International Journal of EXERCISE SCIENCE

Original Research

Examining Changes in Pain Sensitivity Following 8 Minutes of Cycling at Varying Exercise Intensities

BRANDI B. ANTONIO†[1], JEFFREY R. STOUT‡[1], DANIELLE A. STERNER†[1], DAVID H. FUKUDA‡[1], and ABIGAIL W. ANDERSON‡[2]

[1]Physiology of Work and Exercise Response (POWER) Lab, Institute of Exercise Physiology and Rehabilitation Science, University of Central Florida, Orlando, FL, USA; [2]Rehabilitation and Modulation of Pain (RAMP) Lab, Institute of Exercise Physiology and Rehabilitation Science, University of Central Florida, Orlando, FL, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 17(7): 1337-1351, 2024. This study assessed the effect of an eight-minute cycling intervention using varying intensities on exercise-induced hypoalgesia (EIH). The main objective of this study was to examine the effect of varying intensities on pressure pain threshold (PPT) and heat pain threshold (HPT) at the thigh and forearm, tested pre- and post-cycling intervention. Healthy male participants (n = 16) performed a graded exercise test on a cycle ergometer to establish their peak power output (PPO). In subsequent visits, participants completed five different 8-minute cycling interventions, with intensities randomly assigned to one of three counterbalanced orders. HPT and PPT were applied to the thigh and forearm two times before and after each cycling intervention. Additionally, there was a notable effect of intensity on PPT in the thigh, with significant changes at intensities of 90% (p = 0.024) and 100% PPO (p = 0.003). In the forearm, repeated measures ANOVA indicated that there was no significant interaction or main effect for intensity and time. Similarly, for HPT, the analysis did not show significant interaction or main effects for both intensity and location. This study was the first to examine EIH using an 8-minute cycling intervention on a cycling ergometer at individualized intensities. Higher intensity cycling sessions generated EIH locally in the thigh using PPT. A short but high intensity cycling intervention may have clinical relevance, as it can provide an intervention to reduce localized pain immediately after exercise using a pressure pain stimulus.

KEY WORDS: Quantitative sensory testing, endurance athletes, nociception

INTRODUCTION

Pain perception, a dynamic and multi-faceted process, is altered during and after various forms of exercise (33, 38). Aerobic, resistance, and isometric exercise consistently produce exercise-induced hypoalgesia (EIH) in healthy individuals, with moderate effects observed during aerobic exercise (20). EIH is an acute reduction in the perception of pain (decreased pain ratings or a lessening of pain sensitivity) after a bout of exercise (34). The measurement of EIH may involve the application of a noxious stimulus—often a pressure, thermal, or mechanical modality—before and after exercise (26).

Understanding and utilizing EIH can result in practical and beneficial applications. It has been estimated that 20% of individuals in the United States experience chronic pain (26) and physical inactivity is a risk factor for pain development (29). EIH can be induced in as little as one session (38), and populations participating in moderate levels of physical activity have lower levels of musculoskeletal pain (29). Therefore, physical activity can be recommended as a treatment for various pain conditions (29).

Consequently, physical activity and exercise may provide benefits in pain perception. The reduction in pain caused by EIH stems from mechanisms that affect the central nervous system. Pain perception occurs when peripheral nociceptors, located in the muscle (32), are activated and begin conduction through the A-delta and C fibers (17). This signal travels to the dorsal root ganglion of the spinal cord, and then up the spinothalamic tract to the thalamus (17). From there, thalamic neurons connect to the somatosensory cortex, signaling the location, intensity, and quality of acute pain (17).

The most prominent mechanism of EIH is the opioid hypothesis (26), which suggests that the activation of the endogenous opioid system leads to EIH by releasing endogenous opioids throughout the body (13). Specifically, the concentration of beta-endorphins, a type of opioid, has been shown to increase after exercise (13). Beta-endorphins bind to opioid receptors, resulting in the inhibition of tachykinin release, a protein involved in pain transmission (31). Similarly, exercise releases endogenous cannabinoids, which affect how the central nervous system processes pain and may result in analgesia (13). There are several other proposed mechanisms of EIH, including an increase in blood pressure associated with exercise, reduced central nervous system sensitivity, immune system changes, and changes in psychological factors following exercise (38). However, the exact mechanism underlying EIH remains largely unknown (13, 38).

Quantitative sensory testing provides an indirect measure of centrally mediated pain processing, which can provide insight into the analgesic effect of exercise. Both the intensity and duration of aerobic exercise should be considered when examining the effectiveness of EIH (33). It appears that EIH can last up to 30 minutes (34), is induced after exercise for at least ten minutes and exceeds 75% of one's VO_2 peak (20, 33). In pain-free populations, a dose-response relationship has been proposed to exist between exercise intensity and EIH, implying that as intensity increases, so does the magnitude of EIH (8, 20, 34, 38). This was determined by Naugle et al. (20) when examining several studies comparing the pain pressure threshold (PPT) to aerobic exercise intensity. However, because this conclusion was drawn from the results of only four studies, more research must examine the intensity of aerobic exercise and EIH to further build upon this hypothesis (20).

EIH has been demonstrated after cycling through increases in PPT at the local exercising muscle, the quadricep (35). However, EIH has also been generated at both local and remote sites in various investigations utilizing aerobic exercise on a cycle ergometer (36). Furthermore, whether local or remote EIH occurs may be related to the intensity of the exercise (21). Results have been equivocal when looking at local or systemic changes in EIH.

Due to the potential clinical application of EIH (20), it is beneficial to utilize an intervention that is accessible to many different populations, such as cycle ergometry. Currently, research using a cycle ergometer often implements interventions between 25–60 minutes (21, 33, 34) at various percentages of VO_2 peak or HRR. On the other hand, research that utilizes 8-minute cycling interventions have used a fixed wattage independent of one's fitness level (12). Thus, it would be beneficial to utilize a shorter and more accessible intervention, not relying on heart rate or volume of oxygen, in which the intensity is dependent on an individual's fitness level. In addition, utilizing a shorter, standardized 8-minute cycling session versus longer individualized protocols can increase feasibility and adherence when translating the cycling intervention into various settings and populations. The use of an eight-minute cycling intervention at a prescribed individualized intensity can be useful for different populations and needs to be further understood. Therefore, the objective of this study was to assess how EIH is affected by an eight-minute cycling intervention with varying intensities in healthy men. It was hypothesized that higher intensity exercise would lead to a greater EIH response of PPT in the thigh site, based on an investigation by Vaegter et al (35).

METHODS

Participants

The study recruited healthy male participants aged 18 to 30 years who were physically active and engaged in exercise at least 3–4 times per week. Active participants were chosen to control for consistency among EIH responses, as some evidence points to the idea that more fit individuals experience larger magnitudes of EIH (38). To achieve a statistical power of 0.80, a significance level of $\alpha = 0.05$ and an effect size of 0.74 were used (using G*Power Software), and a sample size of 17 participants was determined from an abstract in which they measured the significant changes in PPT after cycling (5). Prior to inclusion in the study, these individuals completed the Physical Activity Readiness Questionnaire (PAR-Q) to ensure suitability for participation. To prevent any potential interference with cycling performance or (28) pain perception, participants were instructed to abstain from intense exercise, specifically lower-body exercise that may cause soreness and affect pain perception, for 24 h prior to each visit. Each visit was also separated by at least 48 hours, ensuring consistency between previously published research (33, 34). Additionally, they were asked to maintain a consistent diet and refrain from consuming food or caffeine for three hours prior to each visit. All participants visited at the same time of day for all seven visits. The study protocol was reviewed and approved by the Institutional Review Board at the University of Central Florida. The participants were fully informed about the study procedures and provided informed consent prior to their participation. Various recruitment methods, such as flyers, posters, information sheets, notices, and online advertisements, were employed to recruit participants from the University of Central Florida campus and surrounding areas. The study aligns with ethical policies of the *International Journal of Exercise Science* (23).

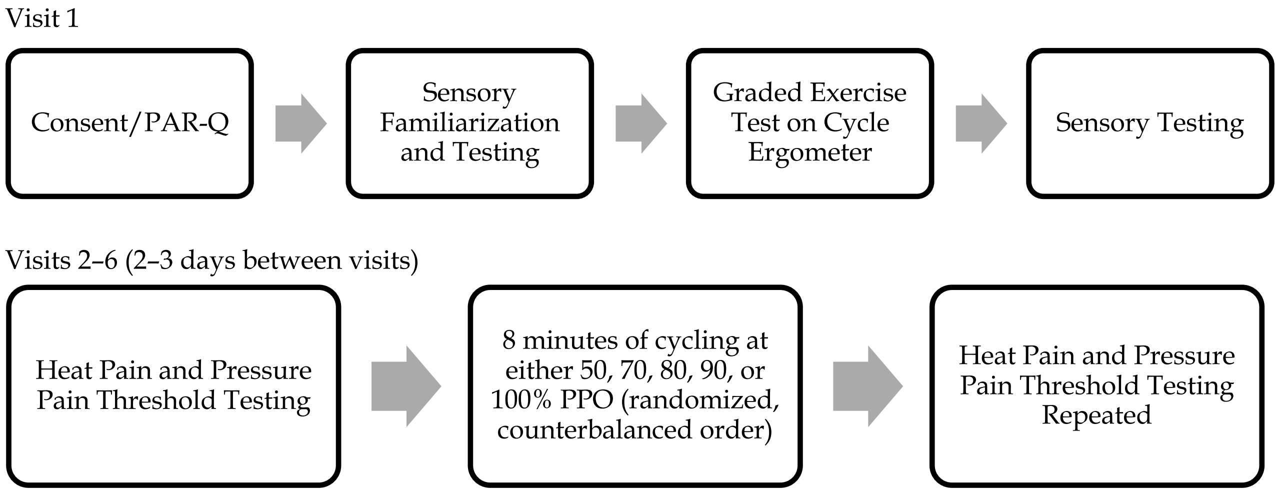


Figure 1. Timeline of procedures.

Protocol

Participants completed a PAR-Q, which evaluates the presence of risk factors during physical activity and considers the family history and disease severity. A questionnaire was used to determine whether the participants could safely engage in physical activity. If a participant answered affirmatively to any of the questions, they were excluded from the study and advised to consult a physician.

Participants' body weight, height, and body composition were assessed. Height was measured using a stadiometer (Health-o-meter Professional Patient Weighing Scale, Model 500 KL, Pelstar, Alsip, IL, USA), while body composition and weight were determined using bioelectrical impedance analysis device (InBody 770, Biospace Co, Ltd. Seoul, Korea).

All the pain sensitivity tests were performed by the same researcher to avoid inter-rater differences. The participants were familiarized with each test before the actual trial. Furthermore, the assigned counterbalanced order was randomized and not controlled by the researchers. However, the researchers were aware of each participant's assigned counterbalanced order because they had to input the intensity into the bike and onto the data collection sheet.

The participants completed a familiarization trial of the PPT during the first visit before the VO_2 peak test was conducted. The trial test was completed one time, only during the first visit, and the subsequent trials were conducted immediately after. Participants were seated with their thighs supported. A computerized pressure algometer (AlgoMed, Ramat Yishai, Israel) with a rubber tip of diameter 1 cm was applied at a constant rate. For the PPT, participants were instructed to say 'stop' or press a button connected to the algometer when the sensation first changed from pressure to pain (pain threshold). The stimulus was then stopped immediately. This was completed twice for both the dominant forearm, 8 cm from the elbow, and thigh, halfway between the anterior superior iliac spine and patella. Each trial was separated by a 1-minute break.

The participants completed a familiarization trial for the heat pain threshold (HPT) before testing during the first visit, before the VO_2 peak test was conducted. The trial test was completed one time, and only during the first session; the subsequent trials were conducted immediately after. Participants were provided with a 2 × 1 inch thermode attached to a TCS-II (QST.Lab, Strasbourg, France). The thermode increased from a baseline of 32 °C at a rate of 1 °C/s to a maximum of 50 °C. The participants were instructed to indicate when the sensation first changed from warmth to pain (pain threshold) by pressing a button. Once the button was pressed, the temperature stopped increasing and quickly returned to a baseline temperature of 32 °C. This procedure was completed twice on the dominant forearm (8 cm distal to the elbow crease) and twice on the dominant thigh (halfway between the anterior superior iliac spine and the top of the patella), and the average was taken for both. Each trial was separated by a 1-minute break.

All participants performed a graded exercise test (GXT) on a cycle ergometer (Lode, Corival cpet, Groningen, The Netherlands) to determine VO2peak and peak power output (PPO). Before testing, each participant was fitted with a heart rate monitor (chest strap and sensor; Polar H10, Polar Electro Oy, Kempele, Finland) to record their heart rate. The seat height was adjusted for each participant and kept constant at each visit. This was adjusted to allow the participant to maintain a slight bend in the knee when reaching full extension while pedaling. The pedals were also equipped with velcro straps that were tightened around the participants' shoes to minimize movement between the shoe and the pedal. Participants completed a five-minute warm-up on a cycle ergometer at a self-selected intensity and cadence. The test consisted of 2-minute stages, beginning at an initial workload of 50 watts (W), then 100 W, followed by an increase of 30 W every 2 min until the participants could no longer maintain 70 RPM (2, 30). The VO2peak was determined to be the highest value achieved during the last completed stage of the test. Open-circuit spirometry was used to estimate VO2peak with a calibrated metabolic cart (True One 2400® Metabolic Measurement System, Parvo-Medics Inc., Sandy, UT) by sampling and analyzing breath-by-breath expired gases. The metabolic cart software continuously recorded ventilation and expired gases with averages every 15 s, calculated VO_2, and determined the VO2peak value. The PPO, measured in W, was the highest power output achieved during the last completed stage.

During visits 2–6, the participants were randomly assigned to one of three counterbalanced orders of cycling intensity, as previously described. Each visit was separated by at least 2–3 days (8, 34). All participants began with a warm-up on a cycle ergometer at a self-selected cadence. The participants then cycled for 8 min at 70 rpm and a power output of 50%, 70%, 80%, 90%, or 100% of the PPO, based on VO_2 peak data obtained during visit 1 while pedaling at 70 rpm. In an examination of the test-retest reliability in maximal exercise testing, it has been shown that the average standard measurement error was 2.58 $mL \cdot kg^{-1} \cdot min^{-1}$ (25). If participants could not complete the full eight minutes, the duration was recorded. Participants also wore a Polar heart rate monitor to record their heart rate. The seat height was adjusted to match the previously recorded height from the graded exercise test during visit one for each participant. Participants completed PPT and HPT before and after cycling during visits 2–6. This was performed twice, before and after on the dominant forearm and thigh. These sites were chosen to allow for EIH to be analyzed in both an exercising site, the thigh, and a non-exercising site, the forearm.

Statistical Analysis
Descriptive statistics were computed to determine participant demographics. The data were prepared by initially averaging the threshold tests for the PPT and HPT at each site. Averaging the temperature of two trials for HPT improves reliability (19). Similarly, in PPT, measurement error can be reduced with two trials, and inter-rater reliability has been shown to be excellent in healthy participants (15). Subsequently, the average values were normalized to the baseline values using percent relative change scores ([(post - pre) / pre) × 100]) for analysis. The data were subjected to analysis using repeated measures ANOVAs with a 5 (condition: 50%, 70%, 80%, 90%, 100%) × 2 (site: forearm, thigh) design to ascertain whether the change scores exhibited significant differences between intensities and sites. In addition, a 5 (condition: 50%, 70%, 80%, 90%, 100%) × 2 (time: Pre, Post) repeated measures ANOVA was conducted to investigate raw PPT and HPT scores in the thigh and forearm individually at different intensities. The objective of this analysis was to determine whether the pre- and post-exercise values displayed significant changes at each intensity level for the forearm or thigh. A Type I error rate of less than or equal to 5% ($p \leq 0.05$) was regarded as statistically significant for all analyses. If the sphericity assumptions were violated, the Greenhouse-Geiser correction was applied as necessary. For effect size, the partial eta squared (η^2_p) statistic was calculated according to Green et al (7). A η^2_p of 0.01, 0.06, and 0.14 represents small, medium, and large effect sizes, respectively. All models and comparisons were computed using SPSS Statistics (Version 18.0, SPSS Inc., Chicago, Ill, USA) and Microsoft Excel (version 2007, Microsoft Corporation; Microsoft Network, LLC, Richmond, WA, USA).

RESULTS

The descriptive statistics of the participants are presented in Table 1. Sixteen participants successfully completed all sessions and were included in the subsequent statistical analysis. Of the 21 participants recruited, five were unable to schedule all 7 visits required to complete the study. Similarly, Jones et al's (9) investigation using 15 minutes of cycling at 60–70% HRR had 16 participants complete the study. Notably, eight participants successfully completed the 8-minute cycling session at 100% intensity level. The average completion time of this session was 6.5 minutes. Kemppainen et al. (12) used a similar workload duration of 8–10 minutes, but at a consistent workload for each participant (100, 200, 250, 300 W). However, they set the pedal frequency to 50 RPM, whereas our current protocol utilized a pedal frequency of 70 RPM. This disparity in pedal frequency could potentially account for the observed discrepancy in cycling time between our study and the findings of Kemppainen et al. (12).

The PPT data, including the means and standard deviations, are presented in Table 2. A 5 × 2 repeated measures ANOVA was conducted to analyze the percent change in PPT at five levels of intensity (50, 70, 80, 90, and 100) and two locations (thigh and forearm). Sphericity was confirmed using Mauchly's test ($p = 0.778$). The results indicated no significant interaction ($F(3.286, 49.291) = 1.296$, $p = 0.282$, $\eta^2_p = 0.080$) or main effect for intensity

($F(3.549, 53.229) = 2.286$, $p = 0.079$, $\eta^2_p = 0.132$). However, the main effect of location was statistically significant ($F(1,15) = 6.125$, $p = 0.026$, $\eta^2_p = 0.290$).

Table 1. Participant characteristics.

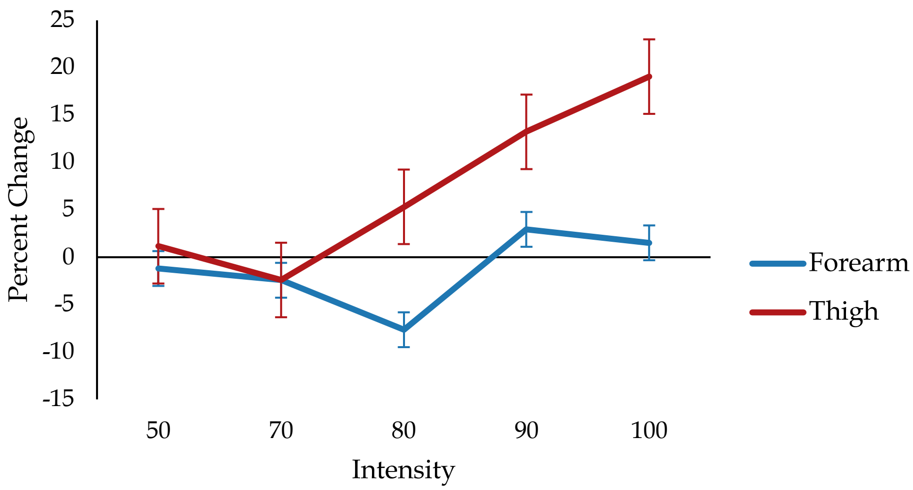
Variable	Mean (SD)	Range
Age (yrs)	22 (2.2)	18–27
Height (cm)	177.4 (6.2)	166.5–188.5
Weight (kg)	75.0 (6.7)	65.7–87.1
Skeletal Muscle Mass (kg)	37.3 (4.1)	30.4–43.5
% Fat	13. 5 (5.3)	3–23.8
VO_2 peak (mL/min/kg)	38.1 (7.0)	27.6–51.5
50% Power Output (W)	105.8 (21.3)	85–160
70% Power Output (W)	148.2 (29.8)	119–224
80% Power Output (W)	169.3 (34.0)	136–256
90% Power Output (W)	190.5 (38.3)	153–288
100% Power Output (W)	211.7 (42.5)	170–320

W = watts.

Table 2. PPT values measured pre and post exercise at each exercise intensity for the thigh and forearm.

	% Peak Power	Variable	Mean (SD)	Range
Thigh (kPa)	50	pre	688.69 (218.54)	374.35–1037.8
		post	699.22 (227.69)	346.9–1154.9
	70	pre	668.13 (155.92)	451.3–882.5
		post	654.89 (202.82)	365.9–1071.15
	80	pre	683.21 (215.57)	369.45–1171.55
		post	712.13 (237.47)	389.05–1258.35
	90	pre	643.94 (190.36)	382.7–1067.25
		post	721.78 (185.85)	396.4–1042.2
	100	pre	667.44 (145.80)	414.55–953.05
		post	798.48 (260.23)	481.9–1500
Forearm (kPa)	50	pre	564.91 (238.00)	276.9–994.25
		post	534.67 (189.36)	224.45–820.25
	70	pre	541.54 (175.91)	285.65–872.2
		post	515.67 (150.72)	309.15–768.3
	80	pre	573.22 (175.62)	333.2–851.15
		post	522.12 (156.43)	306.7–864.35
	90	pre	606.19 (217.03)	256.3–1067.25
		post	575.70 (169.62)	336.15–843.8
	100	pre	566.28 (159.93)	305.3–808
		post	553.20 (140.09)	309.2–762.45

PPT = pain pressure threshold; kPa = kilopascal.



*: significance between quadricep and forearm

Figure 1. Percent change values in pressure pain threshold (PPT) at thigh and forearm sites for each cycling intensity (50, 70, 80, 90, and 100 of peak power output). Bars indicate standard error.

A separate intensity-by-time repeated measures ANOVA was conducted specifically for thigh PPT at different intensities, supporting the assumption of sphericity (p = 0.07). There was a significant effect of intensity (F(4, 60) = 3.676, p = 0.010, η^2_p = 0.197), with Bonferroni post hoc tests indicating significant changes in PPT at intensities of 90% (p = 0.024) and 100% (p = 0.003). In contrast, for the location of the forearm, repeated measures ANOVA revealed no significant interaction (F(4, 60) = 0.317, p = 0.866, η^2_p = 0.021), or main effects for "intensity" (p = 0.082) and "time" (p = 0.085).

The means and standard deviations of HPT are shown in Table 3. A repeated measures ANOVA was conducted on the HPT data to examine the interaction between intensity and location. The assumption of sphericity was confirmed (p = 0.102); however, the analysis revealed no significant interaction (F(4,60) = 1.972, p = 0.110, η^2_p = 0.116), no significant main effect for intensity (F(4, 60) = 0.354, p = 0.851, η^2_p = 0.023), and no main effect for location (F(1, 15) = 2.121, p = 0.166, η^2_p = 0.124).

Table 3. HPT values measured pre and post exercise at each exercise intensity for the thigh and forearm.

	% Peak Power	Variable	Mean (SD)	Range
Thigh (℃)	50	pre	44.71 (2.06)	38.85–46.9
		post	45.28 (0.99)	43.05–46.75
	70	pre	45.18 (1.42)	40.95–47.4
		post	45.24 (1.16)	41.55–46.45
	80	pre	44.79 (1.72)	41.55–47.45
		post	44.56 (0.84)	43.15–46.2
	90	pre	45.05 (1.44)	43.1–47.8
		post	44.89 (1.16)	42.7–46.5
	100	pre	45.07 (1.33)	42–27.35
		post	45.27 (1.46)	42.2–47.6
Forearm (℃)	50	pre	44.72 (1.56)	40.7–46.65
		post	44.40 (1.64)	39.5–45.9
	70	pre	44.35 (1.76)	40.05–46.25
		post	44.23 (2.09)	37.45–46.3
	80	pre	44.23 (1.74)	41.15–47.95
		post	44.05 (1.75)	40.65–45.85
	90	pre	43.84 (1.65)	39.05–45.65
		post	44.00 (1.57)	39.85–45.75
	100	pre	44.45 (1.70)	41.05–47.85
		post	44.31 (1.55)	39.95–46.6

HPT = heat pressure threshold.

DISCUSSION

The main objective of this study was to examine the impact of an 8-minute cycling intervention on EIH in healthy men, focusing specifically on the thigh (local) and forearm (remote). The cycling intervention varied in intensity, ranging from 50% to 100% of each participant's PPO, as established by the graded exercise VO_2 peak test (range: 75–320 W). The results indicated a significant difference in PPT between the thigh and forearm (Figure 2), which is consistent with prior research (18). Furthermore, PPT in the thigh demonstrated an increase after 90% and 100% PPO cycling sessions (Figure 3), thereby illustrating a dose-response relationship between exercise intensity and EIH (20, 34, 38). No significant effects on HPT were observed after any of the cycling intensities, which corroborates with the existing literature (9).

As mentioned above, PPT increased locally following higher-intensity cycling. Similarly, in their study using isometric exercise, Mais et al. (16)observed an increase in PPT at local muscle sites, whereas no such increase was observed at remote sites. Belavy et al. (1) further supported this phenomenon through a comprehensive review, suggesting that exercises targeting local sites are more effective in reducing pain, quantified by measuring pain sensitivity with a pressure algometer, than those targeting remote sites.

Similarly, Gomolka et al. (6) assessed PPT after two separate 15-minute cycling sessions in 30 healthy adults and observed a significant increase in PPT at the thigh in both sessions and at the back in one session, which may suggest that local, rather than remote, PPT is elicited after cycling. Likewise, Vaegter et al. (35) discovered that after 15 minutes of cycling at lactate threshold, PPT of the thigh significantly increased locally in 34 healthy subjects (average age: 25.3 years), but it did not increase remotely in the trapezius. All these similar findings to the current study suggest localized EIH in the thigh following various cycling interventions in similar populations to that of the present study, although none were as short as the 8-minute intervention used in this investigation.

In contrast to our results and the findings of the studies described previously, some investigations have reported both local and systemic increases in PPT. Jones et al. (10) found a significant increase in PPT in both legs and arms after 5 minutes of high intensity (RPE greater than 17) cycling in 36 healthy participants (mean age of 22.1 years). PPT was applied to the rectus femoris for the leg site, and on the first dorsal interosseous muscles of both the arms. However, this study utilized blood flow restriction (BFR) applied peripherally to one arm, perhaps accounting for the difference in PPT at remote exercise sites (10). Furthermore, these participants were described as undergraduate students who did not regularly participate in moderate- or high-intensity exercise. In our investigation, inclusion criteria required participants to regularly engage in exercise. Considering the discrepancies in PPT results between the two studies, differences in methods (use or no use of BFR) and population (active vs. inactive populations) may affect the presence of EIH. Therefore, the results of the current study may only be applicable to our specific population, healthy, college-aged men, and our intervention, eight minutes of cycling at various intensities.

In another investigation by Niwa et al (24), the researchers found an increase in PPT at all assessment sites after exercise. This study examined different intensities of aerobic exercise (using a stationary cycle ergometer) and their effects on EIH; however, the exercise was longer in duration (30 minutes) than our current investigation. Intensities included 30% HRR, 50% HRR, and 70% HRR. Additionally, while an increase in PPT occurred at all sites after exercise, a dose-response relationship still existed; higher-intensity exercise elicited a greater magnitude of EIH (24). The effective lower-intensity exercise in this study may be due to the longer duration of the protocol, compared to the current study which used an eight-minute protocol.

As mentioned above, the current research study utilized a short, eight-minute cycling intervention with various intensities, and EIH was found after the higher-intensity bouts. Albeit using a longer investigation than our current one, Koltyn et al. (14) utilized a thirty-minute cycling intervention at 75% of the participants' VO_2 max, and PPT was significantly higher after the exercise condition. Additionally, Hoffman et al. (8) had participants run on a treadmill for 10 minutes at speeds that corresponded to 50 and 75% VO_2 max. The percentages of both these interventions were determined from a graded exercise test and its equivalent VO_2 uptake speed. They assessed EIH through PPT ratings after completing the exercise bouts. Ultimately, they discovered that pain ratings decreased after the 30-minute session at 75% of VO_2 max, but not after any of the other sessions. These results, in addition to our findings, may indicate that both intensity and duration play pivotal roles when attempting to elicit exercise-induced hypoalgesia.

In contrast to our findings, van Weerdenburg et al. (39) conducted a study involving three interventions: 20 min of aerobic cycling, 12 min of isometric knee extension, or a deep breathing exercise. They observed no EIH in the 15 healthy participants who performed either aerobic or isometric exercises (39). Unlike our current investigation, their study determined the intensity of cycling based on age-predicted maximum heart rate, rather than using a set wattage or intensity on the cycle ergometer. Furthermore, they tested pain via visceral stimulation, pressure algometry, and conditioned pain modulation. No EIH was present after the visceral or pressure modalities (39). Interestingly, the set cycling intensity in their study corresponded to 60-80% of the participants' VO_2 max, which is lower than the intensity (90-100%) we found in our study to induce EIH.

The absence of significant impacts on HPT in the current study is consistent with the results reported by Jones et al (9). In their study, they observed an increase in PPT after exercise (either 15 minutes of cycling at 60-70% HRR or a comparable 'light activity'), while HPT was not affected. In another investigation by Black et al. (3), it was observed that the PPT increased after 10 and 15 minutes of cycling, while the HPT only increased after the 15-minute exercise session and not the shorter, more intense session. Additionally, this study sought to investigate the effects of caffeine ingestion on EIH. However, their results indicated that caffeine did not alter EIH after cycling (3).

Similarly, Ruble et al. (27) found no significant changes in thermal sensitivity or pain thresholds after 30 minutes of aerobic exercise on the treadmill performed at 75% of VO_2 max. One important factor that may influence the EIH response to both pressure pain and heat pain is the duration and area of the stimulus application, as both can affect sensitivity and pain thresholds (40). Jones' study (9) and the present research used similar stimulus application durations, approximately 6-10 seconds. Albeit only in HPT, Yarnitsky et al (40) discovered that pain threshold decreased as the rate of the temperature rise increased. Therefore, it would be important to note the duration of the heat stimulus application in any investigation.

Vaegter et al. (37) found that submaximal isometric exercise increased tolerance to pressure pain but did not affect PPT or HPT. However, Vaegter's study used computer-controlled cuff algometry to test pressure pain, whereas our study used a handheld pressure algometer. The use of cuff algometry targets a larger range of skin tissue and may induce ischemic pain, potentially leading to different results in different studies (9).

Results may have differed between the pressure and heat stimuli due to the two types of nociceptors, A-delta and C fibers, activated by the exercise intervention. While both A-delta and C-fibers detect mechanical and heat sensitivity, they both have different thresholds required for nociception (4). In a review published by Dubin and Patapoutian (4), they concluded that C-fibers detect heat between 39 degrees and 51 degrees Celsius, while A-fiber nociceptors detect heat from 43 to 47 degrees Celsius. Therefore, the heat pain may have been predominately dominated by C-fibers, rather than A-fibers. Both A-delta and C-fibers are activated by muscle contractions in exercise, yet perhaps in different ratios.

Additional influences on EIH following exercise may result from participants' education regarding the topic itself. For example, in an investigation by Jones et al. (11), 20 participants received education about EIH or general education about exercise and pain, and then the PPT was measured before and after 20 minutes of cycling at a target RPE of 14, which corresponded to 65–75% of HRR. PPT showed a greater increase in the intervention group (EIH education), which may indicate that participants' previous knowledge and expectations can affect the results of EIH investigations. This relates to the current study, as participants may have been affected by their previous knowledge of the topic. As the study drew from various populations, some may have already had background knowledge about EIH.

Naugle et al. conducted a study and found that younger adults experience more EIH compared to older adults, in which their average age was 63.7 years (22). The average age of young adults in the study was 21.7 years, which is very similar to our mean age of 22 years. Therefore, our research agrees with Naugle's investigation, and perhaps may be one of the reasons why EIH was generated in our population after certain intensities. In addition, the age of the participants in Nguy's investigation (22), which was described above, may have affected their EIH response to the various forms of exercise.

The limitations of this current investigation are multi-faceted. First, the sample size and the demographics of the participants could be a limiting factor. For example, the sample was restricted to healthy, young men (mean age of 22 years old) between the ages of 18 and 45 years. Therefore, the results of the study may not be applicable to a broader population, such as an elderly population or a female population. Furthermore, the varied fitness level of participants (average VO_2 peak value of 38.1 mL/kg/min; range of 27.6–51.5) could have elicited heterogenous responses to the different cycling intensities. While all pain testing was conducted by one researcher, blinding was not done. Therefore, the researcher was aware of each cycling intensity during the visits. Factors such as sleep and daily nutrition were also not accounted for in this study, which could influence how the participants felt each visit.

The current study is the first to investigate the effect of an 8-minute cycling intervention on PPT and HPT. The cycling intervention utilized the following intensities in a counterbalanced order: 50, 70, 80, 90, 100% PPO. Significant mean differences were found between the forearm and thigh for PPT at 90% and 100% PPO, as well as for the pre- and post-thigh PPT values at the same intensities. In contrast, for the location of the forearm, repeated measures ANOVA revealed no significant interaction or main effects for intensity or time. For the heat pain test, analysis revealed no significant interaction, no significant main effect for intensity, and no main effect for location. Thus, this study highlighted the importance of intensity (90–100% PPO) on EIH, especially when utilizing a short, eight-minute cycling protocol. Additionally, it may indicate that this intervention targeted nociceptors that are activated by mechanical stimuli, rather than thermal stimuli, which emphasizes the multifarious nature of EIH. Further research should seek to investigate this protocol utilizing different populations, or perhaps using a different mode of aerobic exercise, such as a treadmill.

REFERENCES

1. Belavy DL, Van Oosterwijck J, Clarkson M, Dhondt E, Mundell NL, Miller CT, Owen PJ. Pain sensitivity is reduced by exercise training: Evidence from a systematic review and meta-analysis. Neurosci Biobehav Rev 120: 100-108, 2021.

2. Beltz NM, Gibson AL, Janot JM, Kravitz L, Mermier CM, Dalleck LC. Graded exercise testing protocols for the determination of vo(2)max: Historical perspectives, progress, and future considerations. J Sports Med (Hindawi Publ Corp) 2016: 3968393, 2016.

3. Black CD, Gonglach AR, Renfroe JB, Hight RE. The effects of caffeine ingestion on exercise-induced hypoalgesia: A pilot study. Physiol Behav 161: 1-6, 2016.

4. Dubin AE, Patapoutian A. Nociceptors: The sensors of the pain pathway. J Clin Invest 120(11): 3760-3772, 2010.

5. Eustis K. The influence of exercise and aerobic exercise level on pressure-pain sensitivity. Int J Exerc Sci 8(11): 2023.

6. Gomolka S, Vaegter HB, Nijs J, Meeus M, Gajsar H, Hasenbring MI, Titze C. Assessing endogenous pain inhibition: Test-retest reliability of exercise-induced hypoalgesia in local and remote body parts after aerobic cycling. Pain Med 20(11): 2272-2282, 2019.

7. Green S, Salkind, NJ, Akey, TM. Using SPSS for Windows: Analyzing and understanding data. 2nd ed. Upper Saddle River, NJ: Prentice Hall; 2000.

8. Hoffman MD, Shepanski MA, Ruble SB, Valic Z, Buckwalter JB, Clifford PS. Intensity and duration threshold for aerobic exercise-induced analgesia to pressure pain. Arch Phys Med Rehabil 85(7): 1183-1187, 2004.

9. Jones MD, Nuzzo JL, Taylor JL, Barry BK. Aerobic exercise reduces pressure more than heat pain sensitivity in healthy adults. Pain Med 20(8): 1534-1546, 2019.

10. Jones MD, Taylor JL, Barry BK. Occlusion of blood flow attenuates exercise-induced hypoalgesia in the occluded limb of healthy adults. J Appl Physiol (1985) 122(5): 1284-1291, 2017.

11. Jones MD, Valenzuela T, Booth J, Taylor JL, Barry BK. Explicit education about exercise-induced hypoalgesia influences pain responses to acute exercise in healthy adults: A randomized controlled trial. J Pain 18(11): 1409-1416, 2017.

12. Kemppainen P, Paalasmaa P, Pertovaara A, Alila A, Johansson G. Dexamethasone attenuates exercise-induced dental analgesia in man. Brain Res 519(1-2): 329-332, 1990.

13. Koltyn KF, Brellenthin AG, Cook DB, Sehgal N, Hillard C. Mechanisms of exercise-induced hypoalgesia. J Pain 15(12): 1294-1304, 2014.

14. Koltyn KF, Garvin AW, Gardiner RL, Nelson TF. Perception of pain following aerobic exercise. Med Sci Sports Exerc 28(11): 1418-1421, 1996.

15. Mailloux C, Beaulieu LD, Wideman TH, Masse-Alarie H. Within-session test-retest reliability of pressure pain threshold and mechanical temporal summation in healthy subjects. PLoS One 16(1): e0245278, 2021.

16. Mais S, Smith JA. The effect of spinal muscle fatigue and psychosocial factors on pressure-pain threshold in healthy adults. Pain Res Manag 2023: 7336477, 2023.

17. Markenson JA. Mechanisms of chronic pain. Am J Med 101: S6-S18, 1996.

18. Micalos PS, Arendt-Nielsen L. Differential pain response at local and remote muscle sites following aerobic cycling exercise at mild and moderate intensity. SpringerPlus 5: 91, 2016.

19. Moloney NA, Hall TM, Doody CM. Reliability of thermal quantitative sensory testing: A systematic review. J Rehabil Res Dev 49(2): 191-207, 2012.

20. Naugle KM, Fillingim RB, Riley JL, 3rd. A meta-analytic review of the hypoalgesic effects of exercise. J Pain 13(12): 1139-1150, 2012.

21. Naugle KM, Naugle KE, Fillingim RB, Samuels B, Riley JL, 3rd. Intensity thresholds for aerobic exercise-induced hypoalgesia. Med Sci Sports Exerc 46(4): 817-825, 2014.

22. Naugle KM, Naugle KE, Riley JL, 3rd. Reduced modulation of pain in older adults after isometric and aerobic exercise. J Pain 17(6): 719-728, 2016.

23. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

24. Niwa Y, Shimo K, Ohga S, Tokiwa Y, Hattori T, Matsubara T. Effects of exercise-induced hypoalgesia at different aerobic exercise intensities in healthy young adults. J Pain Res 15: 3615-3624, 2022.

25. Vickers J, Ross R. Measurement error in maximal oxygen uptake tests. Fort Belvoir, VA: Defense Technical Information Center, 2003.

26. Rice D, Nijs J, Kosek E, Wideman T, Hasenbring MI, Koltyn K, Graven-Nielsen T, Polli A. Exercise-induced hypoalgesia in pain-free and chronic pain populations: State of the art and future directions. J Pain 20(11): 1249-1266, 2019.

27. Ruble SB, Hoffman MD, Shepanski MA, Valic Z, Buckwalter JB, Clifford PS. Thermal pain perception after aerobic exercise. Arch Phys Med Rehabil 86(5): 1019-1023, 2005.

28. Schmitt A, Wallat D, Stangier C, Martin JA, Schlesinger-Irsch U, Boecker H. Effects of fitness level and exercise intensity on pain and mood responses. Eur J Pain 24(3): 568-579, 2020.

29. Sluka KA, Frey-Law L, Hoeger Bement M. Exercise-induced pain and analgesia? Underlying mechanisms and clinical translation. Pain 159: S91-S97, 2018.

30. Spriet LL. Regulation of substrate use during the marathon. Sports Med 37(4-5): 332-336, 2007.

31. Sprouse-Blum AS, Smith G, Sugai D, Parsa FD. Understanding endorphins and their importance in pain management. Hawaii Med J 69(3): 70-71, 2010.

32. Stacey MJ. Free nerve endings in skeletal muscle of the cat. J Anat 105(Pt 2): 231-254, 1969.

33. Tomschi F, Kieckbusch L, Zachow J, Hilberg T. Does exercise-induced hypoalgesia depend on exercise duration? Biology (Basel) 12(2): 2023.

34. Tomschi F, Lieverkus D, Hilberg T. Exercise-induced hypoalgesia (EIH) in response to different exercise intensities. Eur J Appl Physiol 122(10): 2213-2222, 2022.

35. Vaegter HB, Bjerregaard LK, Redin M-M, Rasmussen SH, Graven-Nielsen T. Hypoalgesia after bicycling at lactate threshold is reliable between sessions. Eur J Appl Physiol 119(1): 91-102, 2019.

36. Vaegter HB, Handberg G, Graven-Nielsen T. Similarities between exercise-induced hypoalgesia and conditioned pain modulation in humans. Pain 155(1): 158-167, 2014.

37. Vaegter HB, Hoeger Bement M, Madsen AB, Fridriksson J, Dasa M, Graven-Nielsen T. Exercise increases pressure pain tolerance but not pressure and heat pain thresholds in healthy young men. Eur J Pain 21(1): 73-81, 2017.

38. Vaegter HB, Jones MD. Exercise-induced hypoalgesia after acute and regular exercise: Experimental and clinical manifestations and possible mechanisms in individuals with and without pain. Pain Rep 5(5): e823, 2020.

39. van Weerdenburg LJ, Brock C, Drewes AM, van Goor H, de Vries M, Wilder-Smith OH. Influence of exercise on visceral pain: An explorative study in healthy volunteers. J Pain Res 2017(10): 2016.

40. Yarnitsky D, Ochoa JL. Studies of heat pain sensation in man: Perception thresholds, rate of stimulus rise and reaction time. Pain 40(1): 1990.