Exercise-Induced Hypoalgesia Is Not Influenced by Physical Activity Type and Amount

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ABSTRACT

BLACK, C. D., J. K. HUBER, L. D. ELLINGSON, C. J. ADE, E. L. TAYLOR, E. M. GRIFFETH, N. R. JANZEN, AND S. L. SUTTERFIELD . Exercise-Induced Hypoalgesia Is Not Influenced by Physical Activity Type and Amount. *Med. Sci. Sports Exerc.*, Vol. 49, No. 5, pp. 975–982, 2017. Physical activity (PA), especially vigorous-intensity PA, has been shown to be related to pain sensitivity. The relationship among PA levels and PA types on endogenous pain inhibition after exercise, termed exercise-induced hypoalgesia (EIH), remains unclear. **Purpose**: This studied examined the EIH response to pressure stimuli among college-age women of differing activity levels. **Methods**: Fifty women were tested. Pressure pain threshold (PPT) values were assessed before and immediately after isometric handgrip exercise to exhaustion in the right and left forearms. Participant's PA levels were assessed by wearing an accelerometer for seven consecutive days during waking hours, excluding water activities. Participants were classified into four PA groups: met the American College of Sports Medicine aerobic recommendations (AERO), met aerobic and resistance training recommendations (AERO + RT), insufficiently aerobically active but resistance trained (RT), and insufficiently active (IA) based on their measured and self-reported PA level and type. **Results**: AERO and AERO + RT had greater vigorous ($P < 0.001$) and total PA ($P < 0.001$) compared with RT and IA. EIH was observed for PPT in both right and left arms ($P < 0.001$), with PPT increasing 7.7% (529 ± 236 vs 569 ± 235 kPa) and 7.0% (529 ± 299 vs 571 ± 250 kPa) in the right and left forearms, respectively. EIH did not differ among activity groups ($P = 0.82$). PPT values were found to be inversely related to vigorous-intensity PA ($r = -0.29$). **Conclusions**: PA levels and types had no effect on endogenous pain inhibition after exercise in college-age women. **Key Words:** PRESSURE PAIN THRESHOLD, EXERCISE-INDUCED HYPOALGESIA, VIGOROUS PHYSICAL ACTIVITY, HANDGRIP

Chronic pain presents a significant public health burden as it may affect up to 50% of adults at any given time (12), is the most commonly reported reason for visiting a doctor (7), and reduces both quality of life and physical function. A lack of physical activity (PA) is associated with chronic pain (14,24), and those who experience chronic pain are less likely to exercise than those without chronic pain (29). Although the current public health guidelines for PA were primarily developed to help reduce the risk of chronic cardiovascular and metabolic disorders, there is evidence suggesting that increased PA may improve pain-related symptoms in those with chronic pain conditions such as osteoarthritis (17), fibromyalgia (6), and low back pain (8). In support of these findings, several recent studies have demonstrated an inverse relationship between PA, especially vigorous PA, and pain sensitivity (i.e., those who are more active are less sensitive to pain) in healthy adults. Cross-sectional studies by Ellingson et al. (10) and Andrzejewski et al. (1) demonstrated that participants who performed more vigorous PA had less sensitivity to thermal and pressure stimuli, respectively. Jones et al. (16) found 6 wk of cycling exercise training (three times a week for 30 min at 75% of heart rate reserve) increased tolerance to ischemic pain. Furthermore, a 12-wk study comparing the effects of aerobic, resistance, combined aerobic and resistance training, and controls found larger increases in pain tolerance when an aerobic training component was included (2).

A single bout of exercise has been shown to activate endogenous pain inhibitory mechanisms and lead to a transient reduction in sensitivity to noxious stimuli termed exercise-induced hypoalgesia (EIH) (for a review, see [18,32]). EIH has been shown to occur after aerobic, resistance, and isometric exercise and to occur regardless of the type of noxious stimulus applied (e.g., pressure, thermal, electrical, and chemical) (32). The precise mechanism(s) underlying EIH remain unresolved and are likely multifaceted with evidence supporting pain inhibitory mechanisms that are both generalized (i.e., occur in body segments that were not involved in exercise) (5,15,20,23) and specific to the exercising muscle/limb (5,19,23). Interestingly, chronic pain conditions such as fibromyalgia (21,22,38), Gulf War syndrome (9), and shoulder myalgia (25), which

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may lead to decreased PA levels, have been shown to disrupt endogenous pain inhibitory function. Scant data exist regarding the relationship between PA levels and endogenous pain inhibitory function in "healthy" individuals. Greater self-reported total and vigorous PA has been shown to be related to greater endogenous pain inhibition assessed via conditioned pain modulation (CPM) (34). In addition, a recent study (41) demonstrated reduced EIH in African Americans compared with non-Hispanic Whites, and that this effect was moderated by reduced self-reported leisure time PA. The magnitude of CPM is thought to be related to the magnitude of the EIH response (27), suggesting similar mechanism(s) of action. Taken together, the finding of reduced CPM (34) and EIH (41) with reduced PA level suggests that PA level may play a key role in endogenous pain inhibitory function.

Building on and extending previous research, the purpose of this study was to determine whether the EIH response to pressure stimuli differed among healthy college-age women who participated in various levels and various types (e.g., aerobic vs resistance training) of PA. We hypothesized participants exhibiting greater objectively measured total and vigorous PA as well as those participating in resistance training would exhibit a greater EIH response.

METHODS

Participants. Fifty women (21.9 ± 3.6 yr old, 165.7 ± 7.3 cm, 67.0 ± 12.8 kg) completed the study. Participants were classified into four PA categories based on objectively assessed daily PA and self-reported participation in 2 d or more of whole-body resistance training per week (confirmed by their activity log): 1) met the American College of Sports Medicine (ACSM) aerobic activity recommendations (AERO; ≥150 min moderate or ≥75 min vigorous PA per week accrued in bouts lasting at least 10 min; $n = 11$), 2) met aerobic and resistance training recommendations (AERO + RT; 2 d or more of whole-body resistance training per week; $n = 16$), 3) insufficiently aerobically active (≤150 min of moderate or ≤75 min of vigorous PA per week) but participate in 2 d or more of whole-body resistance training per week (RT; $n = 8$), and 4) insufficiently active (IA; ≤150 min of moderate or ≤75 min of vigorous PA per week and ≤1 d of whole-body resistance training; $n = 15$). All participants reported maintaining their current PA level for at least 3 months before the study and self-reported that their week of activity monitoring was "typical" of their normal activity. Potential participants who were in a state of amenorrhea, had a current diagnosis of depression or a chronic pain condition, or were taking prescription or over-the-counter medications that could affect pain sensitivity (e.g., antidepressants, narcotics, cardiovascular medication, etc.) were excluded from the study. A sample of 50 was sufficient to detect a moderate (0.60 SD) effect at a power of 0.80 and an alpha level of $P \leq 0.05$ (36). The study was powered in this manner as changes in pain sensitivity of ~0.50 SD are considered clinically meaningful (35). Also, previous research (10) demonstrated differences ranging from 0.51 to 1.24 SD on ratings of thermal pain intensity and unpleasantness between women meeting aerobic PA guidelines and those not meeting guidelines. All procedures were approved by a university institutional review board and participants provided written informed consent before testing.

Experimental overview. Participants completed two pain testing sessions separated by ~1–2 wk, and their daily PA was monitored for 7 d between visits. During the first testing session, participants were screened and completed several questionnaires to assess mood (POMS) (30), anxiety (State-Trait Anxiety Index [STAI]) (37), and two questionnaires related to pain perception, including 1) the Pain Catastrophizing Scale (PCS) (39) and 2) the Pain Attitudes Questionnaire–Revised (PAQ-R) (43). Participants were familiarized with the procedures for determining pressure pain threshold (PPT) as this has been shown to improve the reliability of the measure (4). They were familiarized with the isometric handgrip exercise protocol. At the end of the first visit, it was determined where the participant was in her menstrual cycle and the second visit was scheduled to take place during the luteal phase. If the participant was on hormonal birth control, she was scheduled when she was not in the placebo phase of the medication. After familiarization, participants were given an ActiGraph GT3X+ accelerometer (ActiGraph, Pensacola, FL) and were asked to wear it for 7 d during waking hours (excluding water activity) and simultaneously to keep a log of their activity, when the monitor was put on and taken off, and their wake and sleep times each day. The second visit occurred 7–14 d after the first and consisted of collecting the accelerometer from the participants. The POMS, STAI, PCS, and PAQ-R questionnaires were again completed. Baseline assessments of PPT in the right and left forearm were then made. Each assessment was separated by approximately 30 s and was performed in an alternating fashion from one forearm to the contralateral. After approximately 1 min of rest, maximal voluntary isometric strength (MVC) of the right forearm was then assessed as described in the next section. After MVC was determined, participants rested for approximately 5 min. Isometric exercise at 50% of MVC was then performed until volitional exhaustion with the right forearm. Immediately after cessation of the exercise, PPT was reassessed in both the right and the left forearms in an alternating fashion with approximately 30 s separating each assessment.

Assessment of PPT. An FDIX Force One Pressure Algometer (Wagner Instruments, Greenwich, CT) with a circular rubber tip (1 cm in diameter) interfaced with Medoc Algomed software (Medoc Ltd., Ramat Yishai, Israel) was used to assess PPT. Assessments were performed over the belly of the flexor carpi radialis muscle of both forearms. Participants were seated in a comfortable chair with the arm extended in front of them and resting on a solid, flat surface. Three marks were placed approximately 1 inch apart over the belly of the muscle to ensure similar algometer placement before and after isometric exercise. Applied pressure was increased in a linear manner at ~60 $kPa \cdot s^{-1}$ until the

participant indicated when the stimulus became painful (defined as the point at which the applied pressure "hurt") by pressing a handheld button that stopped data collection and marked the pressure value. Three trials were performed in each forearm before and after exercise, and the two assessments closest to each other were averaged as the criterion value for PPT.

Isometric exercise. A handgrip dynamometer (TSD121C; Biopac, Goleta, CA) was used to perform isometric handgrip exercise. Participants were seated upright in a comfortable chair with the hips and knees at ~90° of flexion with their feet on the floor. The rested their elbow and forearm on a padded brace with the elbow at ~90° of flexion. Initially, three MVC were performed by squeezing the hand dynamometer as forcefully as possible for approximately 3 s. Three minutes of rest were provided between attempts. The highest value was taken as their MVC and used to calculate the target force for the fatiguing exercise. Participants then held 50% of their MVC until volitional exhaustion, which was defined as a drop of force of more than 10%. Visual feedback of the force tracing and strong verbal encouragement were provided.

Data processing. All participants wore a triaxial GT3X+ accelerometer (ActiGraph) on the hip to objectively measure PA over seven consecutive days. Participants were instructed to wear the device during all waking hours, except when showering, swimming, or bathing. Standard accelerometry inclusion criteria consisted of at least 10 h of valid wear time per day for a minimum of three weekdays and one weekend day (40). Accelerometer data (in 1-s epochs) were processed using the validated Sojourn-3 Axis method, which uses an artificial neural net to identify boundaries between activities of different intensities and estimates METs for each bout (28). To calculate minutes spent in different intensity categories of PA, estimated METs were determined for each bout interval and were then separated into PA categories accordingly: <1.5 METs = sedentary, 1.5–2.99 METs = light, 3–5.99 METs = moderate, and >6 METs = vigorous. Consistent with current public health recommendations for aerobic PA, total minutes spent in MVPA in bouts of 10 min or greater were used to determine whether the participant met the 150 min of MVPA recommendation (13).

Statistical analysis. Statistical analysis was performed using SPSS (IBM, Armonk, NY) 19.0. A 4 (activity group) × 2 (before and after isometric exercise) × 2 (right/left forearm) mixed-factorial ANOVA was used to examine differences among groups for PPT in each forearm. A one-way ANOVA was performed to examine group differences in scores on each dimension of the POMS; STAI; PCS; PAQ-R; average minutes spent each day performing sedentary, light, moderate, and vigorous activity; and total minutes of moderate- and vigorous-intensity activity that counted toward meeting ACSM guidelines. Main effects were only examined in the absence of a significant interaction. All *post hoc* comparisons (main comparisons and simple comparisons) were performed using a Bonferroni correction for multiple comparisons. Further analysis was performed by collapsing all 50 participants into two groups based solely on their accelerometer data: 1) those who met ACSM guidelines for aerobic PA (MR) and 2) those who were insufficiently aerobically active. A 2 (activity group) × 2 (before and after isometric exercise) × 2 (right/left forearm) mixed factorial ANOVA was used to examine differences among groups for PPT in each forearm. Independent *t*-tests were used to compare each dimension of the POMS; STAI; PCS; PAQ-R; average minutes spent each day performing sedentary, light, moderate, and vigorous activity; and total minutes of activity that counted toward meeting ACSM guidelines. Bivariate relationships among PA data, percent changes in PPT (calculated as $[(PPT_{post} - PPT_{pre})/PPT_{pre}] \times 100$), and self-reported psychological measures were examined by calculating a Spearman ρ correlation coefficient. Effect sizes were calculated as a Cohen's *d* statistic as the difference in means divided by the pooled standard deviation of the means. As a general guideline, effects of ~0.20 are judged to be small, ~0.50 are judged to be moderate, and ≥0.80 are judged to be large. Statistical significance was set *a priori* at $\alpha < 0.05$.

RESULTS

PA levels. Objectively measured PA data are presented in Table 1. Accelerometer wear time did not differ among the four activity groups ($P = 0.49$). No differences in measured time spent per day being sedentary ($P = 0.15$) or engaged in light ($P = 0.37$) PA were found among groups. Time spent performing moderate-intensity PA each day was reduced in AERO + RT ($P = 0.021$), RT ($P = 0.001$), and IA ($P < 0.001$) compared with the AERO group. Time spent performing vigorous-intensity PA each day was significantly reduced in RT ($P < 0.001$) and IA ($P < 0.001$) compared with the AERO and AERO + RT groups. No differences were observed between the AERO and the AERO + RT groups ($P = 0.75$). Total PA per week that counted toward meeting the aerobic ACSM recommendations was reduced in the RT ($P < 0.001$) and IA ($P < 0.001$) compared with the AERO and the AERO + RT groups. No differences were observed between the AERO and the AERO + RT groups ($P = 0.49$).

When data were collapsed into 2 PA groups (meets aerobic recommendations and IA), no differences were observed for wear time ($P = 0.91$) or time spent performing light-intensity PA ($P = 0.44$). The IA group spent more time being sedentary ($P = 0.045$), and less time performing moderate ($P < 0.001$) and vigorous PA ($P < 0.001$), and accrued less PA that counted toward meeting the ACSM guidelines ($P < 0.001$).

Psychological measures. Self-reported data from the STAI, POMS, PCS, and PAQ-R are shown in Table 2. State anxiety did not differ among the four PA groups ($P = 0.07$), nor did trait anxiety ($P = 0.31$). No differences were observed among groups on the six dimensions of the POMS ($P \geq 0.11$). PCS scores did not differ among groups ($P = 0.65$), nor did scores on the PAQ-R ($P = 0.12$). When collapsed into 2 PA groups, no differences were observed between those meeting

TABLE 1. Objectively measures PA.

Measure	AERO (n = 11)	AERO + RT (n = 16)	RT (n = 8)	IA (n = 15)	MR (Collapsed) (n = 27)	IA (Collapsed) (n = 23)
Wear time (min·d^{-1})	895.9 ± 115.9	864.0 ± 60.0	852.6 ± 48.4	886.4 ± 46.7	877.0 ± 86.6	874.7 ± 49.0
Sedentary (min·d^{-1})	641.7 ± 124.9	653.4 ± 50.1	669.1 ± 69.8	705.1 ± 51.1	648.6 ± 86.5	692.6 ± 59.3***
Light (min·d^{-1})	152.1 ± 40.5	128.3 ± 32.7	131.8 ± 42.7	128.1 ± 39.1	138.0 ± 37.2	129.4 ± 39.5
Moderate (min·d^{-1})	62.9 ± 15.1	48.1 ± 11.8*	39.0 ± 12.2*	39.3 ± 10.2*	54.1 ± 14.9	39.2 ± 10.7***
Vigorous (min·d^{-1})	39.1 ± 11.7	34.0 ± 8.4	12.6 ± 5.6**	13.8 ± 6.6**	36.1 ± 10.0	13.4 ± 6.2***
PA for guidelines (min·wk^{-1})	271.9 ± 89.5	225.8 ± 76.2	56.3 ± 38.6**	69.8 ± 41.2**	244.6 ± 83.5	65.1 ± 39.9***

Values are presented as mean ± SD.
AERO, met the ACSM aerobic PA recommendations; AERO + RT, met the ACSM aerobic PA recommendations plus resistance training; RT, did not meet aerobic guidelines, but performed resistance training; MR (Collapsed), all participants who met ACSM PA recommendations; IA (Collapsed), all participants who did not meet the ACSM aerobic guidelines.
*Significant difference from "AERO" ($P < 0.05$).
**Significant difference from "AERO" and "AERO + RT" ($P < 0.05$).
***Significant difference from MR ($P < 0.05$).

ACSM recommendations and those who were IA on state and trait anxiety ($P \geq 0.31$). Scores on the POMS subscales for tension, anger, fatigue, vigor, and depression did not differ between the MR and the IA groups ($P \geq 0.11$). However, the IA group reported higher scores on the confusion subscale ($P = 0.04$) compared with the MR group. Scores on the PCS ($P = 0.50$) and PAQ-R ($P = 0.06$) also did not differ between groups.

PPT and EIH. Time to exhaustion during isometric handgrip exercise did not differ among the four PA groups ($P = 0.10$). Time to exhaustion was 200 ± 161, 118 ± 54, 104 ± 37, and 151 ± 85 s for the AERO, AERO + RT, RT, and IA groups, respectively. When collapsed into two groups, time to exhaustion did not differ ($P = 0.54$) between the MR (151 ± 116 s) and the IA (134 ± 75 s) groups.

The three-way interaction among forearm, time, and PA group was not significant ($P = 0.51$). The two-way interactions between forearm and time ($P = 0.85$), time and PA group ($P = 0.82$), and forearm and PA group ($P = 0.88$) also were not significant. There was no main effect for forearm ($P = 0.97$), nor was there a main effect for PA group ($P = 0.07$). A significant main effect for time ($P < 0.001$) was found with PPT values being elevated after isometric exercise (Fig. 1). PPT in the right forearm increased 10% ($d = 0.31$ SD), 6% ($d = 0.15$ SD), 8% ($d = 0.15$ SD), and 9% ($d = 0.20$ SD) in the AERO, AERO + R, RT, and IA groups, respectively. In the left forearm, PPT increased 4% ($d = 0.12$ SD), 9% ($d = 0.22$ SD), 9% ($d = 0.22$ SD), and 7% ($d = 0.17$ SD) in the AERO, AERO + R, RT, and IA groups, respectively. A similar pattern was found when the PA groups were collapsed into only MR and IA groups. The three-way interactions among forearm, time, and PA group were not significant ($P = 0.91$). Neither were the two-way interactions between forearm and time ($P = 0.89$), time and PA group ($P = 0.63$), and forearm and PA group ($P = 0.60$). There was no main effect for forearm ($P = 0.91$) nor for PA group ($P = 0.26$). A significant main effect for time ($P < 0.001$) was found with PPT values being elevated after isometric exercise (Fig. 2). PPT in the right forearm increased 8% ($d = 0.18$ SD) and 8% ($d = 0.18$ SD) in the MR and IA groups, respectively. In the left forearm, PPT increased 9% ($d = 0.17$ SD) and 8% ($d = 0.16$ SD) in the MR and IA groups, respectively.

Bivariate correlations. Spearman correlation coefficients are displayed in Table 3. Resting and postexercise PPT values between each forearm were highly correlated ($P < 0.01$). Sedentary time was negatively correlated with light-intensity ($P < 0.01$) and moderate-intensity ($P < 0.01$) PA. Positive correlations were found among light- and moderate-intensity PA ($P < 0.01$), moderate- and vigorous-intensity PA ($P < 0.01$), and between moderate-intensity ($P < 0.01$) and vigorous-intensity ($P < 0.01$) PA and time spent each week engaged in PA counting toward meeting the ACSM guidelines. Interestingly, vigorous-intensity PA was negatively correlated with resting PPT in the left forearm ($P < 0.05$) and postexercise PPT in both the right and the left forearms ($P < 0.05$)—indicating those engaging in greater vigorous PA had lower values for PPT.

DISCUSSION

The primary novel finding of the present study was that the amount and type of daily PA did not influence endogenous pain inhibition after isometric handgrip exercise in

TABLE 2. Self-report psychological variables.

Measure	AERO (n = 11)	AERO + RT (n = 16)	RT (n = 8)	IA (n = 15)	MR (Collapsed) (n = 27)	IA (Collapsed) (n = 23)
STAI state	25.4 ± 4.5	32.0 ± 9.0	26.8 ± 3.2	33.0 ± 11.0	29.3 ± 8.1	30.8 ± 9.5
STAI trait	29.1 ± 5.7	33.0 ± 9.3	31.3 ± 4.0	35.2 ± 10.1	31.4 ± 8.1	33.8 ± 8.6
POMS tension	2.3 ± 2.1	3.8 ± 3.1	2.3 ± 2.6	5.5 ± 4.5	3.2 ± 2.8	4.4 ± 4.2
POMS anger	1.5 ± 1.7	2.8 ± 2.9	2.9 ± 2.3	2.7 ± 2.3	2.2 ± 2.5	2.7 ± 2.2
POMS fatigue	4.6 ± 2.8	4.6 ± 2.2	4.6 ± 3.4	7.3 ± 5.2	4.6 ± 2.5	6.3 ± 4.8
POMS confusion	10.6 ± 2.8	10.2 ± 4.9	12.6 ± 2.4	12.7 ± 3.9	10.4 ± 4.1	12.7 ± 3.4*
POMS vigor	3.5 ± 1.5	3.3 ± 1.5	3.9 ± 1.9	4.2 ± 1.8	3.4 ± 1.5	4.1 ± 1.8
POMS depression	1.4 ± 2.2	1.8 ± 2.4	2.3 ± 1.6	2.7 ± 2.6	1.6 ± 2.3	2.5 ± 2.3
PCS	7.4 ± 6.3	11.1 ± 11.3	11.0 ± 5.7	11.4 ± 8.7	9.6 ± 9.6	11.3 ± 7.6
PAQ-R	67.7 ± 9.4	66.9 ± 12.0	79.1 ± 14.8	71.1 ± 12.1	67.2 ± 10.8	73.9 ± 13.3

Values are mean ± SD.
AERO, met the ACSM aerobic PA recommendations; AERO + RT, met the ACSM aerobic PA recommendations plus resistance training; RT, did not meet aerobic guidelines, but performed resistance training; MR (Collapsed), all participants who met ACSM PA recommendations; IA (Collapsed), all participants who did not meet the ACSM aerobic guidelines.
*Significant difference from MR ($P < 0.05$).

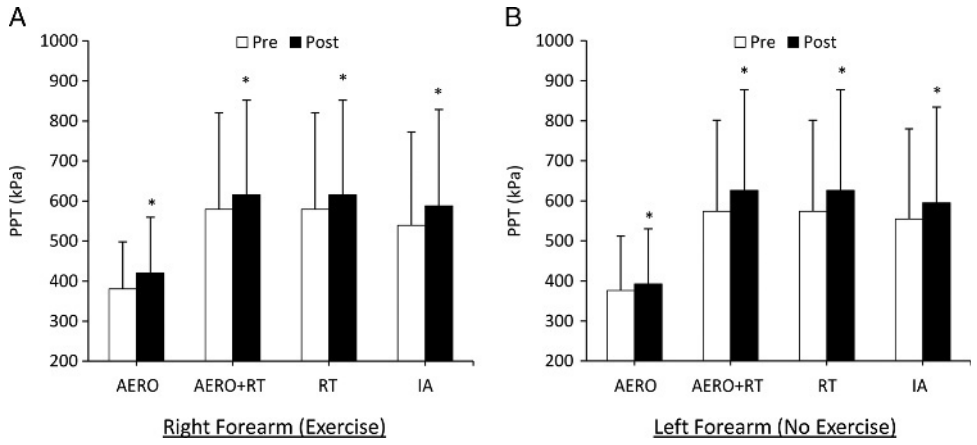

FIGURE 1—PPT before and immediately after isometric exercise in the exercising forearm (A) and resting contralateral forearm (B) among participants who met the ACSM aerobic PA recommendations (AERO); who met the ACSM aerobic guidelines and performed 2 d of resistance training each week (AERO + RT); who did not meet the ACSM aerobic guidelines, performed 2 d of resistance training (RT); and who did not meet the aerobic guidelines and did not perform resistance training (IA). *Significant difference ($P < 0.05$) from preexercise (main effect).

healthy, college-age women. Participants who met current ACSM recommendation guidelines for PA (with and without performing resistance training) performed nearly three times as much vigorous PA each day than their counterpart who did not meet ACSM recommendations. In addition, participants in the AERO and AERO + RT groups accumulated almost four times as much PA that counted toward meeting the ACSM recommendations (i.e., occurred in bouts of at least 10 min) as participants in the RT and IA groups. Despite the marked difference in PA among the groups, the EIH response to isometric handgrip exercise was similar among the four PA groups in both the right (exercising) and the left forearms. Correlational analyses suggested positive relationships between moderate and vigorous-intensity daily PA and total PA counting toward ACSM recommendations. In contrast to previous findings (1,10), a negative relationship was found between vigorous-intensity PA and forearm PPT values, with individuals who performed greater vigorous PA having lower absolute values for PPT during and after isometric exercise.

Limited evidence exists examining the role of PA in endogenous pain modulation. Greater self-reported total and vigorous PA (34) was shown to be related to a larger pain inhibitory response through CPM response (34). Similarly, a recent study found that men and women who accumulated at least 150 min of PA each week, assessed via accelerometry, demonstrated a greater CPM response than those who did not accumulate 150 min of PA (42). Greater CPM has also been observed in triathletes compared with nonathlete controls (11). However, only scant evidence on role of PA in the EIH response exists with a single study demonstrating that reduced self-reported leisure time PA moderated the reduced EIH response seen in African Americans compared with non-Hispanic Whites (41). To our knowledge, our study was only the second to use accelerometers to objectively assess PA concomitant to a measure of endogenous pain inhibition and was the first to consider both aerobic and resistance activity. On the basis of the previous findings for CPM (11,34,42) and the Umeda et al. (41) study for EIH, we hypothesized that

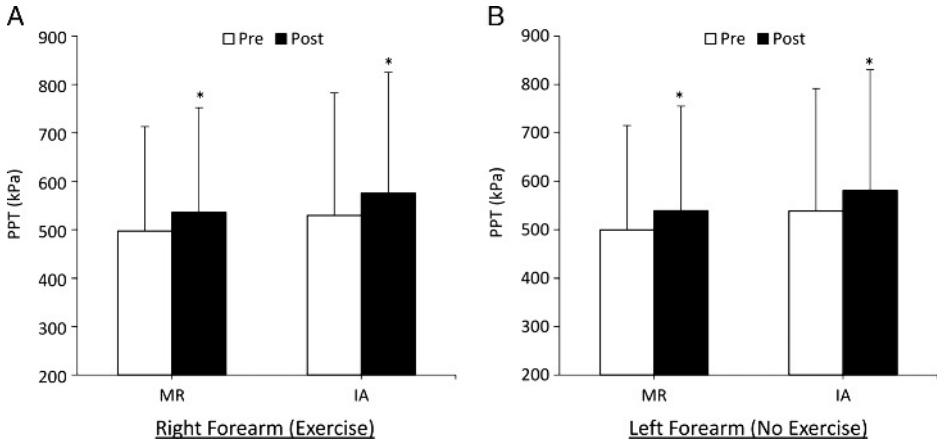

FIGURE 2—PPT before and immediately after isometric exercise in the exercising forearm (A) and resting contralateral forearm (B). PA data were collapsed into those who met the ACSM aerobic PA recommendations ($n = 27$; MR) and those who did not meet ACSM aerobic guideline ($n = 23$; IA). *Significant difference ($P < 0.05$) from preexercise (main effect).

TABLE 3. Spearman correlation matrix among PA and pain measures.

	Resting PPT Right	Resting PPT Left	Post-Ex PPT Right	Post-Ex PPT Left	% EIH Right	% EIH Left	Sedentary Time	Light PA	Moderate PA	Vigorous PA	ACSM Rec Time	PCS	PAQ-R
Resting PPT right	1.00												
Resting PPT left	0.92**	1.00											
Post-Ex PPT right	0.95**	0.93**	1.00										
Post-Ex PPT left	0.91**	0.96**	0.93**	1.00									
% EIH right	−0.42*	−0.31	−0.20	−0.26	1.00								
% EIH left	−0.10	−0.19	−0.07	0.03	0.16	1.00							
Sedentary time	0.02	−0.04	−0.01	−0.10	0.07	0.11	1.00						
Light PA	0.03	0.04	0.06	0.03	−0.06	−0.04	−0.54**	1.00					
Moderate PA	−0.11	−0.12	−0.14	−0.16	0.04	−0.17	−0.33**	0.55**	1.00				
Vigorous PA	−0.25	−0.34*	−0.29*	−0.31*	−0.05	0.02	−0.20	0.17	0.49**	1.00			
ACSM rec time	−0.22	−0.30*	−0.27	−0.30	−0.03	−0.06	−0.26	0.20	0.57**	0.92**	1.00		
PCS	−0.05	−0.01	−0.10	−0.06	−0.16	0.05	−0.04	−0.03	0.01	−0.10	−0.11	1.00	
PAQ-R	0.10	0.12	0.13	0.18	0.08	0.22	0.14	−0.09	−0.22	0.26	−0.20	−0.16	1.00

*Significant correlation ($P \leq 0.05$).
**Significant correlation ($P \leq 0.01$).

greater total and vigorous PA would be associated with a greater EIH response. Surprisingly, no differences were found among our four activity groups, and neither PA, regardless of intensity, or sedentary time was associated with the magnitude of EIH. It is difficult to directly compare our findings with previous studies given the differences in age, sex, and noxious stimuli used. However, one possible explanation for our lack of an effect of PA was that despite not accumulating enough PA to meet the ACSM recommendations, participants in the IA + RT and IA groups did engage in approximately 13 min of vigorous PA each day—even if it did not occur in bouts of at least 10 min and, as such, did not count toward meeting the PA recommendations. Ellingson et al. (10) found that women who met weekly PA recommendations reported reduced ratings of pain intensity and unpleasantness compared with women who were IA, and that a negative association existed between pain ratings and vigorous PA. Ellingson's participants who met PA recommendations averaged 16 min of vigorous PA each day, similar to the 13 $\text{min}\cdot\text{d}^{-1}$ of the women who were IA in the present study. It is possible that there is a threshold level of vigorous PA that is associated with a reduction in pain sensitivity, and below which pain sensitivity and endogenous pain modulation is not affected. Future studies examining a dose response of vigorous PA on the EIH could provide important insights in this area.

A second possible explanation for the lack of effect of PA on EIH in the present study is related to age. There is evidence EIH may decline with age (26,33). The mechanisms underlying this decline remain unresolved and are likely the consequence of multiple factors such as age-related declines in CPM (27), reduced release of endocannabinoids (3), and/or reduced release of endogenous opioids (31). Our participants were for the most part young, college-age women (mean age of ~22 yr old) with only 7 of 50 participants older than 25 yr old. PA tends to decline with age (40), and it is possible that age-related decline in PA, especially vigorous PA, plays some role in the age-related decline in endogenous pain modulation (33). In this way, we hypothesize that age and decreased PA levels may work in concert to lead to altered EIH responses. Data from Ellingson et al. (10) and Naugle et al. (34) support this hypothesis and suggests that increased PA may help to preserve endogenous pain modulation at least into middle age. We did not collect data regarding the PA levels of participants as children and adolescents in the present study. However, given the mean age of our participants and the fact that our RT and IA groups were still more active than those tested in previous studies (10), it is plausible our participants had not been inactive for a long enough period to impair their endogenous pain inhibitory pathways.

Although not widely studied, there is evidence linking PA levels to pain sensitivity. Greater amounts of vigorous PA have been shown to lead to higher PPT values (1) and lower ratings of intensity and unpleasantness to suprathreshold thermal stimuli (10). Aerobic exercise training also has been shown to lead to greater tolerance of ischemic pain (16) and to the application of pressure (2) in previously untrained men. In the present study, no difference was found among the AERO, AERO + RT, RT, and IA groups for absolute values of PPT in either the right or left forearm. When data were collapsed into two groups (MR and IA only), again no difference was observed despite the large differences between the groups in vigorous and total PA. Interestingly, a significant negative relationship between vigorous PA, total ACSM PA, and PPT was observed in the present study. Mechanistically, it is unclear why this occurred, and the study was not specifically designed to answer this questions. Multiple factors could plausibly contribute to our more active participants having lower PPT. Although not measured, differences in subcutaneous fat (e.g., if our more active participants had lower levels of subcutaneous fat) over the forearms could contribute this finding. Although no differences were observed among groups for pain catastrophizing or on the PAQ, it is possible that psychological factors and previous pain experiences also could have contributed to our findings. Andrzejewski et al. (1) demonstrated higher PPT across a host of anatomical locations in individuals who engaged in greater amounts of vigorous PA, but the study fails to report the sex of its participants—stating simply participants were university students. If men were include in the sample then a comparison to our study, which consisted of only college-age women, is difficult. Certainly, further study in

this area accounting for additional anatomical and psychological factors could provide more definitive evidence of the role of PA in sensitivity to pressure stimuli. In addition, given the relatively small number (n = 8) of participants in the RT group, further study with a larger sample would allow for more definitive conclusions on the potential role resistance training may/may not play in altering endogenous pain inhibition.

In summary, the present study showed that endogenous pain inhibition after an acute bout of isometric handgrip exercise did not differ among college-age women who engaged in different levels and types of PA. An inverse relationship was found between levels of vigorous-intensity PA and forearm PPT. These findings are in contrast to several previous studies and further demonstrate the complex interaction that may exist between PA and pain processing.

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