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Psychological Profiles and Pain Characteristics of Older Adults With Knee Osteoarthritis

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Abstract

Objective—To identify psychological profiles in persons with knee osteoarthritis (OA) and to determine the relationship between these profiles and specific pain and sensory characteristics, including temporal summation and conditioned pain modulation.

Methods—Individuals with knee OA (n = 194) completed psychological, health, and sensory assessments. Hierarchical cluster analysis was used to derive psychological profiles that were compared across several clinical pain/disability and experimental pain responses.

Results—Cluster 1 had high optimism with low negative affect, pain vigilance, anger, and depression, along with the lowest self-reported pain/disability and the lowest sensitivity to mechanical, pressure, and thermal pain ($P < 0.01$ for all). Cluster 2 had low positive affect with high somatic reactivity, while cluster 3 showed high pain vigilance with low optimism. Clusters 2 and 3 had intermediate levels of self-reported pain/disability and cluster 3 experienced central sensitization to mechanical stimuli. Participants in cluster 3 also displayed significant pain facilitation ($P < 0.05$). Cluster 4 exhibited the highest pain vigilance, reactivity, negative affect, anger, and depression. These individuals experienced the highest self-reported pain/disability, including widespread pain ($P < 0.001$ for all). Cluster 4 was most sensitive to mechanical,

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pressure, and thermal stimuli, and showed significant central sensitization to mechanical and thermal stimuli ($P < 0.001$ for all).

Conclusion—Our findings demonstrate the existence of homogeneous psychological profiles displaying unique sets of clinical and somatosensory characteristics. Multidisciplinary treatment approaches consistent with the biopsychosocial model of pain should provide significant advantages if targeted to profiles such as those in our OA sample.

Introduction

Osteoarthritis (OA) is a highly prevalent painful condition representing the leading cause of disability among older adults (1). Peripheral markers of disease severity (e.g., radiographs and magnetic resonance imaging) explain only a small to moderate proportion of the variability in OA-related pain and disability (2–6). Importantly, psychosocial factors have been consistently associated with symptoms of OA (7). For example, OA pain and function have been associated with greater depressive symptoms, while depressive symptoms were a robust predictor of knee pain worsening over a 2-year period (8). Similarly, psychosocial factors have been directly associated with outcomes to a variety of treatment interventions (9,10). Moreover, quantitative sensory testing (QST) on patients with OA has revealed subgroups within the OA population characterized by significant altered central nervous system (CNS) processing of pain (11–14). Taken together, these findings suggest considerable phenotypic heterogeneity in this condition based on both psychosocial and neurosensory functioning (15). Therefore, an integrated, multivariate assessment including various measures of psychological and CNS function may be particularly relevant for further understanding the pain associated with OA. This multifactorial approach may also lead to development of evidence-based treatments that are tailored to the individuals' psychosocial and QST profiles.

Whereas most previous investigators have examined psychological factors as individual variables, a more sophisticated approach would consider patterns of responses across multiple psychological measures. For example, Murphy and colleagues (15) used cluster analysis of clinical and psychological variables to characterize adults with hip/knee OA. The authors reported 3 distinct subgroups: 1) participants that experienced high clinical pain, high depressive symptoms, high fatigue levels, and the highest endorsement of somatic symptoms (34.9%); 2) participants with low levels of clinical pain but moderate levels of depressive symptoms and fatigue, while also endorsing many somatic symptoms (29.5%); and 3) participants with the lowest levels of depressive symptoms and fatigue who endorsed the lowest number of somatic symptoms (32.6%). These findings suggest the presence of multiple empirically detectable subgroups within the OA population that vary in their responses across multiple symptom domains, perhaps reflecting distinct patterns of CNS dysfunction. However, that study combined clinical and psychosocial variables in developing clusters, and the authors did not include QST to assess CNS function in a racially diverse sample.

Previous studies have used QST to examine the extent to which OA is associated with alterations in central pain processing. Participants with OA were more sensitive to pain both

at the affected joint and at unaffected sites compared to nonpain controls (11,12). Dysfunctional central sensitization (12) and descending pain inhibition (12,13) also have been reported in persons with OA, lending further support to a significant central contribution to pain associated with OA (14). However, no studies to date have examined whether different psychological subgroups differ in their QST responses and clinical pain, function, and disability. Such a study could potentially elucidate factors that contribute to OA presentation and may aid in optimal treatment selection.

The objectives of the present study were to identify psychological profiles in persons with knee OA and to determine the relationship between these profiles and specific pain and sensory characteristics, including temporal summation and conditioned pain modulation. We hypothesized that 1) specific psychological profiles would emerge based on responses across multiple psychological measures, 2) the profiles would significantly differ with respect to their reports of clinical pain and functional impact of their knee pain, and 3) these profiles would differ in their sensitivity to heat/mechanical pain, temporal summation, and pain inhibition.

Patients and Methods

One hundred ninety-four individuals (ages 45–85 years) who self-identified as African American or non-Hispanic white were recruited as part of an ongoing project at the University of Florida (UF) and the University of Alabama at Birmingham (UAB) studying racial differences in knee osteoarthritic pain (Understanding Pain and Limitations in Osteoarthritic Disease [UPLOAD]). Participants were recruited through posted fliers, radio/print ads, word of mouth referrals, and clinic-based recruitment methods between January 2010 and October 2012. The study was approved by the UF/UAB Institutional Review Boards.

Participants presented with unilateral or bilateral symptomatic knee OA based upon the American College of Rheumatology criteria (16). Participants were excluded if they had 1) prosthetic knee replacement or other clinically significant surgery of the affected knee; 2) uncontrolled hypertension (blood pressure >150/95 mm Hg), heart failure, or history of acute myocardial infarction; 3) peripheral neuropathy; 4) systemic rheumatic disorders (i.e., rheumatoid arthritis, systemic lupus erythematosus, fibromyalgia); 5) daily opioid use; 6) cognitive impairment; 7) excessive anxiety regarding protocol procedures; and 8) hospitalization within the preceding year for psychiatric illness.

General study procedures

Participants attended a health assessment and a QST session. The detailed study design and procedures have been reported previously (17–19). Briefly, participants completed general health and demographic questionnaires. During the health assessment, a study physician or nurse practitioner completed a brief history and physical examination that included joint palpation of the knees to designate the participants' most painful knee as the index knee for QST procedures. The QST session took place within 4 weeks of the health assessment. Individuals completed psychological measures (detailed below) followed by QST assessments, including thermal, mechanical, temporal summation, and conditioned pain

modulation (CPM). For the first part of QST, the order was randomized, with thermal and mechanical tests counterbalanced. After a rest period, CPM was assessed. Recorded instructions were played prior to commencement of each procedure.

Psychological measures

Center for Epidemiologic Studies Depression Scale (CES-D)—This 20-item questionnaire is designed to measure the frequency of depressive symptoms during the past week on a 4-point Likert scale (20).

Coping Strategies Questionnaire-Revised (CSQ-R)—The CSQ-R assesses passive and active coping techniques related to pain (21,22). Participants rated the frequency with which they engage in various coping techniques using a 7-point scale.

Kohn Reactivity Scale (KRS)—The KRS is commonly used to measure aspects of hypervigilance (23) and general reactivity and arousability (24) to common experiences across 24 items using a 5-point scale.

Life Orientation Test-Revised (LOT-R)—The LOT-R (25) is a 10-item questionnaire assessing dispositional optimism on a 5-point Likert scale.

Positive and Negative Affect Scale (PANAS)—The PANAS consists of 20 items rated on a 5-point scale (26,27). High scores on positive affect reflect enthusiasm, energy, and alertness, while high scores on negative affect reflect distress and aversive mood states.

Pain Vigilance and Awareness Questionnaire (PVAQ)—Attention to pain was assessed with the PVAQ (28,29). Consisting of 16 items, participants indicated how frequently they engaged in various behaviors over the past few weeks using a 6-point scale.

State-Trait Anger Expression Inventory (STAXI)—The STAXI is a 44-item questionnaire designed to evaluate anger (30). Participants rated the frequency/intensity of angry feelings on a 4-point scale. For the present study, the trait subscale was used, reflecting general anger.

Self-report measures of pain and function—The following pain measures were included to characterize cluster participants using a comprehensive pain and functional assessment battery.

Participants were asked to identify body areas, in addition to the knee, where they experienced pain. The areas included were the head, neck, hands, arms, chest, shoulders, stomach, upper and lower back, legs, and feet. These areas were added and a sum score was computed for each participant.

The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) (31) assesses symptoms of knee OA in the past 48 hours. For this study, the 4-point Likert scale version was used. The WOMAC yields 3 subscales, including pain during activities (5

items), stiffness during the day (2 items), and impairments in physical function (17 items), with higher scores indicating worse pain, stiffness, and impairments in physical function.

The Graded Chronic Pain Scale (GCPS) evaluates global pain severity and pain-related interference over the past 6 months and consists of 7 items related to pain intensity and pain interference (i.e., loss of work days due to pain, interference in daily activities) (32). With a 0–10 numerical rating scale, participants rated the intensity of their current knee pain and the worst and average pain during the past 6 months. These 3 items were averaged and multiplied by 10 to generate a characteristic pain intensity score. Using the same scale, participants rated the degree to which their knee pain interfered with daily activities (3 items) during the past 6 months, which was averaged and multiplied by 10 to generate a disability score.

QST procedures

Thermal—All thermal stimuli were delivered using a computer-controlled Medoc PATHWAY Pain & Sensory Evaluation System. The position of the thermode was moved between trials to avoid sensitization and/or habituation of cutaneous receptors. Heat pain thresholds and tolerances were assessed on both the knee and the ipsilateral ventral forearm using an ascending method of limits with a 16 × 16–mm Advanced Thermal Stimulator (Medoc). Heat pain threshold was first assessed and followed by heat pain tolerance. For each trial, the probe would start at the baseline temperature (32°C) and increase at a rate of 0.5°C/second until the participant responded by pressing a button. Participants were instructed to press the button when the sensation “first became painful” (heat pain threshold) and when they “no longer felt able to tolerate the pain” (heat pain tolerance). For all procedures, the temperature was recorded for heat pain threshold and tolerance. Each test was repeated 3 times and the mean temperature was used for analysis.

Five minutes following the assessment of heat pain threshold and tolerance, participants underwent a second thermal procedure to assess temporal summation of thermal pain. Participants were instructed to verbally rate the intensity of peak pain evoked by each of 5 brief, repetitive, suprathreshold heat pulses on a scale of 0–100, where 0 = no pain sensation and 100 = the most intense pain sensation imaginable. Target temperatures were delivered by a Contact Heat-Evoked Potential Stimulator (CHEPS, Medoc) thermode for <1 second, with an ∼2.5-second interpulse interval during which the temperature of the contactor returned to baseline (32°C). During the temporal summation trials, 3 different temperatures were used (44°C, 46°C, and 48°C). The procedure was terminated if the participant rated the thermal pain at 100. The average rating over the 5 trials, an index of overall sensitivity to suprathreshold heat pain, and the maximum increase in pain, a measure of temporal summation, were determined for each participant and used in the analyses. The latter was calculated by subtracting the first trial rating from the maximum rating provided at each temperature.

Mechanical—Pressure pain thresholds were evaluated at multiple sites, including 2 sites on the most affected knee and on ipsilateral sites outside the knee: quadriceps, trapezius, and extensor carpi radialis longus. The order of testing was counterbalanced and randomized.

For each site, a handheld digital pressure algometer (AlgoMed, Medoc) was applied at a constant rate of 30 kPa/second. The participant was instructed to press a button when the sensation "first became painful." The amount of pressure (kPa) that first produced a painful sensation was recorded. The pressure pain threshold procedure was repeated 3 times for each testing site to create an average pressure pain threshold for the site. The maximum pressure for the 2 knee sites was 600 kPa, while the other sites were set at 1,000 kPa. If participants did not report pain at the maximum pressure level, the procedure was terminated and a score of 600 or 1,000 was assigned for that trial.

After pressure pain, participants underwent a second procedure to assess sensitivity to punctate mechanical stimuli with a calibrated nylon monofilament delivering a target force of 300 gm. Testing sites were randomized and included the patella and the back of the ipsilateral hand. To assess mechanical punctate sensitivity at each site, participants provided verbal pain ratings after a single contact, followed by 10 contacts at a rate of 1 contact/second. Ratings were made on a scale of 0–100, where 0 = no pain sensation and 100 = the most intense pain sensation imaginable. The procedure was repeated and the ratings were summed for the single and multiple contacts for analysis.

CPM—CPM was evaluated by determining the ability of a conditioning stimulus (i.e., cold water immersion) to diminish the painfulness of a test stimulus (i.e., thermal pain during temporal summation). First, participants underwent a series of 5 heat pain trials to measure baseline sensitivity. Heat pain trials were delivered to the left ventral forearm with a CHEPS thermode (Medoc). Following the first series of heat pain trials, participants immersed their right hand into the cold water bath for 1 minute. Then, participants removed their hand and a second series of thermal pain trials was conducted. After a 5-minute period, the procedure was repeated. For both the test and conditioning stimuli, temperatures were tailored to evoke moderate pain (40–60 of 100), based on earlier ratings of heat pain and cold pain.

Statistical analysis

The psychological variables were included in the analytical clustering procedure after checking they were not highly intercorrelated ($r \leq 0.51$). Hierarchical cluster analysis was chosen employing Ward's clustering method with squared Euclidean distances as the similarity measure. Visual inspection of the dendrogram along with changes to the agglomeration coefficients were used to establish the optimal cluster solution (33). We examined the cluster group differences across the clustering variables to determine the appropriateness and internal validity of the cluster solution.

External cluster validation

The empirically derived clusters were compared across self-report measures of clinical pain and disability as well as measures of somatosensory function (QST) using one-way analysis of covariance procedures with Bonferroni post hoc adjustments. Race, age, education, and study site were included as covariates. Chi-square analyses were used to compare the clusters on categorical data. Analyses were performed with IBM SPSS Statistics 20 for Windows, and a critical value of 0.05 was considered statistically significant.

Results

The study participants (n = 194) had a mean ± SD age of 57 ± 7.7 years, were mostly women (69%), and were approximately equally divided into non-Hispanic white (48%) and African Americans (51%). The final cluster solution yielded 4 subgroups (Table 1). Individuals in cluster 1 (27%) had the highest scores on the LOT-R along with the lowest scores on the passive dimension of the CSQ-R, CES-D, negative affect subscale of the PANAS, PVAQ, KRS, and STAXI (high optimism/low negative affect; $P < 0.05$ for all). Cluster 2 (23%) was characterized by high scores on the KRS with low scores on the positive affect subscale of the PANAS (low positive affect; $P < 0.05$). Cluster 3 (32%) had the lowest scores on the LOT-R along with high scores on the PVAQ (low optimism; $P < 0.05$). Individuals in cluster 4 (16%) had the highest scores on the PVAQ, KRS, and negative affect subscale of the PANAS (somatic sensitivity/pain hypervigilance; $P < 0.001$). High optimism/low negative affect cluster 1 endorsed more psychologically adaptive patterns compared to the somatic sensitivity/pain hypervigilance cluster 4, which endorsed more psychologically maladaptive patterns ($P < 0.05$). There were also significant differences between the clusters in their race and age composition, as well as in levels of educational achievement ($P < 0.05$ for all) (Table 2). High optimism/low negative affect cluster 1 and low positive affect cluster 2 included proportionately more non-Hispanic white participants, while low optimism cluster 3 and somatic sensitivity/pain hypervigilance cluster 4 were composed of proportionately more African American participants. Low optimism cluster 3 and somatic sensitivity/pain hypervigilance cluster 4 had lower educational achievement than high optimism/low negative affect cluster 1 and low positive affect cluster 2. Low positive affect cluster 2 individuals were older than participants in the other clusters.

There were also significant differences between the clusters across several pain characteristics, controlling for race, age, and education (Table 3). The participants with high somatic sensitivity and pain hypervigilance (i.e., cluster 4) reported a significantly greater number of pain areas than the other clusters. Also, low optimism cluster 3 and somatic sensitivity/pain hypervigilance cluster 4 reported higher pain and disability scores across all pain measures, (i.e., WOMAC and GCPS) compared to high optimism/low negative affect cluster 1 and low positive affect cluster 2.

Regarding QST findings, there were no significant differences in heat pain threshold and tolerance between the clusters at both the forearm and the knee ($P > 0.05$). On the other hand, the participants with high optimism and low negative affect (i.e., cluster 1) showed the highest pressure pain thresholds across all sites tested, while the individuals with high somatic sensitivity and pain hypervigilance (i.e., cluster 4) showed the lowest pressure pain thresholds across all sites (Table 4). There were also significant differences between the clusters in mechanical and thermal temporal summation data at the 46°C and 48°C stimulus intensity levels (Table 5). The participants with high optimism and low negative affect provided significantly lower mechanical and thermal pain ratings compared to the individuals with high somatic sensitivity and pain hypervigilance ($P < 0.05$). However, there were no differences between the clusters at the 44°C temperature.

There were significant differences between the clusters during the CPM procedure for the maximum and average pain ratings of heat pain and change scores from pre– to post–cold water immersion ($P < 0.05$) (Table 6). In general, high optimism/low negative affect cluster 1 displayed a decrease in pain ratings after the cold water immersion, while the other clusters' pain ratings did not change or tended to increase, but only the increase in pain ratings by low optimism cluster 3 reached statistical significance ($P < 0.05$).

Discussion

We sought to identify psychological profiles in persons with knee OA and to determine the relationship between these profiles and specific pain and sensory characteristics using an extensive QST battery. Several important findings emerged from these analyses. First, the results supported the hypothesis that different psychological profiles exist within persons with knee OA. Second, our results suggest that groupings based on psychological characteristics differ considerably in their clinical pain with distinct somatosensory presentation. In general, our findings support the need for a biopsychosocial model of pain assessment and treatment in persons with knee OA.

As may be expected, the group of individuals with the least favorable psychological profile also showed the greatest levels of clinical pain and disability. These findings are similar to previous results from an older cohort of both knee and hip OA participants (15), in which one cluster had the highest levels of clinical pain and mood disturbances, a second cluster had low levels of clinical pain and intermediate levels of depression, while a third cluster had the lowest levels of clinical pain and depression. However, their study clustered a mixture of clinical and pain symptoms and conditions and did not include measures of somatosensory function (i.e., QST).

The present study attempted to relate psychosocial profiles to responses to a comprehensive standardized battery of QST measures in a cohort of individuals with knee OA. There were several expected and unexpected result patterns. First, as expected, the participants with the greatest psychological distress experienced widespread pain and the highest levels of clinical pain and disability. Although all clusters had similar heat pain thresholds and tolerance, the individuals with high somatic sensitivity and pain hypervigilance were also the most sensitive to pressure across several body sites and exhibited greater thermal and mechanical temporal summation. Similar to our cluster 4, Murphy and colleagues (15) identified a group of individuals with the highest levels of clinical pain, negative mood, and fatigue, suggesting a stronger CNS contribution to their condition. Our findings provide more direct evidence in support of their conclusions (15), such that central sensitization may be a stronger contributor to the symptom profile in these individuals.

Second, the participants with the lowest levels of CNS arousability and pain vigilance and the highest levels of optimism (high optimism/low negative affect cluster 1) were the least sensitive across all tested stimulus modalities. Measures of somatic reactivity and pain-specific vigilance previously have been negatively associated with pain tolerance (34,35), while greater dispositional optimism (i.e., positive outcome expectancies) has been associated with enhanced pain inhibitory capacity and less temporal summation (18,19).

However, even though the well-adapted cluster was the only group that tended to show pain inhibition after the cold water immersion, this effect was small in magnitude and did not reach statistical significance after correcting for multiple comparisons. Furthermore, most participants in the present study did not experience descending pain inhibition, supporting previous findings in other samples of persons with OA (12,13).

Finally, most of the participants with high optimism and low negative affect (i.e., cluster 1) were non-Hispanic white, while most of the individuals with high somatic sensitivity and pain hypervigilance (i.e., cluster 4) were African American. The pronounced differences between these 2 groups across several clinical and experimental variables further support previous research on race differences in psychological, clinical, and experimental pain (34,36). However, all of the analyses controlled for race; therefore, other factors beyond race significantly contributed to these discrepancies.

In general, profiles based on psychosocial and somatosensory presentation may provide mechanism-based information that can be exploited in tailoring treatment to optimize clinical outcomes. For example, it could be speculated that persons in cluster 1 with less negative psychosocial profiles and limited evidence of central sensitization may experience adequate pain relief from peripherally targeted treatments. In contrast, individuals displaying significant psychological distress and somatosensory dysfunction (cluster 4) will likely benefit from a comprehensive treatment approach targeting central mechanisms of sensitization in addition to their peripheral pain generator. Future studies should assess whether these psychosocial and somatosensory profiles are able to reliably predict therapeutic outcomes.

The present study has several limitations. First, the cross-sectional nature of the present study design does not allow for causal inferences between the psychological profiles and the other pain and sensory measures. Therefore, it is not known whether the psychological profiles predict the sensory and clinical pain characteristics or, inversely, whether chronic pain has subsequently impacted the individual's psychological profiles. Future longitudinal studies should be performed to specifically address this question. Second, other variables not measured in our study could potentially moderate some of the relationships examined, and further research using additional measures may be useful. Although we controlled for race, age, education, and study site, additional variables such as body mass index and socioeconomic status may be important to include in future studies. Lastly, the present sample was largely composed of community-dwelling adults, which may explain the smaller size of the psychologically distressed cluster relative to the psychologically well adjusted. Analyses undertaken in other samples, such as those from clinical settings, may yield different results.

In summary, our study further supports the notion that there are large individual differences among persons with knee OA with respect to pain and levels of psychological function. However, cluster analysis allows us to identify psychological profiles that vary with respect to clinical pain and responses to QST. Multidisciplinary pain treatment approaches consistent with the biopsychosocial model of pain should provide significant advantages if these are targeted to profiles such as those present in our OA sample. Future research should

compare similar groups of individuals in their responses to treatments including psychological interventions.

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Significance & Innovations

- Our study suggests that there are large interindividual differences among persons with knee osteoarthritis (OA) with respect to psychological function.
- Multidisciplinary treatments targeting profiles such as those present in our OA sample are likely to improve therapeutic outcomes in persons with knee OA.

Table 1

Mean ± SD for each variable used for cluster assignment in our osteoarthritis participants (n = 194)[*]

Measures	Cluster 1 (n = 54)	Cluster 2 (n = 45)	Cluster 3 (n = 63)	Cluster 4 (n = 32)	*P*
CSQ-R active	3.0 ± 0.9	2.7 ± 1.0	3.1 ± 1.0	2.9 ± 1.0	0.297
CSQ-R passive	1.9 ± 1.2[†]	2.5 ± 1.0[‡]	3.3 ± 1.3	3.7 ± 1.1	0.001[§]
KRS-18	66.8 ± 7.5[¶]	85.3 ± 7.0[‡]	75.4 ± 7.8[#]	91.5 ± 10.8	0.001[§]
PVAQ	30.7 ± 9.1[†]	34.0 ± 8.9[‡]	54.9 ± 7.5[#]	63.0 ± 8.4	0.001[§]
CES-D	6.4 ± 5.5[**]	10.6 ± 7.6	9.3 ± 5.9	12.4 ± 10.2	0.001[§]
PANAS positive	39.2 ± 7.0[††]	35.0 ± 6.8[‡]	39.6 ± 7.3	39.1 ± 6.2	0.001[§]
PANAS negative	13.4 ± 4.2[†]	15.8 ± 3.9	16.0 ± 6.9	16.2 ± 4.9	0.001[§]
STAXI trait	15.7 ± 2.2[‡‡]	16.3 ± 2.3	16.3 ± 2.9	18.1 ± 6.8	0.024[§]
LOT-R	19.1 ± 4.7[§§]	17.4 ± 4.2	16.4 ± 3.7	17.8 ± 4.1	0.001[§]

[*] CSQ-R = Coping Strategies Questionnaire-Revised; KRS-18 = 18-item Kohn Reactivity Scale; PVAQ = Pain Vigilance and Awareness Questionnaire; CES-D = Center for Epidemiologic Studies Depression Scale; PANAS = Positive and Negative Affect Scale; STAXI = State-Trait Anger Expression Inventory; LOT-R = Life Orientation Test-Revised.

[†] Significant group differences between cluster 1 and cluster 4 and between cluster 1 and cluster 3 ($P < 0.01$ with Bonferroni adjustment).

[‡] Significant group differences between cluster 2 and cluster 4 and between cluster 2 and cluster 3 ($P < 0.01$ with Bonferroni adjustment).

[§] Significant.

[¶] Significant group differences between cluster 1 and cluster 4, between cluster 1 and cluster 3, and between cluster 1 and cluster 2 ($P < 0.01$ with Bonferroni adjustment).

[#] Significant group differences between cluster 3 and cluster 4 ($P < 0.01$ with Bonferroni adjustment).

[**] Significant group differences between cluster 1 and cluster 4 and between cluster 1 and cluster 2 ($P < 0.01$ with Bonferroni adjustment).

[††] Significant group differences between cluster 1 and cluster 2 ($P < 0.01$ with Bonferroni adjustment).

[‡‡] Significant group differences between cluster 1 and cluster 4 ($P < 0.01$ with Bonferroni adjustment).

[§§] Significant group differences between cluster 1 and cluster 3 ($P < 0.01$ with Bonferroni adjustment).

Table 2

Demographic characteristics of the osteoarthritis participants by cluster membership (n = 194)*

	Cluster 1 (n = 54)	Cluster 2 (n = 45)	Cluster 3 (n = 63)	Cluster 4 (n = 32)	*P*
Age, mean ± SD years	56.5 ± 7.8	60.2 ± 9.4†	56.7 ± 6.8	54.3 ± 5.4	0.007‡
Test site					0.302
UF	68.5 (37)	75.6 (34)	80.6 (50)	84.4 (27)	
UAB	31.5 (17)	24.4 (11)	19.4 (12)	15.6 (5)	
Education					0.003‡
High school	26.7 (13)	33.3 (15)	58.7 (37)	53.1 (17)	
2-year college degree	21.7 (11)	20.0 (9)	22.2 (14)	21.9 (7)	
4-year college degree	28.3 (17)	20.0 (10)	11.2 (7)	18.8 (6)	
Graduate degree	23.3 (13)	26.7 (11)	7.9 (5)	6.2 (2)	
Sex					0.295
Female	66.7 (36)	80.0 (36)	63.5 (40)	71.9 (23)	
Male	33.3 (18)	20.0 (9)	36.5 (23)	28.1 (9)	
Race					0.001‡
Non-Hispanic white	67.9 (36)	65.1 (28)	35.5 (22)	25.0 (8)	
African American	32.1 (17)	34.9 (15)	64.5 (40)	75.0 (24)	

*Values are the percentage (number) unless indicated otherwise. UF = University of Florida; UAB = University of Alabama at Birmingham.

†Significant group differences between cluster 2 and cluster 4 ($P < 0.01$ with Bonferroni adjustment).

‡Significant.

Table 3

Mean ± SD for the pain variables measured by cluster assignment in our osteoarthritis participants (n = 194)*

	Cluster 1 (n = 54)	Cluster 2 (n = 45)	Cluster 3 (n = 63)	Cluster 4 (n = 32)	Adjusted *P*†
No. of pain areas	4.7 ± 3.9‡	5.4 ± 3.8§	5.0 ± 4.3	7.6 ± 5.6	0.049¶
WOMAC pain	5.4 ± 3.3‡	6.7 ± 3.4§	7.4 ± 4.7#	10.7 ± 5.2	0.001¶
WOMAC stiffness	2.9 ± 1.7‡	3.0 ± 1.7§	3.1 ± 2.2#	4.7 ± 3.5	0.003¶
WOMAC function	16.4 ± 12.2**	21.3 ± 11.4§	23.5 ± 15.0#	35.3 ± 18.2	0.001¶
GCPS pain intensity	39.8 ± 17.9††	45.2 ± 20.2§	51.9 ± 24.8#	66.9 ± 22.2	0.002¶
GCPS disability	28.2 ± 23.7††	39.6 ± 26.2§	41.9 ± 30.8#	66.6 ± 27.9	0.001¶

*WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; GCPS = Graded Chronic Pain Scale.

†Controlling for race (0 = non-Hispanic white, 1 = African American), age, and education (1 = high school, 2-year college degree, 4-year college degree, graduate degree) as covariates.

‡Significant group differences between cluster 1 and cluster 4 ($P < 0.01$ with Bonferroni adjustment).

§Significant group differences between cluster 2 and cluster 4 ($P < 0.01$ with Bonferroni adjustment).

¶Significant.

#Significant group differences between cluster 3 and cluster 4 ($P < 0.01$ with Bonferroni adjustment).

**Significant group differences between cluster 1 and cluster 4 and between cluster 1 and cluster 3 ($P < 0.01$ with Bonferroni adjustment).

††Significant group differences between cluster 1 and cluster 4, between cluster 1 and cluster 3, and between cluster 1 and cluster 2 ($P < 0.01$ with Bonferroni adjustment).

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Table 4

Mean ± SD for the quantitative sensory testing variables measured by cluster assignment in our osteoarthritis participants (n = 194)[*]

	Cluster 1 (n = 54)	Cluster 2 (n = 45)	Cluster 3 (n = 63)	Cluster 4 (n = 32)	Adjusted *p*[†]
HPTh forearm, °C	42.2 ± 2.7	42.0 ± 3.2	41.1 ± 3.4	41.4 ± 3.2	0.618
HPTo forearm, °C	46.8 ± 2.0	45.8 ± 2.6	45.6 ± 2.7	45.5 ± 2.2	0.231
HPTh knee, °C	42.2 ± 3.2	42.3 ± 3.0	41.0 ± 3.3	41.5 ± 3.4	0.445
HPTo knee, °C	46.7 ± 2.2	46.1 ± 2.6	45.1 ± 3.3	45.1 ± 2.6	0.282
PPTh knee, kg	374.2 ± 178.0[‡]	322.1 ± 160.6	275.3 ± 161.3	264.7 ± 158.6	0.049[§]
PPTh quadriceps, kg	471.6 ± 224.9[¶]	415.4 ± 216.8	381.8 ± 210.5	350.7 ± 154.1	0.041[§]
PPTh trapezius, kg	323.3 ± 171.2[‡]	275.7 ± 182.4	224.4 ± 112.3	209.3 ± 119.2	0.006[§]
PPTh forearm, kg	288.0 ± 161.1[¶]	240.2 ± 171.1	221.8 ± 122.3	195.2 ± 99.7	0.026[§]

[*] HPTh = heat pain threshold; HPTo = heat pain tolerance; PPTh = pressure pain threshold.

[†] Controlling for race (0 = non-Hispanic white, 1 = African American), age, and education (1 = high school, 2-year college degree, 4-year college degree, graduate degree) as covariates.

[‡] Significant group differences between cluster 1 and cluster 4 and between cluster 1 and cluster 3 ($P < 0.05$ with Bonferroni adjustment).

[§] Significant.

[¶] Significant group differences between cluster 1 and cluster 4 ($P < 0.05$ with Bonferroni adjustment).

Table 5

Mean ± SD for the temporal summation variables measured by cluster assignment in our osteoarthritis participants (n = 194)

	Cluster 1 (n = 54)	Cluster 2 (n = 45)	Cluster 3 (n = 63)	Cluster 4 (n = 32)	Adjusted *P**
Forearm mechanical pain max	13.1 ± 19.3†	23.5 ± 25.1	30.7 ± 28.1	38.4 ± 30.9	0.008‡
Forearm mechanical pain change	7.9 ± 13.2§	14.7 ± 19.2	19.7 ± 18.9	22.8 ± 20.2	0.044‡
Knee mechanical pain max	19.8 ± 22.3†	34.7 ± 29.1	39.8 ± 29.7	54.5 ± 31.2	0.001‡
Knee mechanical pain change	12.1 ± 14.5†	22.7 ± 22.5	23.9 ± 18.9	29.3 ± 17.9	0.002‡
Forearm 44°C heat pain max	30.7 ± 25.9§	40.8 ± 30.7	46.1 ± 25.2	48.1 ± 26.7	0.117
Forearm 44°C heat pain change	3.4 ± 7.9§	6.8 ± 9.9	9.4 ± 15.1	9.6 ± 13.7	0.283
Knee 44°C heat pain max	21.9 ± 19.9‡	30.8 ± 28.7	37.6 ± 26.3	45.3 ± 24.1	0.016‡
Knee 44°C heat pain change	2.6 ± 6.2§	3.4 ± 6.3	8.3 ± 14.1	9.6 ± 14.5	0.050‡
Forearm 46°C heat pain max	35.6 ± 26.2‡	43.6 ± 29.3	53.3 ± 28.4	55.6 ± 28.0	0.033‡
Forearm 46°C heat pain change	3.8 ± 6.2‡	6.3 ± 8.4	11.4 ± 15.2	15.7 ± 19.7	0.018‡
Knee 46°C heat pain max	32.8 ± 26.6‡	43.9 ± 31.1	55.6 ± 30.4	59.0 ± 27.5	0.009‡
Knee 46°C heat pain change	7.8 ± 13.2§	6.7 ± 11.6	12.5 ± 18.6	16.3 ± 18.1	0.049‡
Forearm 48°C heat pain max	45.7 ± 28.0§	56.0 ± 32.8	64.8 ± 28.6	74.8 ± 25.6	0.021‡
Forearm 48°C heat pain change	8.4 ± 9.9†	10.7 ± 12.1	14.2 ± 17.3	23.3 ± 21.6	0.009‡
Knee 48°C heat pain max	44.1 ± 30.4†	51.9 ± 31.9	64.5 ± 29.9	72.0 ± 26.4	0.009‡
Knee 48°C heat pain change	11.2 ± 13.9§	9.8 ± 12.5	15.5 ± 18.1	21.8 ± 22.1	0.042‡

*Controlling for race (0 = non-Hispanic white, 1 = African American), age, education (1 = high school, 2-year college degree, 4-year college degree, graduate degree), and testing site (0 = University of Florida, 1 = University of Alabama at Birmingham) as covariates.

†Significant group differences between cluster 1 and cluster 4 and between cluster 1 and cluster 3 ($P < 0.01$ with Bonferroni adjustment).

‡Significant.

§Significant group differences between cluster 1 and cluster 4 ($P < 0.01$ with Bonferroni adjustment).

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Table 6

Mean ± SD changes to heat pain ratings before and following cold water immersion in persons with knee osteoarthritis

	Cluster 1 (n = 54)	Cluster 2 (n = 45)	Cluster 3 (n = 63)	Cluster 4 (n = 32)	Adjusted *P**
Maximum pain					0.003†
Preimmersion	49.4 ± 26.8	56.1 ± 25.5	57.8 ± 24.6	66.3 ± 23.9	
Postimmersion	46.6 ± 26.2	59.7 ± 25.6	64.6 ± 23.3	70.2 ± 22.1	
Average pain					0.002†
Preimmersion	48.6 ± 25.5	58.4 ± 24.3	60.7 ± 22.5	65.1 ± 21.7	
Postimmersion	46.0 ± 24.5	59.3 ± 24.4	62.9 ± 21.5	67.7 ± 19.8	
Change from pre- to postimmersion	1.0 ± 1.8‡	0.8 ± 2.0§	−1.1 ± 1.7	−6.8 ± 2.4	0.047†

*Controlling for race (0 = non-Hispanic white, 1 = African American), age, education (1 = high school, 2-year college degree, 4-year college degree, graduate degree), and testing site (0 = University of Florida, 1 = University of Alabama at Birmingham) as covariates.

†Significant.

‡Significant group differences between cluster 1 and cluster 4 ($P < 0.01$ with Bonferroni adjustment).

§Significant group differences between cluster 2 and cluster 4 ($P < 0.01$ with Bonferroni adjustment).