General Section
Research Paper

OPEN

PAIN REPORTS

Physical activity, sitting time, and thermal quantitative sensory testing responses in African Americans

Felicitas A. Huber[a,b,*], Rachel Carpenter[a], Burel R. Goodin[b], Stephen Bruehl[c], Cynthia Karlson[a], Uma Rao[d,e], Kerry Kinney[a], Subodh Nag[f], Matthew C. Morris[a,c]

Abstract

Introduction: Prior research suggests that African Americans (AAs) have more frequent, intense, and debilitating pain and functional disability compared with non-Hispanic Whites (NHWs). Potential contributing factors to this disparity are physical activity and sedentary behavior, given that AAs are less physically active, and physical activity is associated with antinociception (whereas sedentary behavior is linked to pronociception). However, impact of these factors on pain processing has largely been unexplored in AAs, especially before chronic pain onset.

Objective: This study examined relationships between physical activity, sedentary behavior (sitting time), and laboratory measures of pain and pain modulation in adult AAs. These included heat pain threshold and tolerance, temporal summation of pain (TSP, a marker of central sensitization), and conditioned pain modulation (CPM, a marker of descending pain inhibition).

Methods: Multiple regressions were conducted to examine the effects of physical activity and sitting time on heat threshold and tolerance. Multilevel models were conducted to assess the relationship between physical activity, sitting time, and temporal summation of pain. Additional multilevel models were conducted to assess the relationship between physical activity, sitting time, and conditioned pain modulation.

Results: Higher level of physical activity, but not sitting time, was associated with reduced TSP slopes. Neither physical activity nor sitting time was associated with CPM slopes. No significant relationships between physical activity or sitting time and heat pain threshold or tolerance were detected.

Conclusions: These findings suggest that physical activity is associated with reduced TSP, an effect which may be driven by reduced spinal hyperexcitability in more active individuals. Thus, structural and individual interventions designed to increase physical activity in healthy, young AAs may be able to promote antinociceptive processes (ie, reduced TSP/reduced pain facilitation) potentially protective against chronic pain.

Keywords: African Americans, Physical activity, Sedentary behavior, Pain modulation, Quantitative sensory testing

1. Introduction

Over 100 million Americans suffer from chronic pain, a serious public health issue estimated to cost $261 to 300 billion annually.[57] Significant physical, psychological, and socioeconomic effects of chronic pain include sleep disturbance,[1] mood disorders,[65] and reduced work productivity.[28] Although all racial groups experience chronic pain, there are differences in the perception, experience, and impact of pain across groups. African Americans (AAs) experience a greater burden of pain, including more frequent, intense, and debilitating pain severity and functional disability compared with non-Hispanic Whites

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

[a] Department of Psychiatry and Human Behavior, University of Mississippi Medical Center, Jackson, MS, USA, [b] Department of Anesthesiology, Washington University Pain Center, Washington University School of Medicine, St. Louis, MO, USA, [c] Department of Anesthesiology, Vanderbilt University Medical Center, Nashville, TN, USA, [d] University of California at Irvine, Irvine, CA, USA, [e] Children's Hospital of Orange County, Orange, CA, USA, [f] Department of Biochemistry, Cancer Biology, Neuroscience and Pharmacology, Meharry Medical College, TN, Nashville, USA

**Corresponding author. Address: Department of Psychiatry and Human Behavior, University of Mississippi Medical Center, 2500 North State St, Jackson, MS 39216. Tel.: (912) 323 2682. E-mail address: feh9986@utulsa.edu (F. A. Huber).*

PR9 8 (2023) e1118

http://dx.doi.org/10.1097/PR9.0000000000001118

(NHWs).[1,25,35] Differences in socioeconomic status (SES),[26] racial discrimination,[72] neighborhood disadvantage,[53] rates of posttraumatic stress disorder,[22] and other mental health conditions[4] are commonly cited explanations for these chronic pain disparities, but other potentially relevant factors such as physical activity levels are less explored.

Lower levels of physical activity may be an important driver of pain disparities affecting AAs. African Americans show lower levels of physical activity compared with NHWs[46,56,67] and report fewer opportunities to engage in physical activity due to structural factors (eg, fewer safe, walkable neighborhoods, and gyms).[53] Physical activity is known to improve a host of chronic pain outcomes including pain severity,[5] sleep,[29] cellular inflammation,[60] and quality of life.[20] In addition, physical activity reduces the rates of other adverse health conditions such as hypertension and cardiovascular disease.[19] Thus, physical activity may be particularly important in mitigating high-impact chronic pain[20,44] and may even protect against chronic pain. Conversely, sedentary behavior may have a pronociceptive effect and increase chronic pain risk.

Previous research suggests that physical activity is associated with antinociceptive mechanisms, whereas sedentary behavior is associated with pronociceptive mechanisms.[31] First, the literature on pain processing in athletes demonstrates higher pain tolerance for professional athletes compared with nonathletes.[62] Second, prolonged sitting has been associated with higher prevalence of lower back pain in a nationally representative sample of >7000 Korean adults.[42] Third, higher physical activity has been associated with reduced chronic pain risk on 2 pain vulnerability markers: temporal summation of pain (TSP) and conditioned pain modulation (CPM).[40,41] However, such associations have focused largely on NHWs and have not been systematically explored in AAs. In addition, greater physical activity is not consistently associated with all QST outcomes (less facilitation and more inhibition as reflected in TSP and CPM, respectively), necessitating further examination.[31]

Temporal summation of pain occurs when a painful stimulus is repeatedly administered at the same intensity, with <3 seconds interstimulus intervals, and perceived pain intensity increases across the stimulus series.[15] This pain "summation" is thought to reflect hyperexcitability in spinal nociceptive neurons and captures pain facilitation mechanisms associated with central sensitization, a salient contributor to chronic pain.[15,61,69] Conditioned pain modulation is a "pain inhibits pain" task in which pain experienced in response to a test stimulus is reduced through contemporaneous application of a second conditioning stimulus applied distally.[32] Greater reduction in pain ratings is thought to reflect more efficient CPM and greater descending inhibition. This type of pain inhibition is mediated through brain to spinal cord circuitry (ie, periaqueductal gray–rostral ventral medulla connections to the spinal cord). Less efficient pain inhibition during a CPM task is associated with the development of chronic postsurgical pain and has been demonstrated in individuals with existing chronic pain conditions.[70,71]

In sum, previous research has found that decreased pain inhibition and increased pain facilitation play significant roles in conferring chronic pain risk. Physical activity may buffer against chronic pain risk by enhancing antinociceptive processes in the ascending (ie, TSP) and descending (ie, CPM) modulatory pathways. Conversely, sedentary behavior may increase chronic pain risk through pronociceptive mechanisms. Thus, it was hypothesized that greater physical activity and less sedentary behavior would be associated with lower TSP and greater CPM. Finally, to assess whether physical activity and sedentary behavior would be associated with increased overall pain sensitivity, relationships with heat pain threshold and tolerance were also examined.

2. Methods

2.1. Participants

This study used baseline data from a larger ongoing longitudinal study examining the relationship between adversity and pain in healthy AA adults without chronic pain. Exclusion criteria were age (younger than 18 years or older than 45 years due to parent study requirements), chronic pain (ie, reporting clinically significant pain daily/almost daily for past 3 months[6]), medical conditions affecting the central nervous system (eg, Cushing, hyperthyroidism), medications affecting the pain or stress response, and meeting criteria for substance use disorder within 3 months (assessed through Structured Clinical Interview for DSM-V [SCID]).[18]

2.2. Procedure

On arrival at the laboratory, participants provided verbal and written informed consent and the experimenter gave an overview of procedures. Next, exclusion criteria were assessed, the numerical rating scale was explained (NRS: 0 = no pain, 100 = worst pain possible), and participants were instructed on how to rate pain during procedures. The quantitative sensory testing (QST) protocol was identical to one used previously.[36,38] Thermal stimuli were delivered through a computerized Medoc TSA-II NeuroSensory Analyzer (Medoc US, Minneapolis, MN) using commercially available software (TPS-CoVAS version 3.19; Medoc Inc, Ramat Yishay, Israel). Order of testing was as follows: heat pain threshold, heat pain tolerance, TSP, and CPM. All tasks were practiced before testing commenced. Questionnaires were administered at the end of the testing session using a research electronic data capture system (REDCap).

Thermode heat stimuli were always applied to the nondominant volar forearm. For assessment of heat pain threshold, participants were instructed to press a button as soon as the heat stimulus first became painful (starting temperature: 32°C, ramp rate: 0.5°C/second). For assessment of heat pain tolerance, participants were instructed to press the button when they could not stand the pain from the heat any longer (starting temperature was 40°C, ramp rate of 0.5°C/second). For both threshold and tolerance, 4 trials were administered and thermode was moved slightly in between trials. For TSP, a sequence of 10 heat pulses with a 48°C target stimulus intensity was delivered. Each pulse was 0.5 seconds in duration and started at a temperature of 40°C, with sequential pulses administered at a frequency of 0.4 Hz. Participants were instructed to rate the NRS pain intensity shortly after the peak of each heat pulse. For CPM, the Pain-60 temperature (P60) for use as the test stimulus was determined first: thermode temperature was set at 45°C and adjusted until a pain rating of 60/100 was achieved.[36] Next, the 2 phases of the CPM task were administered. For the test phase, the P60 test stimulus was administered for 3 trials of 30 seconds each (10 seconds ITIs), with NRS ratings obtained after each trial. In the conditioning phase, 3 trials of 30 seconds were again administered, while participants also experienced the conditioning stimulus (submerging dominant hand in a hot 46.5°C water bath; Boekel General Purpose Water Bath, Boekel Scientific, Feasterville, PA).[37,39] NRS ratings of test stimulus pain were obtained after each trial.

2.3. Measures

2.3.1. International physical activity questionnaire short form

The international physical activity questionnaire (IPAQ) is a self-report measure capturing the levels of physical activity among adults.[10] Three specific types of activity are assessed: walking, moderate-

intensity activities, and vigorous-intensity activities. Scoring followed the IPAQ protocol (available online at https://sites.google.com/view/ipaq/score). Responses of less than 10 minutes were set to 0 (applied to 2 participants' data). Then, total physical activity in minutes per week was calculated (walk + moderate + vigorous activity in min total), and activities of greater than 180 were recoded to 180 minutes. The "number of days" variables were examined to ensure no participant had entered a value > 7.

Consistent with the IPAQ scoring manual, groups were formed based on energy requirement defined in METs (ie, metabolic equivalent of a task) multiplied by minutes performed. Specifically, each type of activity (walking, moderate, and vigorous activity) has a MET energy expenditure estimate. Reported time spent in minutes for each activity was multiplied by its MET value, so a total MET-min/week value across activities was estimated to derive physical activity groups representing low, moderate, and high activity levels (according to standard IPAQ scoring instructions). The continuous MET-min/week variable was not used for analyses due to significant positive skew that remained after applying corrective transformations (ie, outlier correction, log transformation).

2.3.2. Sedentary behavior (sitting time)

To measure sedentary behavior, participants were asked to estimate their time spent sitting per day. Response options included number of hours and minutes. Sitting time was normally distributed. Therefore, this variable was included as a continuous variable in analyses.

2.3.3. Pain intensity during temporal summation of pain and conditioned pain modulation tasks

Participants rated perceived pain intensity on a numeric rating scale ranging from 0 (no pain) to 100 (worst pain possible).

2.3.4. Control variables

Age, sex, and years of education were assessed using a brief demographic questionnaire. Given established sex differences in pain processing[50] as well as known associations between age, sex, education, and chronic pain,[11,27] these variables were included as control variables.

2.4. Analysis plan

All variables were first examined for non-normality. Outliers were identified using Wilcox MAD–median procedure[66] with a threshold of 2.24[52] and then winsorized to the nearest neighbor value before analysis (age, years of education, and sitting time were winsorized). The criterion for significance was set at $\alpha = 0.05$ (2-tailed) for all analyses. Previous literature on physical activity and QST showed associations in the moderate to strong range.[21,40,41,54] Using the lowest value for power calculation ($f^2 = 0.16$, based on Ref. 54), a sample of $N = 52$ would provide a power of 0.80 at 0.05 (2-tailed). Our sample consisted of 129 participants.

2.4.1. Preliminary analyses

First, the relationship between physical activity and sitting time was examined to determine whether both variables should be included in the same model. A 2 (sex) $\times$ 3 (physical activity group) ANCOVA assessing the relationship between physical activity and sitting time was conducted, controlling for age and years of education.

2.4.2. Heat pain threshold and tolerance

For analyses of pain threshold and tolerance, the mean of the last 3 trials was used. For each heat pain threshold and tolerance analysis, a multiple regression was conducted including physical activity, sitting time, age, years of education, and sex. Physical activity was dummy coded before analyses.

2.4.3. Temporal summation of pain

Multilevel models were conducted in HLM v. 8[47] to assess the relationship between physical activity (level 2), sitting time (level 2), and within-person changes in pain ratings across the 10 heat pulses (level 1) during TSP. Preliminary analyses showed an initial increase in pain ratings during the train of stimuli which captures sensitization that occurs during TSP, followed by deceleration in pain ratings. Analyses focused on relations between predictors and the linear TSP slope (entered as linear trend). Age, sex, and years of education were entered as control variables for analysis of initial pain ratings (intercept) and TSP slope. The interaction between physical activity and TSP slope across the pulse series was examined as well as the interaction between sitting time and TSP slope. Significant interactions in all analyses were followed up by probing simple effects.[45]

2.4.4. Conditioned pain modulation

Multilevel models were conducted as above to assess the relationship between physical activity (level 2), sitting time (level 2), and within-person changes in pain ratings across the CPM task (level 1). A decrease in pain ratings from the testing phase (P60 alone) to conditioning phase (P60 + hot water bath) was expected if CPM was successfully elicited. As within-person differences across the pulse series during conditioning have been reported previously,[37] we focused on predicting the CPM slope (ie, the linear trend). A linear trend was created with baseline value at time point 0 (average rating across 3 preconditioning trials of the test phase) and the 3 conditioning trials as time points 1 to 3 (conditioning phase). The interaction between physical activity and CPM slope was examined as well as the interaction between sitting time and CPM slope.

3. Results

3.1. Participants and background characteristics

Of 162 participants enrolled, one was excluded for not meeting age requirements and another was excluded due to chronic pain diagnosis (both revealed after baseline assessment was completed). Three participants did not complete the TSP task (for 2, the maximum pain rating was reached before task completion; 1 participant declined to finish). One participant did not complete the study because of scheduling issues. Twelve participants were excluded because of physical activity scoring issues (ie, entering "I don't know" on key questions). Two participants were excluded due to questionable validity in responding to the "sitting time" question (ie, endorsed 0 time spent sitting). Finally, 13 participants had missing survey data due to experimenter error. This left a total of 129 participants for analysis. In the sample of 129 participants, 79 (61.2%) were female and 50 (31.8%) were male. **Table 1** presents mean and standard deviations (SD) for sample demographic characteristics.

3.2. Physical activity

Group 1 (low activity) averaged 176.78 total MET-min/week (median = 82.50, interquartile range = 396.00, n = 30), group 2

(moderate activity) averaged 1681.23 total MET-min/week (median = 1732.50, interquartile range = 1150.00, n = 41), and group 3 (high activity) averaged 5558.49 total MET-min/week (median = 4297.50, interquartile range = 3589.40, n = 58). See **Figure 1** for distribution of MET-min/week per category.

3.3. Sitting time

On average, participants estimated spending 440.24 minutes per week sitting (median = 420 minutes, interquartile range = 300). **Figure 2** depicts the distribution of sitting time.

3.4. Preliminary analyses (relationship between physical activity and sitting time)

The results from the ANCOVA indicated that there were no significant main effects of physical activity ($F(2,121) = 1.45$, $P = 0.24$, $\eta^2 = 0.023$) or sex on sitting time ($F(1,121) = 0.02$, $P = 0.88$, $\eta^2 < 0.001$). There was also no significant interaction between sex and physical activity on sitting time ($F(2,121) = 2.74$, $P = 0.07$). Given the lack of association between physical activity and sitting time, both were included as predictors in the same model.

3.5. The relationship between physical activity, sitting time, and heat pain threshold and tolerance

In the regression analysis predicting heat pain threshold, the results indicated a nonsignificant model ($F(6,122) = 1.30$, $P = 0.26$) that explained 6% of the variance ($R^2 = 0.06$). Neither physical activity, sitting time, nor any of the control variables emerged as significant predictors (medium activity $\beta = 0.04$, high activity $\beta = 0.02$, sitting time $\beta = 0.06$, sex $\beta = -0.09$, age $\beta = 0.10$, education $\beta = 0.16$).

In the regression analysis predicting heat pain tolerance, the results also indicated a nonsignificant model ($F(6,122) = 2.04$, $P = 0.07$) that explained 9% of the variance ($R^2 = 0.09$). Sex emerged as the only significant predictor ($B = -0.83$, $SEB = 0.29$, $\beta = -0.25$, $P = 0.005$), with male sex being associated with higher heat pain tolerance. Neither physical activity, sitting time, nor any of the control variables emerged as significant predictors (medium activity $\beta = 0.13$, high activity $\beta = 0.04$, sitting time $\beta = 0.11$, age $\beta = 0.001$, education $\beta = 0.07$).

Table 1

Participant demographic characteristics.

Characteristics	M/n	SD/%
Age (y)		
Mean (SD)	25.82	6.27
Range	18–44	
Sex		
Female	79	61.2%
Male	50	38.8%
Hispanic or Latino Heritage		
Non-Hispanic/Latinx	127	98.4%
Hispanic/Latinx	2	1.6%
Marital status		
Single	110	85.3%
Married	13	10.1%
Cohabitating	6	4.7%
Employment		
In school	59	45.7%
<40 h/wk	24	18.6%
≥ 40 h/wk	38	29.5%
Unemployed	3	2.3%
Education		
High school/GED	49	38%
Vocational/technical degree	2	1.6%
Associate's degree	5	3.9%
Bachelor's degree	38	29.5%
Graduate degree	35	27.1%

3.6. The relationship between physical activity, sitting time, and temporal summation of pain

Table 2 and **Figure 3** present the results of multilevel modeling analysis of TSP. The results revealed a significant TSP slope, indicating a significant TSP effect over time across groups (ie, pain ratings were increasing across pulse series). The interaction between physical activity and TSP slope was significant, indicating that physical activity affected the steepness of the TSP slope. Tests of simple slopes revealed that all groups exhibited TSP; however, groups engaging in greater amounts of physical activity showed reduced TSP slopes (**Fig. 3**; low activity: slope = 2.36, $P < 0.001$, medium activity: slope = 2.14, $P < 0.001$, high activity: slope = 1.91, $P < 0.001$), which is consistent with an association between greater physical activity and reduced pain facilitation.

The interaction between sex and TSP slope was significant as well, indicating that sex affected the extent of TSP. Tests of simple slopes revealed that while both men and women showed TSP, men showed a steeper slope (ie, greater TSP) than women (men: slope = 2.10, $P < 0.001$; women: slope = 1.62, $P = 0.002$). The interaction between age and TSP slope was significant as well: Whereas all age groups showed TSP, greater TSP was observed in younger (slope = 2.76, $P < 0.001$) as compared with older (slope = 2.41, $P < 0.001$) participants.

3.7. The relationship between physical activity, sitting time, and conditioned pain modulation

Table 3 presents the results of a multilevel model predicting CPM. Contrary to expectation, none of the predictors emerged as significant. **Figures 4** and **5** portray the pattern of observed CPM effects. Similar to previous studies,[12,13] some individuals exhibited pain inhibition, whereas others exhibited pain facilitation during the CPM protocol. It is thus unlikely that our results are due to unusual CPM responses in our sample.

4. Discussion

Higher pain facilitation (reflected in TSP) and decreased pain inhibition (reflected in CPM) both significantly contribute to the risk of developing chronic pain.[59] Physical activity may lower the likelihood of developing chronic pain by engaging antinociceptive mechanisms in pain modulatory pathways.[40,41] Conversely, sedentary behavior may raise the risk of chronic pain through pronociceptive pathways. We aimed to explore the relationship between physical activity/sitting time and degree of pain facilitation and pain inhibition in AAs using dynamic QST measures. In addition, given the general lack of research on (in)activity and pain in AAs, pain sensitivity (as measured with static QST) was also examined. Higher levels of physical activity were associated with reduced TSP in AAs. However, greater physical activity was neither associated with elevated CPM nor reduced static pain sensitivity. In addition, contrary to expectation, self-reported sitting time was not associated with TSP, CPM, or static QST.

4.1. Greater physical activity was associated with reduced temporal summation of pain

Consistent with prior literature in predominately White samples,[40,41] greater physical activity was associated with reduced

Table 2

Results of multilevel modeling analysis of temporal summation of pain.

	Estimate	CI	SE	*P*
Fixed effects				
Pain ratings				
Intercept	**63.539**	29.69, 97.39	17.272	**<0.001**
Sex	1.203	−7.37, 9.77	4.372	0.784
Sitting time	−0.024	−0.05, 0.00	0.012	0.048
Age	0.350	−0.42, 1.12	0.392	0.374
Education	−1.203	−2.77, 0.36	0.797	0.134
Physical activity group	−4.022	−9.37, 1.33	2.731	0.143
TSP slope	**2.584**	1.48, 3.69	0.562	**<0.001**
Sex × TSP slope	**−0.481**	−0.74, −0.23	0.130	**<0.001**
Sitting × TSP slope	0.001	0.001, 0	0.0006	0.126
Age × TSP slope	**−0.030**	−0.05, −0.01	0.012	**0.011**
Education × TSP slope	0.016	−0.03, 0.06	0.024	0.499
Physical activity group × TSP slope	**−0.224**	−0.38, −0.07	0.081	**0.006**
Quadratic trend	**−0.148**	−0.20, −0.10	0.025	**<0.001**

Physical activity group based on scoring of the International Physical Activity Questionnaire Short Form; quadratic trend models habituation across pulse series; bolded values are significant.
Confidence Interval: Estimate ± (1.96 × standard error).
CI, confidence interval; Intercept, mean pain rating when predictors are equal to 0, ie, pain rating for first pulse; TSP slope, temporal summation of pain slope.

TSP in this sample of AAs. These findings suggest that being physically active could potentially reduce the risk for chronic pain in AAs, given that greater TSP is predictive of the development of chronic postsurgical pain[43] and is frequently found in chronic pain populations.[34] Temporal summation of pain is thought to capture mechanisms associated with central sensitization, specifically hyperexcitability of spinal nociceptive neurons.[15,49,69] The present findings suggest the possibility that greater physical activity may dampen this spinal hyperexcitability, associated supraspinal signaling, and/or pain perception. Although one can only speculate about potential biological mechanisms that mediate this effect, research on the role of physical activity in aging suggests that physical activity may have anti-inflammatory and antioxidant effects.[16,33,40,58,68] Specifically, physical activity is associated with lower levels of inflammatory markers such as C-reactive protein and IL-6, and regular exercise upregulates antioxidant defense systems[68] that reduce oxidative stress linked to elevated pain.[7] Either of these mechanisms may contribute to the antinociceptive effects of physical activity. Furthermore, TSP is hypothesized to involve N-methyl-D-aspartate (NMDA) receptor activation,[3,23] and animal research shows that regular exercise leads to reduced NMDA receptor phosphorylation.[31,33] Thus, greater physical activity may lead to reduced NMDA receptor activity, ultimately resulting in reduced TSP. More basic science research is needed to clarify the role of these mechanisms in conveying the antinociceptive effects of physical activity.

4.2. Physical activity was not associated with conditioned pain modulation

Surprisingly, physical activity was not associated with CPM, which suggests that physical activity may not improve CPM-associated descending inhibition. This is contrary to previous research which found associations between elevated physical activity and improved pain inhibition.[21,40,41,54] Reasons for these discrepant findings are unclear. Our CPM results may reflect altered associations between physical activity and pain inhibition in AAs, but this could only be addressed in studies directly comparing these associations across racial groups. Another potential explanation for these conflicting results relates to the younger age of our sample (mean age of sample = 25.8 years). Given that CPM efficiency is known to decrease with age,[24] physical activity may be less relevant as a determinant of CPM in younger individuals because their CPM is already efficient. On a speculative note, physical activity may improve CPM inhibition as we age and protect against pronociceptive age-related effects. Indeed, one study of healthy middle-aged participants found that greater physical activity was linked to reduced TSP and greater CPM (mean age: men = 39.28; women = 45.64[41]).

Table 3

Results of multilevel modeling analysis of conditioned pain modulation.

	Estimate	CI	SE	*P*
Fixed effects				
Pain ratings				
Intercept	51.630	26.38, 76.88	12.881	**<0.001**
Sex	0.316	−6.07, 6.70	3.259	0.923
Sitting time	0.005	−0.01, 0.02	0.009	0.564
Age	−0.033	−0.61, 0.54	0.293	0.912
Education	0.118	−1.05, 1.28	0.595	0.843
Physical activity group	0.284	−3.70, 4.27	2.035	0.889
CPM slope	−1.088	−8.28, 6.11	3.670	0.767
Sex × CPM slope	−0.656	−2.47, 1.16	0.928	0.480
Sitting × CPM slope	−0.004	−0.01, 0	0.003	0.104
Age × CPM slope	0.013	−0.15, 0.18	0.084	0.876
Education × CPM slope	0.084	−0.25, 0.42	0.171	0.622
Physical activity group × CPM slope	−1.027	−2.16, 0.11	0.579	0.077

Physical activity group based on scoring of the International Physical Activity Questionnaire Short Form; bolded values are significant.
Confidence Interval Estimate ± (1.96 × standard error).
CI, confidence interval; CPM slope, conditioned pain modulation slope; Intercept, mean pain rating when predictors are equal to 0, ie, average rating across 3 preconditioning trials of phase 1.

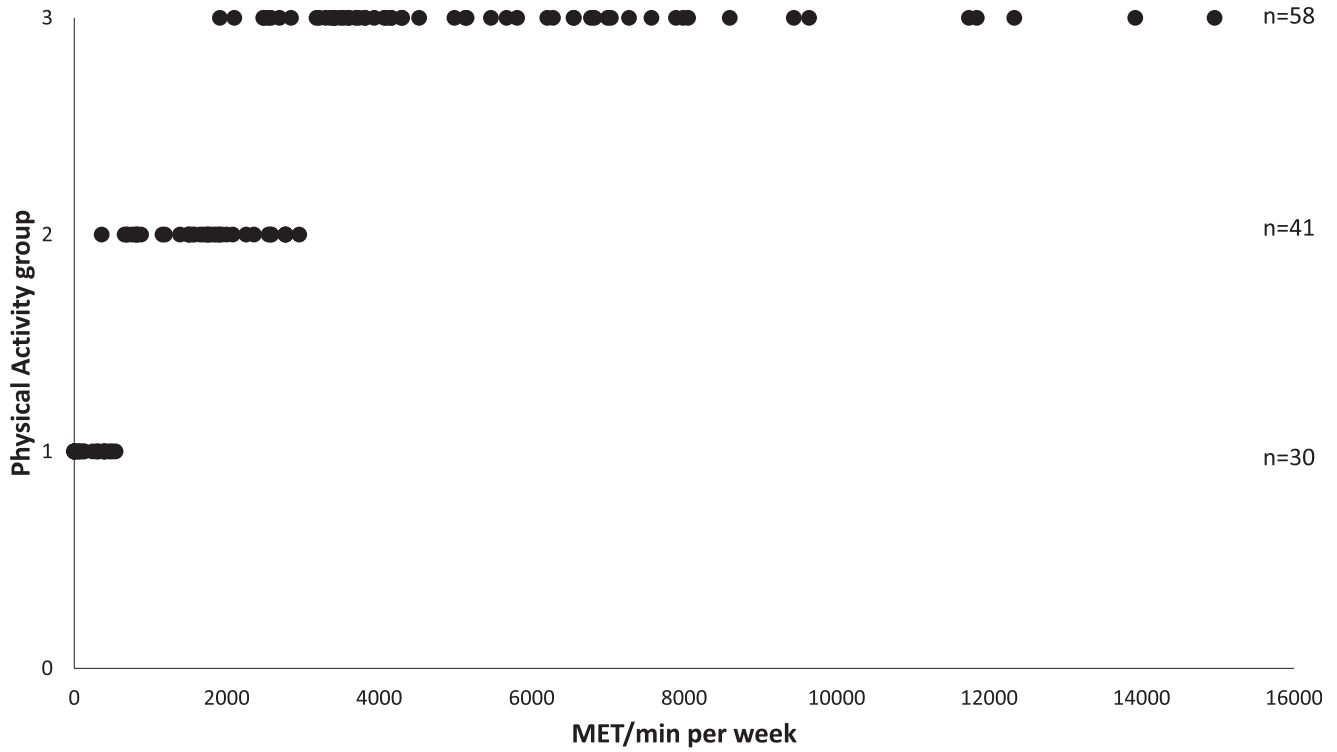

Figure 1. Total MET/min per week for each group (dots represent participants). Physical activity groups based on International Physical Activity Questionnaire Short Form scoring. Physical activity group 1 = low level of activity, group 2 = medium level of activity, group 3 = high level of activity; MET, metabolic equivalent of a task.

Finally, the issue of dose-response effects may be relevant. Athletes have been shown to exhibit improved CPM,[21] perhaps due to improved opioidergic functioning,[48] and our sample may not have been exercising strenuously enough to produce these favorable effects. Prior work does suggest associations between exercise intensity and degree of exercise-related analgesia.[5]

4.3. Sitting time was not associated with temporal summation of pain or conditioned pain modulation

In this study, sitting time was not associated with TSP or CPM. This may be due to how sitting time was measured. Naugle et al.[40] indicated that less sedentary time was associated with better CPM, but sedentary behavior was defined with an accelerometer, not with self-report as in the current work.[40] As sedentary behavior is defined as any waking behavior characterized by an energy expenditure of ≤1.5 metabolic equivalents (eg, watching TV, reading[63]), it is possible that sitting time was not accurately captured by our subjective measure.

Alternatively, it is possible that our sample was not showing enough sedentary behavior to observe deleterious effects on CPM or TSP. Park et al.[42] determined that sitting increases chronic pain risk if individuals sit for more than 7 hours. In our sample, the mean sitting time was exactly 7 hours, potentially indicating that time spent sitting was not high enough to affect pain modulation. Overall, more research is needed on validity of self-reported sedentary behavior measures and whether there is a dose-dependent effect of sitting time on pain modulation.

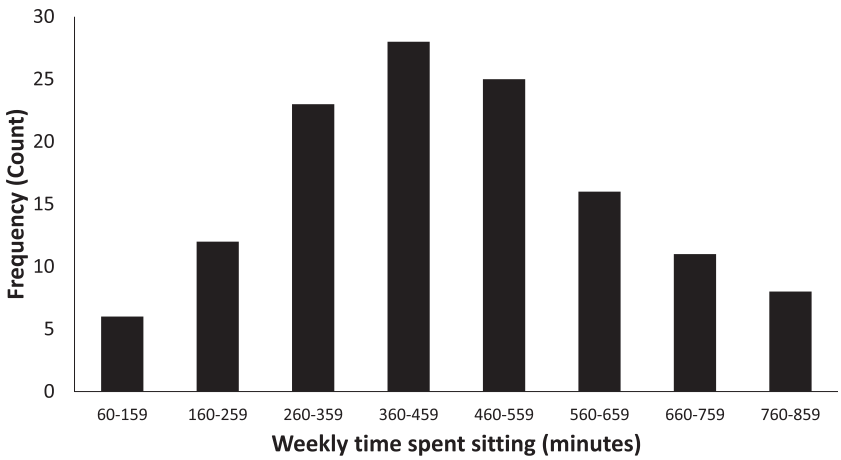

Figure 2. Histogram of weekly time spent sitting in minutes.

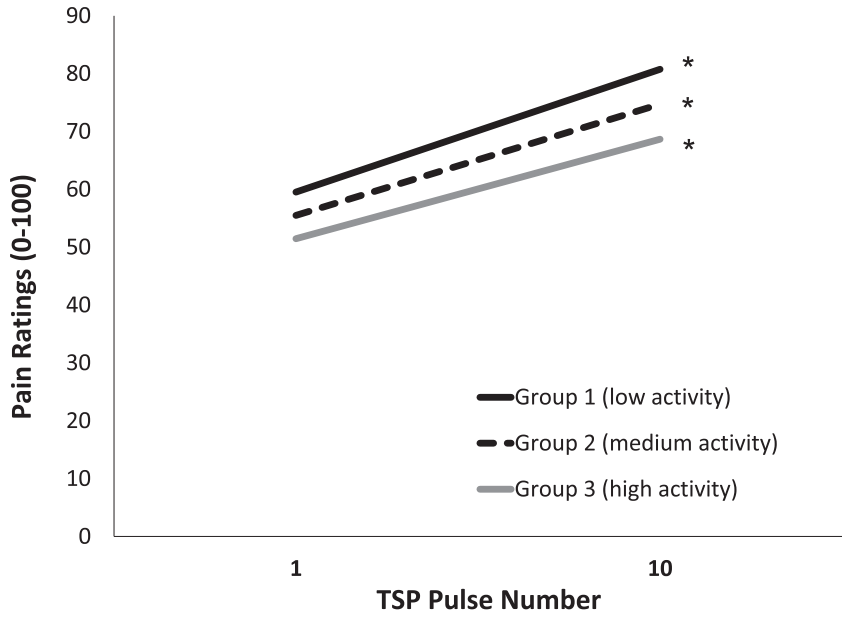

Figure 3. Physical activity and temporal summation (TSP) of pain. Each line depicts a simple regression line relating heat pulse number to the dependent variable (pain) at different levels of the physical activity moderator; physical activity groups based on International Physical Activity Questionnaire Short Form scoring; differences in slope indicate differences in summation between groups; the group × pulse interaction indicates that the slopes for these groups were all significantly different from one another; the asterisks are indicating that slopes are all positive and different from 0. *$P < 0.001$.

4.4. Heat pain threshold and tolerance

Neither our heat pain threshold nor tolerance measures were associated with physical activity or sitting time. Prior research has found mixed results with some studies finding no associations,[41] while others show that increased activity is associated with higher pain threshold[2] and tolerance.[21] This may be because static QST measures assess the output of pain processing at a single point in time. Notably, dynamic QST measures (such as CPM and TSP) assess modulatory function and are more specific to assessing ascending and descending pain processing as it occurs.[49] That our activity measures were associated with TSP but not static QST could be due to compensatory mechanisms that circumvent generalized pain sensitivity.

4.5. Physical activity and the African American pain disparity

Our results suggest that similar to NHWs, physical activity is associated with reduced TSP in a sample of healthy AAs. Prior research suggests that AAs show higher TSP and pain facilitatory processes in general.[8,55] Thus, already enhanced TSP may be further exacerbated by lower levels of physical activity. Activity-focused interventions may be able to mitigate enhanced TSP and chronic pain risk in AA individuals. It will be important to consider

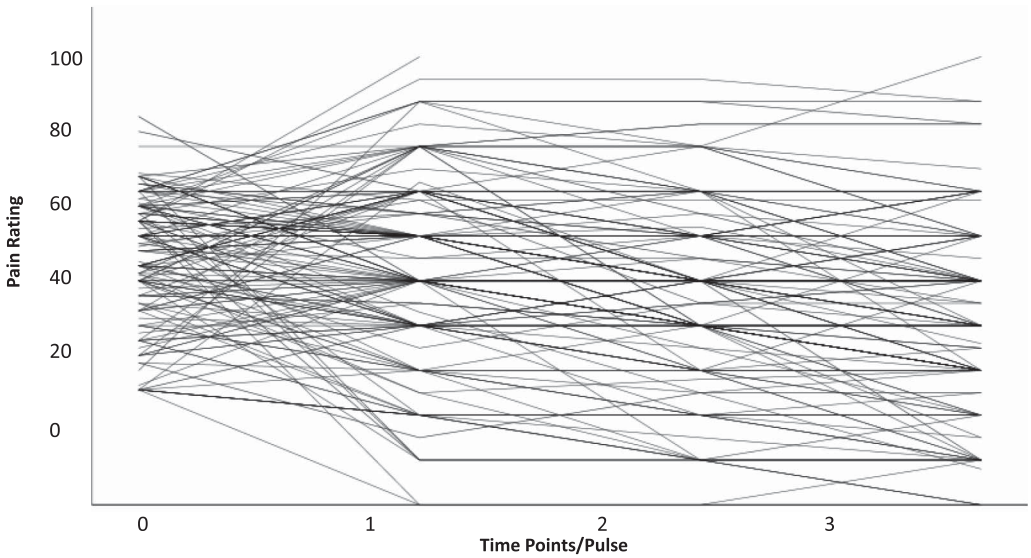

Figure 4. Mean test stimulus pain ratings in the test phase and during presentation of stimuli 1 to 3 during the conditioning phase of the CPM protocol. Each line = 1 participant. The first number is a within-person mean of the test phase ratings (pulse 0); the next 3 are within-person ratings, not means (pulse 1–3). CPM, conditioned pain modulation.

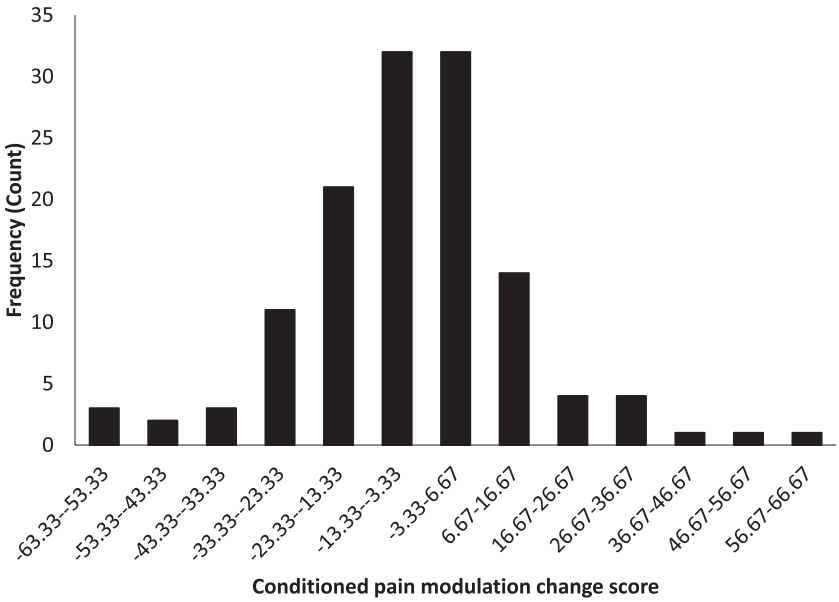

Figure 5. Histogram depicting the frequency with which individuals inhibited (negative values), facilitated (positive values), or showed no change during conditioned pain modulation (CPM). Values depict average change score = (average of 3 preconditioning trials) − (average of 3 conditioning trials).

resource deprivation and limited access to physical space when implementing these.[53]

In this study, physical activity did not affect CPM efficiency in AAs. Prior research has generally shown that AAs show reduced inhibition during CPM compared with NHWs.[9] However, if the physical activity level between groups is held constant, no racial differences in CPM efficiency seem to exist between NHWs and AAs.[64] Thus, CPM may not necessarily be different across groups, but lower levels of physical activity in the AA population may lead to less efficient CPM.

4.6. The impact of sex and age on temporal summation of pain slopes

Current findings indicated significant interaction effects between age and TSP (eg, TSP was less pronounced as age increased) as well as sex and TSP (eg, men demonstrated higher TSP). The age × TSP interaction in this study contrasts with most published research[12,14,30] but may be related to sample characteristics. For instance, Edwards and Fillingim found that older adults (mean age: 62.2 years) exhibited enhanced temporal summation compared with a younger group (mean age: 22.4 years).[14] Our current sample (mean age: of 25.82 years) was similar to the referenced younger group, potentially indicating that our sample was not old enough to show deleterious age-related changes. Present findings regarding sex outcomes are mixed in terms of their consistency with prior work. Similar to prior literature,[17] we found that men have higher pain tolerances than women. However, the sex × TSP interaction pattern showed enhanced TSP slope for men. This could be explained by mediating psychological variables (anxiety, gender-based reported willingness to report pain) not assessed in this study.[51]

4.7. Limitations

First, our study analyzed a sample of healthy, young, and well-educated AAs without chronic pain using a cross sectional design, thereby limiting generalizability to other groups (eg, chronic pain or older populations). Similarly, this study solely examined AAs without a control group (NHWs), thereby precluding direct examination of how our measures may vary across racial groups. In addition, we assessed physical activity and sedentary behaviors through self-report rather than objective indicators. As self-report is dependent on memory, participants may have underestimated or overestimated physical activity levels. An accelerometer may have better captured these behaviors. Future studies should include objective measures such as accelerometers to quantify physical activity. Furthermore, several variables potentially affecting TSP were not assessed including behavioral factors (eg, sleep), health-related factors (eg, obesity), and psychological factors (eg, depression, anxiety, gender role stereotypes).

4.8. Summary

This study examined the impact of physical activity and sedentary behavior on pain facilitatory and inhibitory processes in healthy and relatively young AAs. Multilevel models indicated that the high level of physical activity, but not amount of sedentary behavior, was associated with reduced TSP, a marker of central sensitization. Neither physical activity nor sedentary behavior was related to descending pain inhibition as assessed through CPM. Thus, greater physical activity may exert antinociceptive effects (ie, reduced TSP) that could potentially reduce chronic pain risk and may be an important factor in reducing pain disparity for AAs.

Disclosures

The authors have no conflict of interest to declare.

Acknowledgements

This research was supported, in part, by grants from the National Institutes of Health (U54 MD007593, U54MD007586, R01MH108155, R01MD010757, R01DA040966,

R01HL164823, R01DA058794, R01 DA050334, R01 MD016838). The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH.
Data availability statement: The data for this study are available from the Principal Investigator (M.C.M.) upon reasonable request. The data are not publicly available due to the dataset containing identifiers that could compromise the privacy of research participants.

Article history:
Received 9 July 2023
Received in revised form 29 September 2023
Accepted 9 October 2023

References

[1] Anderson KO, Green CR, Payne R. Racial and ethnic disparities in pain: causes and consequences of unequal care. J Pain 2009;10:1187–204.
[2] Andrzejewski W, Kassolik K, Brzozowski M, Cymer K. The influence of age and physical activity on the pressure sensitivity of soft tissues of the musculoskeletal system. J Bodyw Mov Ther 2010;14:382–90.
[3] Arendt-Nielsen L, Petersen-Felix S, Fischer M, Bak P, Bjerring P, Zbinden AM. The effect of N-methyl-D-aspartate antagonist (ketamine) on single and repeated nociceptive stimuli: a placebo-controlled experimental human study. Anesth Analg 1995;81:63–8.
[4] Baker TA, Buchanan NT, Small BJ, Hines RD, Whitfield KE. Identifying the relationship between chronic pain, depression, and life satisfaction in older African Americans. Res Aging 2011;33:426–43.
[5] Bruehl S, Burns JW, Koltyn K, Gupta R, Buvanendran A, Edwards D, Chont M, Wu YH, Qu'd D, Stone A. Are endogenous opioid mechanisms involved in the effects of aerobic exercise training on chronic low back pain?: a randomized controlled trial. PAIN 2020;161:2887–97.
[6] Bruehl S, France CR, France J, Harju A, al'Absi M. How accurate are parental chronic pain histories provided by offspring? PAIN 2005;115: 390–7.
[7] Bruehl S, Milne G, Schildcrout J, Shi Y, Anderson S, Shinar A, Polkowski G, Mishra P, Billings FTI. Oxidative stress is associated with characteristic features of the dysfunctional chronic pain phenotype. PAIN 2022;163: 786–94.
[8] Bulls HW, Goodin BR, McNew M, Gossett EW, Bradley LA. Minority aging and endogenous pain facilitatory processes. Pain Med 2016;17: 1037–48.
[9] Campbell CM, France CR, Robinson ME, Logan HL, Geffken GR, Fillingim RB. Ethnic differences in diffuse noxious inhibitory controls. J Pain 2008;9:759–66.
[10] Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, Oja P. International physical activity Questionnaire: 12-country reliability and validity. Med Sci Sports Exerc 2003;35:1381–95.
[11] Dahlhamer J, Lucas J, Zelaya C, Nahin R, Mackey S, DeBar L, Kerns R, Von Korff M, Porter L, Helmick C. Prevalence of chronic pain and high-impact chronic pain among adults—United States, 2016. MMWR Morb Mortal Weekly Rep 2018;67:1001–6.
[12] Edwards RR. Age-related differences in endogenous pain modulation: a comparison of diffuse noxious inhibitory controls in healthy older and younger adults. Diss Abstr Int Sect B Sci Eng 2003;63:4956.
[13] Edwards RR. Individual differences in endogenous pain modulation as a risk factor for chronic pain. Neurology 2005;65:437–43.
[14] Edwards RR, Fillingim RB. Effects of age on temporal summation and habituation of thermal pain: clinical relevance in healthy older and younger adults. J Pain 2001;2:307–17.
[15] Eide PK. Wind-up and the NMDA receptor complex from a clinical perspective. Eur J Pain 2000;4:5–15.
[16] Fancourt D, Steptoe A. Physical and psychosocial factors in the prevention of chronic pain in older age. J Pain 2018;19:1385–91.
[17] Fillingim RB, King CD, Ribeiro-Dasilva MC, Rahim-Williams B, Riley JL. Sex, gender, and pain: a review of recent clinical and experimental findings. J Pain 2009;10:447–85.
[18] First MB. Structured clinical interview for the DSM (SCID). The encyclopedia of clinical psychology. John Wiley & Sons, Ltd, 2015. p. 1–6. doi: 10.1002/9781118625392.wbecp351.
[19] Flack JM, Peters R, Shafi T, Alrefai H, Nasser SA, Crook E. Prevention of hypertension and its complications: theoretical basis and guidelines for treatment. J Am Soc Nephrol 2003;14:S92–S98.
[20] Geneen LJ, Moore RA, Clarke C, Martin D, Colvin LA, Smith BH. Physical activity and exercise for chronic pain in adults: an overview of Cochrane Reviews. Cochrane Database Syst Rev 2017;4:CD011279.
[21] Geva N, Defrin R. Enhanced pain modulation among triathletes: a possible explanation for their exceptional capabilities. PAIN 2013;154: 2317–23.
[22] Green CR, Anderson KO, Baker TA, Campbell LC, Decker S, Fillingim RB, Kalauokalani DA, Lasch KE, Myers C, Tait RC, Todd KH, Vallerand AH. The unequal burden of pain: confronting racial and ethnic disparities in pain. Pain Med 2003;4:277–94.
[23] Guirimand F, Dupont X, Brasseur L, Chauvin M, Bouhassira D. The effects of ketamine on the temporal summation (wind-up) of the R(III) nociceptive flexion reflex and pain in humans. Anesth Analg 2000;90:408–14.
[24] Hackett J, Naugle KE, Naugle KM. The decline of endogenous pain modulation with aging: a meta-analysis of temporal summation and conditioned pain modulation. J Pain 2020;21:514–28.
[25] Institute of Medicine. Relieving pain in America: a blueprint for transforming prevention, care, education, and research, 2011.
[26] Janevic MR, McLaughlin SJ, Heapy AA, Thacker C, Piette JD. Racial and socioeconomic disparities in disabling chronic pain: findings from the health and retirement study. J Pain 2017;18:1459–67.
[27] Johannes CB, Le TK, Zhou X, Johnston JA, Dworkin RH. The prevalence of chronic pain in United States adults: results of an Internet-based survey. J Pain 2010;11:1230–9.
[28] Kawai K, Kawai AT, Wollan P, Yawn BP. Adverse impacts of chronic pain on health-related quality of life, work productivity, depression and anxiety in a community-based study. Fam Pract 2017;34:656–61.
[29] Kleinman L, Mannix S, Arnold LM, Burbridge C, Howard K, McQuarrie K, Pitman V, Resnick M, Roth T, Symonds T. Assessment of sleep in patients with fibromyalgia: qualitative development of the fibromyalgia sleep diary. Health Qual Life Outcomes 2014;12:111.
[30] Lautenbacher S, Kunz M, Strate P, Nielsen J, Arendt-Nielsen L. Age effects on pain thresholds, temporal summation and spatial summation of heat and pressure pain. PAIN 2005;115:410–8.
[31] Law LF, Sluka KA. How does physical activity modulate pain? PAIN 2017; 158:369–70.
[32] Le Bars D, Willer J-C. Diffuse noxious inhibitory controls (DNIC). Senses Compr Ref 2010;5:762–73.
[33] Lima LV, Abner TSS, Sluka KA. Does exercise increase or decrease pain? Central mechanisms underlying these two phenomena. J Physiol 2017; 595:4141–50.
[34] McPhee ME, Graven-Nielsen T. Recurrent low back pain patients demonstrate facilitated pronociceptive mechanisms when in pain, and impaired antinociceptive mechanisms with and without pain. PAIN 2019; 160:2866–76.
[35] Meints SM, Cortes A, Morais CA, Edwards RR. Racial and ethnic differences in the experience and treatment of noncancer pain. Pain Manag 2019;9:317–34.
[36] Morris MC, Bruehl S, Stone AL, Garber J, Smith C, Palermo TM, Walker LS. Does quantitative sensory testing improve prediction of chronic pain trajectories? A longitudinal study of youth with functional abdominal pain participating in a randomized controlled trial of cognitive behavioral treatment. Clin J Pain 2021;37:648–56.
[37] Morris MC, Walker L, Bruehl S, Hellman N, Sherman AL, Rao U. Race effects on conditioned pain modulation in youth. J Pain 2015;16:873–80.
[38] Morris MC, Walker L, Bruehl S, Hellman N, Sherman AL, Rao U. Race effects on temporal summation to heat pain in youth. PAIN 2015;156: 917–22.
[39] Morris MC, Walker LS, Bruehl S, Stone AL, Mielock AS, Rao U. Impaired conditioned pain modulation in youth with functional abdominal pain. PAIN 2016;157:2375–81.
[40] Naugle KM, Ohlman T, Naugle KE, Riley ZA, Keith NR. Physical activity behavior predicts endogenous pain modulation in older adults. PAIN 2017;158:383–90.
[41] Naugle KM, Riley JL. Self-reported physical activity predicts pain inhibitory and facilitatory function. Med Sci Sports Exerc 2014;46:622–9.
[42] Park S-M, Kim H-J, Jeong H, Kim H, Chang B-S, Lee C-K, Yeom JS. Longer sitting time and low physical activity are closely associated with chronic low back pain in population over 50 years of age: a cross-sectional study using the sixth Korea National Health and Nutrition Examination Survey. Spine J 2018;18:2051–8.
[43] Petersen KK, Arendt-Nielsen L, Simonsen O, Wilder-Smith O, Laursen MB. Presurgical assessment of temporal summation of pain predicts the development of chronic postoperative pain 12 months after total knee replacement. PAIN 2015;156:55–61.
[44] Pinto Rz, Ferreira Ph, Kongsted A, Ferreira MI, Maher Cg, Kent P. Self-reported moderate-to-vigorous leisure time physical activity predicts less

pain and disability over 12 months in chronic and persistent low back pain. Eur J Pain 2014;18:1190–8.
[45] Preacher KJ, Curran PJ, Bauer DJ. Computational tools for probing interactions in multiple linear regression, multilevel modeling, and latent curve analysis. J Educ Behav Stat 2006;31:437–48.
[46] Ransdell LB, Wells CL. Physical activity in urban white, African-American, and Mexican-American women. Med Sci Sports Exerc 1998;30: 1608–15.
[47] Raudenbush SW, Congdon RT. Hlm 8: Hierarchical linear and nonlinear modeling. Chapel Hill, NC: Scientific Software International, Inc., 2019.
[48] Rhudy JL. Does endogenous pain inhibition make a better athlete, or does intense athletics improve endogenous pain inhibition? PAIN 2013; 154:2241–2.
[49] Rhudy JL, Hellman N. Chapter 32 - adverse life events, sensitization of spinal nociception, and chronic pain risk. In: Rajendram R, Patel VB, Preedy VR, Martin CR, editors. The neurobiology, physiology, and psychology of pain. Academic Press, 2022. p. 359–73. doi: 10.1016/B978-0-12-820589-1.00032-4
[50] Rhudy JL, Williams AE. Gender differences in pain: do emotions play a role? Gend Med 2005;2:208–26.
[51] Robinson ME, Wise EA, Gagnon C, Fillingim RB, Price DD. Influences of gender role and anxiety on sex differences in temporal summation of pain. J Pain 2004;5:77–82.
[52] Rousseeuw PJ, van Zomeren BC. Unmasking multivariate outliers and leverage points. J Am Stat Assoc 1990;85:633–9.
[53] Senteio C, Veinot T. Trying to make things right: adherence work in high-poverty, African American neighborhoods. Qual Health Res 2014;24: 1745–56.
[54] Shiro Y, Ikemoto T, Terasawa Y, Arai Y-CP, Hayashi K, Ushida T, Matsubara T. Physical activity may Be associated with conditioned pain modulation in women but not men among healthy individuals. Pain Res Manag 2017;2017:e9059140.
[55] Sibille K, Goodin B, Herrera D, Riley J, Fillingim R. Ethnic differences in temporal summation of thermal pain. J Pain 2011;12:P16.
[56] Siddiqi Z, Tiro JA, Shuval K. Understanding impediments and enablers to physical activity among African American adults: a systematic review of qualitative studies. Health Educ Res 2011;26:1010–24.
[57] Smith TJ, Hillner BE. The cost of pain. JAMA Netw Open 2019;2: e191532.
[58] Sommer C, Kress M. Recent findings on how proinflammatory cytokines cause pain: peripheral mechanisms in inflammatory and neuropathic hyperalgesia. Neurosci Lett 2004;361:184–7.
[59] Staud R. Abnormal endogenous pain modulation is a shared characteristic of many chronic pain conditions. Expert Rev Neurother 2012;12:577–85.
[60] Stewart LK, Flynn MG, Campbell WW, Craig BA, Robinson JP, Timmerman KL, Mcfarlin BK, Coen PM, Talbert E. The influence of exercise training on inflammatory cytokines and C-reactive protein. Med Sci Sports Exerc 2007;39:1714–9.
[61] Sturycz CA, Hellman N, Payne MF, Kuhn BL, Hahn B, Lannon EW, Palit S, Güereca YM, Toledo TA, Shadlow JO, Rhudy JL. Race/ethnicity does not moderate the relationship between adverse life experiences and temporal summation of the nociceptive flexion reflex and pain: results from the Oklahoma study of native American pain risk. J Pain 2019;20:941–55.
[62] Tesarz J, Schuster AK, Hartmann M, Gerhardt A, Eich W. Pain perception in athletes compared to normally active controls: a systematic review with meta-analysis. PAIN 2012;153:1253–62.
[63] Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, Chastin SFM, SBRN Terminology Consensus Project Participants, Chinapaw MJM, Altenburg TM, Aminian S, Arundell L, Atkin AJ, Aubert S, Barnes J, Barone Gibbs B, Bassett-Gunter R, Belanger K, Biddle S, Biswas A, Carson V, Chaput J-P, Chastin S, Chau J, ChinAPaw M, Colley R, Coppinger T, Craven C, Cristi-Montero C, de Assis Teles Santos D, del Pozo Cruz B, del Pozo-Cruz J, Dempsey P, do Carmo Santos Gonçalves RF, Ekelund U, Ellingson L, Ezeugwu V, Fitzsimons C, Florez-Pregonero A, Friel CP, Fröberg A, Giangregorio L, Godin L, Gunnell K, Halloway S, Hinkley T, Hnatiuk J, Husu P, Kadir M, Karagounis LG, Koster A, Lakerveld J, Lamb M, Larouche R, Latimer-Cheung A, LeBlanc AG, Lee E-Y, Lee P, Lopes L, Manns T, Manyanga T, Martin Ginis K, McVeigh J, Meneguci J, Moreira C, Murtagh E, Patterson F, Rodrigues Pereira da Silva D, Pesola AJ, Peterson N, Pettitt C, Pilutti L, Pinto Pereira S, Poitras V, Prince S, Rathod A, Rivière F, Rosenkranz S, Routhier F, Santos R, Saunders T, Smith B, Theou O, Tomasone J, Tremblay M, Tucker P, Umstattd Meyer R, van der Ploeg H, Villalobos T, Viren T, Wallmann-Sperlich B, Wijndaele K, Wondergem R. Sedentary behavior research network (SBRN)—terminology consensus project process and outcome. Int J Behav Nutr Phys Act 2017;14:75.
[64] Umeda M, Griffin C, Cross A, Heredia C, Okifuji A. Conditioned pain modulation among young, healthy, and physically active African American and non-Hispanic White adults. J Psychosom Res 2017;98: 64–70.
[65] Velly AM, Mohit S. Epidemiology of pain and relation to psychiatric disorders. Prog Neuropsychopharmacol Biol Psychiatry 2018;87: 159–67.
[66] Wilcox RR. Understanding and applying basic statistical methods using R. Hoboken, NJ: John Wiley & Sons, 2016.
[67] Williams WM, Yore MM, Whitt-Glover MC. Estimating physical activity trends among blacks in the United States through examination of four national surveys. AIMS Public Health 2018;5:144–57.
[68] Woods JA, Wilund KR, Martin SA, Kistler BM. Exercise, inflammation and aging. Aging Dis 2012;3:130–40.
[69] Woolf CJ. Windup and central sensitization are not equivalent. PAIN 1996;66:105–8.
[70] Yarnitsky D. Role of endogenous pain modulation in chronic pain mechanisms and treatment. PAIN 2015;156(suppl 1):S24–31.
[71] Yarnitsky D, Granot M, Granovsky Y. Pain modulation profile and pain therapy: between pro-and antinociception. PAIN 2014;155:663–5.
[72] Ziadni MS, Sturgeon JA, Bissell D, Guck A, Martin KJ, Scott W, Trost Z. Injustice appraisal, but not pain catastrophizing, mediates the relationship between perceived ethnic discrimination and depression and disability in low back pain. J Pain 2020;21:582–92.