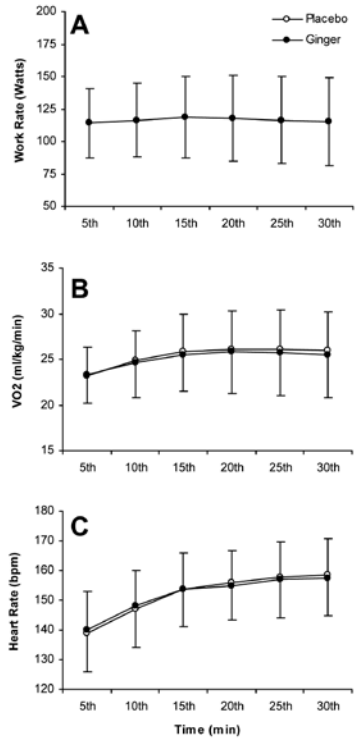

Figure 1 — (A) Work rate, (B) oxygen consumption, and (C) heart rate during 30 min of moderate-intensity cycling exercise (60% of VO_{2peak}), $M \pm SD$.

muscle pain ($p = .768$, $\eta_p^2 = .004$) or RPE ($p = .979$, $\eta_p^2 < .000$), and there was not a significant Condition × Time interaction for muscle pain ($p = .427$, $\eta_p^2 = .037$) or RPE ($p = .551$, $\eta_p^2 = .028$). Mean values for muscle pain during exercise were 2.3 ± 1.5 and 2.4 ± 1.7 ($p = .76$) for the placebo and ginger conditions, respectively.

The time courses of recovery of VO_2 and heart rate after exercise are shown in Figure 3. No main effect for condition was observed for VO_2 recovery ($p = .944$, $\eta_p^2 < .000$) or heart-rate recovery ($p = .538$, $\eta_p^2 = .03$), nor was there a significant Condition × Time interaction for VO_2 recovery ($p = .588$, $\eta_p^2 = .038$) or heart-rate recovery ($p = .657$, $\eta_p^2 = .046$). A significant main effect for time was observed for both VO_2 ($p < .000$, $\eta_p^2 = .934$) and heart rate ($p < .000$, $\eta_p^2 = .941$), with values decreasing over time toward resting levels.

Values 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 time ($p = .608$, $\eta_p^2 = .016$) or condition ($p = .402$, $\eta_p^2 = .031$) was found, nor was there a significant Condition × Time interaction ($p = .111$, $\eta_p^2 = .092$).

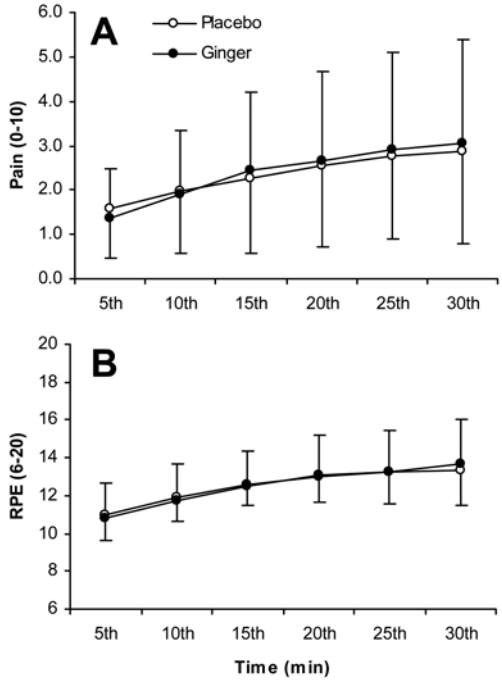

Figure 2 — (A) Ratings of quadriceps muscle-pain intensity and (B) ratings of perceived exertion (RPE) during 30 min of moderate-intensity cycling exercise (60% of VO_{2peak}), $M \pm SD$.

Discussion

The purpose of the current experiment was to examine the acute effects of oral consumption of a 2-g dose of ginger on naturally occurring quadriceps pain, RPE, oxygen consumption, and heart rate during and after 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 with placebo. In addition, ginger consumption did not alter recovery of oxygen consumption or heart rate in the 20 min 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 et al., 2000; Wigler,

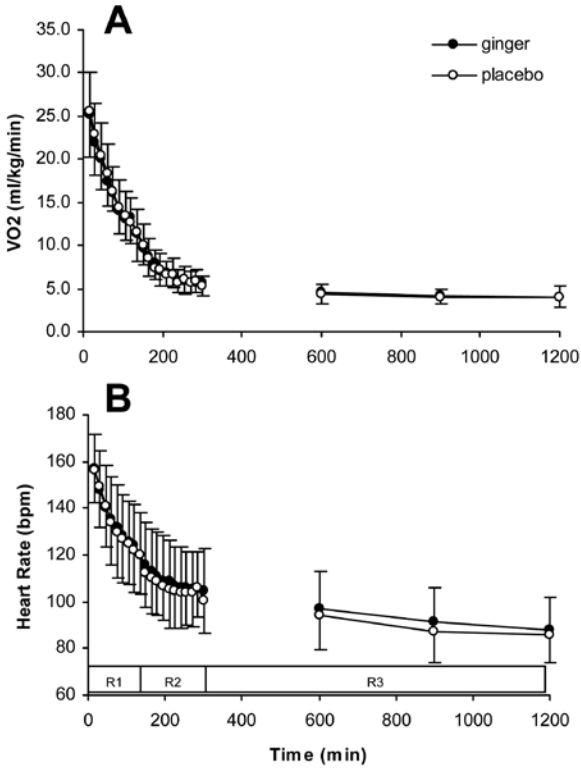

Figure 3 — (A) Oxygen consumption and (B) heart rate during 20 min of recovery from moderate-intensity cycling exercise (60% of VO_{2peak}). Recovery is divided into three distinct periods—R1 = values during cycling at 25 W for 2 min, R2 = values during resting on the cycle ergometer for 3 min, and R3 = values during resting on a padded bench for 15 min. Values are mean ± *SD*.

Grotto, Caspi, & Yaron, 2003). The hypoalgesic effects of ginger are thought to occur through the inhibition of prostaglandin and leukotriene synthesis (Ojewole; Young et al.), as well as modulation of the TRPV1 vanilloid receptor (Cortright et al., 2007). Thus ginger could mimic dual-action anti-inflammatory drugs and have more potent effects than aspirin alone. The current 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 current study because the dose was insufficient or the acute nature of the assessment (30–60 min after ingestion) did not allow adequate time for the ginger to move to the central nervous system or periphery and act. The 2 g of ginger consumed provided a mean dose of 29.3 ± 5.6 mg/kg (ranging from 20 to 43 mg/kg) 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),

but the relative dose administered in the current study appears to be within the range that has been reported to reduce acetic-acid-induced writhing in mice (Young et al.). Moreover, chronic administration of a much smaller dose (170–510 mg/day) 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-g dose has been shown to reduce nausea (Ernst & Pittler, 2000; Lien et al., 2003). The time course of action of ginger and its constituents after oral administration in humans remains unclear. An oral dose similar to that administered in the current study was found to reduce nausea within 60 min (Ernst & Pittler; Lien et al.). Animal models using intraperitoneal administration, which should presumably lead to fast bioavailability, have demonstrated acute analgesic and anti-inflammatory effects within 30 min (Ojewole; Young et al.). Depending on the predominant site of hypoalgesia it is plausible that the 30-min latency between the ingestion of ginger and the start of cycling exercise was not sufficient for the ginger to exert an antinociceptive effect.

A novel finding of the current study was that ginger did not alter oxygen consumption during or after exercise. Evidence from rodent models indicates that ginger might 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 rat hind limb (Eldershaw et al., 1992). In contrast to these findings, intraperitoneal administration of 6-gingerol has also been shown to induce a dose-dependent drop in body temperature in rats (Ueki, Miyoshi, Shido, Hasegawa, & Watanabe, 2008). In the current study ginger ingestion did not alter oxygen consumption compared with placebo during work-matched bouts of submaximal cycling. This finding is consistent with those of a previous study from our laboratory that demonstrated that a 2-g dose of ginger did not alter resting metabolic rate (compared with placebo) within 30 min of ingestion (unpublished observations), as well as the finding that the addition of ginger to a meal did not increase postprandial oxygen consumption compared with the meal alone (Henry & Piggott, 1987). Taken together these findings suggest that oral ginger consumption exerts little effect on metabolism at rest or during exercise in humans. Data from the current study contrast with those of Liburt (2005), who found a 22% faster recovery of the fast phase of oxygen consumption after a maximal exercise test in horses after ginger ingestion compared with ingestion of water or cranberry extract. Although another 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 current study, how ginger might enhance recovery from a bout of exercise. Previous research has clearly demonstrated that endurance training speeds recovery of both oxygen consumption and heart rate after 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 or why ginger could mimic the effects of endurance training. The results from the current study cast doubts on the efficacy of ginger to improve metabolic recovery after exercise.

In conclusion, the current study found that consumption of a 2-g oral dose of dietary ginger did not significantly alter naturally occurring quadriceps pain intensity and perception of effort during submaximal cycling exercise compared with placebo. These finding are potentially significant given that ginger has been previously been shown to have anti-inflammatory and hypoalgesic effects. In addition, oxygen consumption and heart rate during and after exercise were not found to differ between ginger and placebo conditions. These findings highlight the need for future study of the time course by which chronic ginger consumption produces the hypoalgesic 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.

References

Afzal, M., Al-Hadidi, D., Menon, M., Pesek, J., & Dhami, M.S. (2001). Ginger: An ethnomedical, chemical and pharmacological review. *Drug Metabolism and Drug Interactions, 18*(3-4), 159–190.

Ali, B.H., Blunden, G., Tanira, M.O., & Nemmar, A. (2008). Some phytochemical, pharmacological and toxicological properties of ginger (*Zingiber officinale Roscoe*): A review of recent research. *Food and Chemical Toxicology, 46*(2), 409–420.

Altman, R.D., & Marcussen, K.C. (2001). Effects of a ginger extract on knee pain in patients with osteoarthritis. *Arthritis and Rheumatism, 44*(11), 2531–2538.

Bliddal, H., Rosetzsky, A., Schlichting, P., Weidner, M.S., Andersen, L.A., Ibfelt, H.H., et al. (2000). A randomized, placebo-controlled, cross-over study of ginger extracts and ibuprofen in osteoarthritis. *Osteoarthritis and Cartilage, 8*(1), 9–12.

Borg, G.A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise, 14*(5), 377–381.

Cook, D.B., O'Connor, P.J., Eubanks, S.A., Smith, J.C., & Lee, M. (1997). Naturally occurring muscle pain during exercise: assessment and experimental evidence. *Medicine and Science in Sports and Exercise, 29*(8), 999–1012.

Cook, D.B., O'Connor, P.J., Oliver, S.E., & Lee, Y. (1998). Sex differences in naturally occurring leg muscle pain and exertion during maximal cycle ergometry. *The International Journal of Neuroscience, 95*(3-4), 183–202.

Cortright, D.N., Krause, J.E., & Broom, D.C. (2007). TRP channels and pain. *Biochimica et Biophysica Acta, 1772*(8), 978–988.

Eldershaw, T.P., Colquhoun, E.Q., Dora, K.A., Peng, Z.C., & Clark, M.G. (1992). Pungent principles of ginger (*Zingiber officinale*) are thermogenic in the perfused rat hindlimb. *International Journal of Obesity and Related Metabolic Disorders, 16*(10), 755–763.

Ernst, E., & Pittler, M.H. (2000). Efficacy of ginger for nausea and vomiting: A systematic review of randomized clinical trials. *British Journal of Anaesthesia, 84*(3), 367–371.

Grzanna, R., Phan, P., Polotsky, A., Lindmark, L., & Frondoza, C.G. (2004). Ginger extract inhibits beta-amyloid peptide-induced cytokine and chemokine expression in cultured THP-1 monocytes. *Journal of Alternative and Complementary Medicine (New York, N.Y.), 10*(6), 1009–1013.

Hagberg, J.M., Hickson, R.C., Ehsani, A.A., & Holloszy, J.O. (1980). Faster adjustment to and recovery from submaximal exercise in the trained state. *Journal of Applied Physiology, 48*(2), 218–224.

Henry, C.J., & Piggott, S.M. (1987). Effect of ginger on metabolic rate. *Human Nutrition. Clinical Nutrition, 41*(1), 89–92.

Iwasaki, Y., Morita, A., Iwasawa, T., Kobata, K., Sekiwa, Y., Morimitsu, Y., et al. (2006). A nonpungent component of steamed ginger—[10]-shogaol—increases adrenaline secretion via the activation of TRPV1. *Nutritional Neuroscience, 9*(3-4), 169–178.

Kiuchi, F., Iwakami, S., Shibuya, M., Hanaoka, F., & Sankawa, U. (1992). Inhibition of prostaglandin and leukotriene biosynthesis by gingerols and diarylheptanoids. *Chemical & Pharmaceutical Bulletin, 40*(2), 387–391.

Koo, K.L., Ammit, A.J., Tran, V.H., Duke, C.C., & Roufogalis, B.D. (2001). Gingerols and related analogues inhibit arachidonic acid-induced human platelet serotonin release and aggregation. *Thrombosis Research, 103*(5), 387–397.

Lantz, R.C., Chen, G.J., Sarihan, M., Solyom, A.M., Jolad, S.D., & Timmermann, B.N. (2007). The effect of extracts from ginger rhizome on inflammatory mediator production. *Phytomedicine, 14*(2–3), 123–128.

Liburt, N.R. (2005). *Effects of ginger and cranberry extracts on markers of inflammation and performance following intense exercise in horses*. Master's thesis, Rutgers, the State University of New Jersey.

Lien, H.C., Sun, W.M., Chen, Y.H., Kim, H., Hasler, W., & Owyang, C. (2003). Effects of ginger on motion sickness and gastric slow-wave dysrhythmias induced by circular vection. *American Journal of Physiology. Gastrointestinal and Liver Physiology, 284*(3), G481–G489.

McKeever, K.H. (2006). Patent application for *Compositions and methods for optimizing exercise recovery*. US Patent and Trademark Office.

McNair, D.M., Lorr, M., & Droppleman, L. (1992). *Profile of Mood States Questionnaire*. San Diego, CA: EDITS.

Motl, R. W., O'Connor P.J., Tubandt, L., Puetz, T., & Ely, M.R. (2006). Effect of caffeine on leg muscle pain during cycling exercise among females. *Medicine and Science in Sports and Exercise, 38*(3), 598–604.

Nurtjahja-Tjendraputra, E., Ammit, A.J., Roufogalis, B.D., Tran, V.H., & Duke, C.C. (2003). Effective anti-platelet and COX-1 enzyme inhibitors from pungent constituents of ginger. *Thrombosis Research, 111*(4–5), 259–265.

O'Connor, P.J., & Cook, D.B. (1999). Exercise and pain: The neurobiology, measurement, and laboratory study of pain in relation to exercise in humans. *Exercise and Sport Sciences Reviews, 27,* 119–166.

O'Connor, P.J., Motl, R.W., Broglio, S.P., & Ely, M.R. (2004). Dose-dependent effect of caffeine on reducing leg muscle pain during cycling exercise is unrelated to systolic blood pressure. *Pain, 109*(3), 291–298.

Ojewole, J.A. (2006). Analgesic, antiinflammatory and hypoglycaemic effects of ethanol extract of *Zingiber officinale* (Roscoe) rhizomes (*Zingiberaceae*) in mice and rats. *Phytotherapy Research, 20*(9), 764–772.

Park, I., & Schutz, R.W. (1999). "Quick and easy" formulae for approximating statistical power in repeated measures ANOVA. *Measurement in Physical Education and Exercise Science, 3,* 249–270.

Posner, J. (1984). A modified submaximal effort tourniquet test for evaluation of analgesics in healthy volunteers. *Pain, 19*(2), 143–151.

Tjendraputra, E., Tran, V.H., Liu-Brennan, D., Roufogalis, B.D., & Duke, C.C. (2001). Effect of ginger constituents and synthetic analogues on cyclooxygenase-2 enzyme in intact cells. *Bioorganic Chemistry, 29*(3), 156–163.

Tripathi, S., Bruch, D., & Kittur, D.S. (2008). Ginger extract inhibits LPS induced macrophage activation and function [online]. *BMC Complementary and Alternative Medicine, 8*(1), 1.

Ueki, S., Miyoshi, M., Shido, O., Hasegawa, J., & Watanabe, T. (2008). Systemic administration of [6]-gingerol, a pungent constituent of ginger, induces hypothermia in rats via an inhibitory effect on metabolic rate. *European Journal of Pharmacology, 584*(1), 87–92.

Wigler, I., Grotto, I., Caspi, D., & Yaron, M. (2003). The effects of Zintona EC (a ginger extract) on symptomatic gonarthritis. *Osteoarthritis and Cartilage, 11*(11), 783–789.

Young, H.Y., Luo, Y.L., Cheng, H.Y., Hsieh, W.C., Liao, J.C., & Peng, W.H. (2005). Analgesic and anti-inflammatory activities of [6]-gingerol. *Journal of Ethnopharmacology, 96*(1–2), 207–210.