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The Impact of Varied Music Applications on Pain Perception and Situational Pain Catastrophizing

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Abstract

We evaluated how pain processing and situational pain catastrophizing differed between two music interventions (Unwind and favorite music) and a control condition (white noise). Healthy adults (n=70) completed quantitative sensory testing (QST) measuring pressure pain threshold (PPT_h) and tolerance (PPT_o), heat pain threshold (HPT_h), offset analgesia (OA), temporal summation of pain (TSP), and conditioned pain modulation (CPM). Participants completed three QST rounds with the presence of white noise (control condition), a relaxing music app (Unwind), and their favorite music, which were presented in a randomized order. The Situational Pain Catastrophizing Scale was completed after each round. Friedman tests and post-hoc Wilcoxon signed-rank tests were used to compare pain processing and catastrophizing across the three conditions. Participants' PPT_h, PPT_o, and HPT_h were significantly higher during the favorite music condition compared to the other two conditions, indicating lower pain sensitivity when listening to favorite music. In contrast, OA was lower in the favorite music condition. Although TSP and CPM were induced by the QST paradigm, these did not differ across the three conditions.

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Situational pain catastrophizing was also significantly lower during the favorite music condition. Several measures of pain sensitivity and situational pain catastrophizing were lower when listening to favorite music compared to relaxing music or white noise. More research is necessary to determine the mechanism(s) by which music modulates pain processing.

Keywords

Pain Sensitivity; Music; Analgesia; Pain Catastrophizing; Quantitative Sensory Testing

INTRODUCTION

Music is a ubiquitous experience that transcends age, sex, race, and culture. With an increasing interest in non-opioid alternatives, music has gained attention as a potential adjunctive therapy to reduce pain.⁵ Previous studies suggest that music may reduce overall pain severity in individuals with chronic pain^{9, 27, 28, 39, 44} across diagnostic categories, including fibromyalgia,^{27,44} neuropathic, musculoskeletal and inflammatory pain,²⁷ osteoarthritis,³⁹ and during palliative care (predominantly cancer-related pain).²⁸ Music may also reduce pain in different clinical settings, including in the emergency department⁹ and in the perioperative period.^{24, 36, 64} The impact of music on pain processing has been investigated in experimental settings using quantitative sensory testing (QST), which involves the application of well-defined and calibrated sensory stimuli to characterize psychophysical responses to pain.⁴⁸ Individual differences in sensory processing discerned by QST have been associated with differences in clinical pain.⁵⁸ Some studies have suggested that music alters pain processing, increasing pain thresholds and reducing temporal summation of pain.^{7, 22, 31, 35, 40}

In addition to preliminary evidence of efficacy for reducing pain,³⁸ music interventions have been characterized as low-risk, practical, and easy to implement. Prior studies have found that healthy adults and postsurgical patients report greater pain tolerance and less post-surgical pain when listening to music compared to white noise, which is often used as a control condition.^{4, 30, 53} A less explored question asks what type of music most effective, as musical taste differs, and different types of music evoke varying responses across individuals. Thus, whether an individual enjoys or feels connected to a particular piece of music, such as to their favorite music, may substantially impact the degree to which it reduces pain and negative psychological processes.^{31, 40, 64} Many studies investigating the impact of music on pain have used classical music,^{27, 39, 44, 64} Others have employed deconstructed simple beats and harmonies,¹⁸ a selection of relaxing soundtracks,^{7, 9} or a general selection of music genres for participants to choose from,^{11, 25} with variable effectiveness among individuals. At least one recent study has suggested the importance of choice and cognitive agency in particular.³¹

Similarly, music has been shown to modulate psychological factors associated with the experience of pain.²³ A common negative psychological process associated with worsened pain is pain catastrophizing,^{2, 15, 16, 41, 47, 59} which occurs during or in anticipation of pain, and includes magnification, rumination, and feelings of helplessness in the face of

pain. While catastrophizing is often assessed as a trait using the Pain Catastrophizing Scale (PCS),⁵⁴ assessment during a procedure or in the setting of experimental pain testing can be accomplished using the briefer situational pain catastrophizing scale (SPCS). Notably, research has shown that greater situational pain catastrophizing is associated with lower pain thresholds and tolerance, as well as greater pain severity ratings among healthy adults.¹⁷ While one study did not observe a difference in situational catastrophizing between a control condition and relaxing music,⁷ it has yet to be explored in the context of favorite music.

The present study aimed to pragmatically investigate the impact of relaxing music versus participant-chosen favorite music on pain processing. Specifically, we investigated how nociceptive processing during quantitative sensory testing (QST) varied between two different types of music conditions (relaxing music on the Unwind app vs. participants' personal selection of favorite music) and a control condition (white noise). We used a randomized block design, where each participant experienced all three conditions in a random order, and pain sensitivity was compared across the three conditions within the same participant. We also explored differences in negative catastrophic thinking about experimental pain stimuli (situational pain catastrophizing) across the three conditions.

METHODS

This observational study of healthy adults was approved by the Partners Human Research Committee/Institutional Review Board (2019P000824) and registered with [ClinicalTrials.gov](https://clinicaltrials.gov/ct2/show/study/NCT04087564) (NCT04087564). Participants were recruited from July 18, 2019-February 25, 2020 through Rally, a Partners Healthcare research website. All interested participants were screened via email to determine their eligibility. Inclusion criteria were: 1) 18 years of age, 2) English speaking, 3) no current chronic opioid use (prescription >30 days), and 4) no previous diagnosis of hearing loss, neuropathy, or chronic pain. Eligible participants were then scheduled for a study visit and were asked to provide a list of their seven favorite songs (Figure 1). Informed consent was obtained from each study participant. The study took approximately 1.5–2 hours to complete, and participants received a \$40 Amazon gift card upon study completion.

Quantitative Sensory Testing of Pain

Each participant completed four rounds of Quantitative Sensory Testing (QST).⁷ For the first round (baseline), QST was completed in the absence of sound. Values for baseline testing are included in Supplemental Table S1 but were not otherwise used in the analysis. QST was then repeated for three more rounds, each with one of the three different conditions (white noise, Unwind, favorite music) playing during that round. To balance any potential order effects, the order of conditions was randomized (Figure 1). The duration of each QST round was approximately 20 minutes, followed by a 5-minute rest period.

Pressure pain threshold (PPT_h) and tolerance (PPT_o).—PPT_h and PPT_o were measured using a digital pressure algometer (Wagner FDX, Greenwich, CT, USA) with a flat round transducer (probe area, 0.785 cm). PPT_h and PPT_o were each assessed bilaterally at two locations, 1) the dorsal aspect of the proximal forearm (Forearm PPT_h and Forearm PPT_o) and 2) over the trapezius muscle at the upper back (Trapezius PPT_h and Trapezius

PPTol), as in previous studies.^{51, 52} Pressure was gradually increased (1 lb./sec), with a maximal exerted pressure of 20 lbs. Participants were asked to verbally indicate when the pressure first became painful (PPT_h) and then again when they wanted the pressure to stop (i.e., no longer tolerable, PPT_o). PPT_hs and PPT_os were averaged across sides (left and right) at each site to compute four main pressure pain-related outcomes: 1) forearm PPT_h and 2) forearm PPT_o, 3) trapezius PPT_h and 4) trapezius PPT_o. PPT_h and PPT_o were assessed during each of the three conditions.

Heat pain threshold (HPT_h) and offset analgesia (OA).—Contact heat stimuli were administered using a 1.6 X 1.6 cm square (2.56 cm²) contact thermode (Medoc Advanced Medical Systems, Ramat Yishai, Israel). The contact thermode was positioned on the skin on the volar aspect of the left forearm and affixed in place with a soft Velcro strap. The probe remained in place for the duration of both threshold and offset analgesia testing. The temperature of the probe started at a baseline temperature of 32°C and increased at a rate of 2°C/sec, with a maximum possible temperature of 50°C. Participants were instructed to press a button on a remote when thermal stimulation first became painful (HPT_h). Subsequently, subjects were instructed to press a button when their pain intensity became a 5/10 rating in response to the thermal stimulation. During only the baseline testing session, the 5/10 threshold temperature was measured three times, and the average was then used to determine the starting temperature for the OA protocol used for that participant. The placement of the thermode was marked and replaced in the same location for each of the following conditions. For the subsequent three randomized order trials (white noise, Unwind, favorite music) the temperature probe was again placed on the forearm in the previously marked location and a single measurement of the HPT_h and the 5/10 threshold were performed.

After HPT_h and 5/10 threshold testing, the OA protocol began using the original temperature profile determined in the baseline round, with the same temperature profile used across all three conditions. OA was assessed once per condition (white noise, Unwind, favorite music) using methods adapted from previous descriptions.^{1, 26, 42, 45, 63} First, the thermode temperature was steadily increased from 32°C at a rate of 2°C/sec until the T1 plateau temperature was reached (T1=one degree less than the 5/10 rating). T1 plateau was held for five seconds, after which the temperature was increased 1°C to the T2 plateau (the previously indicated average 5/10 threshold temperature). T2 was held for five seconds, after which the temperature was decreased 1°C to the T3 plateau (same temperature as T1). T3 was held for five seconds, after which the thermode temperature steadily decreased to 32°C and was removed from the forearm. During the OA paradigm, participants were asked to rate their pain on a scale of 0 (no pain) to 10 (worst pain imaginable) approximately 2 seconds into each of the three temperature plateaus (T1, T2, T3). OA was calculated using the difference between T3 and T1 pain ratings.

Temporal summation of pain (TSP).—TSP was assessed using standardized weighted pinprick applicators (128mN, 256mN, and 512mN), similar to those described by Rolke et al.⁴⁸ The pinpricks were applied to the dorsal aspect of the index finger between the first and second interphalangeal joints of each hand, and participants were asked to rate their pain on

a scale from 0–10. The highest weighted probe that induced a pain score between 1–3/10 on single stimulation was then selected for repeated administration (temporal summation testing). After a break of at least 10 seconds after the single application, a train of 10 stimuli were applied at the same spot at a rate of 1 stimulation/sec. The subject again rated pain on a scale of 0–10 after the 5th and 10th stimulus. TSP was calculated using the difference between 10th stimulation pain score and the single stimulation pain score.

Conditioned pain modulation (CPM).—CPM is a phenomenon where one stimulus inhibits the perceived pain of another. A test stimulus is first applied alone and then in the presence of another painful conditioning stimulus. CPM is the difference in perceived pain from the test stimulus alone vs. in the presence of the conditioning stimulus.⁶⁰ In the current study, PPT_h measured over the trapezius served as the test stimulus, and cold pain applied to the hand on the contralateral side using immersion in a cold water bath was the conditioning stimulus, thus meeting the recommendation that the CPM paradigm employ both mechanical (i.e., pressure pain) and thermal (cold pain) stimuli.⁶¹

Participants' PPT_h over the left trapezius had been previously tested in isolation (see "Pressure Pain" above), which served as the baseline PPT_h. In the CPM paradigm, participants were asked to briefly submerge their right hand up to their wrist in the cold-water bath (set at 6°C) for five seconds. After five seconds, the tester began assessing the participant's PPT_h (i.e., the conditioned PPT_h). CPM was measured once per condition (white noise, Unwind, favorite music) and was calculated as shown in the following equation:⁴⁶

$$((\text{Conditioned PPT}_h - \text{Baseline PPT}_h) / \text{Baseline PPT}_h) * 100$$

Situational Pain Catastrophizing

After each QST session, subjects completed the 6-item Situational Pain Catastrophizing Scale (SPCS) [23] to assess participants' negative, pain-related thinking that occurred in response to the experimental pain stimuli.^{54, 55} Participants were instructed to think about the most recent QST session and rate the statements (e.g., "I felt that I couldn't stand it") on a scale from 0 (not at all) to 4 (all the time). SPCS statements after each QST session were summed, with higher scores reflecting greater situational pain catastrophizing.

Music Conditions

All study sessions began with a baseline administration of QSTs, which occurred in silence. This round of testing served as a training session to introduce participants to the experimental paradigm, answer questions, and teach the protocol to ensure subsequent runs across the three conditions would be smoother and more uniform. Participants then completed three additional rounds of QST in the different conditions: 1) white noise, 2) Unwind, and 3) favorite music. The order of the conditions was randomized for each participant using the "Randomization" function in REDCap,²⁹ and all participants experienced all conditions.

In the white noise condition, participants listened to a one-hour track titled “White noise” from Apple Music. As defined, white noise maintains the same intensity at all audible frequencies,³³ dissimilar from the two music conditions, where frequency and intensity of sound elements vary. The Unwind smartphone-based app (Unwind; Bose Corporation, Boston, MA, USA) has five different instrumental tracks, all of which were created by a machine learning algorithm that combined elements of various human-composed instrumental soundtracks. These tracks were designed to be relaxing and have been previously employed in a study among patients presenting to the ED.^{7, 8, 19} Participants were presented with a list of tracks, of which they could listen to a short sample before selecting one of the five tracks to listen to during one round of QST. All tracks were approximately ten minutes in length, and thus these tracks were partially repeated during the course of the QST testing round. In the favorite music condition, participants listened to their self-selected favorite songs sent to study staff prior to visit. When asked to provide songs for the session, study staff told participants, “These [songs] do not have to be anything specific other than songs you enjoy listening to.” We requested that participants select seven songs to allow sufficient time to cover the QST session (pilot testing had indicated 20 minutes as longest possible duration), considering that most songs are at least three minutes in length, thus ensuring the completion of QST procedures without silence or repetition of songs. During the QST session, the seven selected songs were played in a randomized order using the shuffle feature on Apple Music. Depending on how long each session took to complete, all songs may not have been played. In all three conditions, a JBL Charge 3 speaker was used. Participants were asked to adjust the volume of the speaker to a comfortable level, such that they were still able to clearly hear and respond to instructions during testing.

Statistical analysis

Participants’ pain, situational catastrophizing, and demographic characteristics were summarized using frequencies, percentages, means, and standard deviations. Because the data were not normally distributed, non-parametric Friedman tests were used to assess differences in QST pain outcomes (PPT_h and PPT_o, HPT_h and OA, TSP, and CPM) and situational catastrophizing across the three conditions (p .05). Post-hoc analyses with Wilcoxon signed-rank tests were conducted to make pair-wise comparisons among the three conditions when appropriate (p .05). Corrections for multiple comparisons were not conducted. For each pain variable, the effect size was calculated by dividing the test statistic by the square root of the number of observations.³⁴ Spearman correlations were used to explore whether situational pain catastrophizing reported during each condition (white noise, Unwind, favorite music) was significantly associated with pain variables.

A power analysis was conducted to determine the minimum sample size to test our study aim. Results indicated that a required sample size to achieve 80% power for detecting an effect at a significance level of .05 was 64. Taking potential dropout into account, 70 participants were planned for recruitment. All data were analyzed using SPSS (v28).

RESULTS

Participant characteristics

Participant characteristics are summarized in Table 1. Screening identified 101 eligible participants, with some participants not scheduling a visit or otherwise declining participation (Figure 1). Ultimately, 70 participants presented for visit, provided informed consent, and completed all QST sessions and questionnaires. Participants were majority female (67%), had a college degree or higher (79%), and had an average age of 35 years ($SD=18.3$; range: 18–86). Participants self-identified as White (59%), Asian (23%), Black (6%), Hispanic/Latino (14%), and other (7%). Participant characteristics were similar across the six randomized groups (six possible orders of presentation of the three conditions), making it less likely that order of presentation could account for any observed effects.

For the favorite music condition, 461 total tracks were compiled. To give a descriptive account of what type of music participants chose to listen to during the session, each music track was categorized based on genre. Chosen songs belonged to a variety of genres, including Pop (26%), Alternative/Indie (25%), R&B/Soul/Disco (13%), Country (9%), Hip-Hop/Rap (8%), Rock/Metal (7%), Electronic/Dance/EDM (5%), Folk (4%), Jazz (2%), and Classical (1%). Many participants had multiple genres represented among the seven songs in their playlist (see Supplemental Table S2 for a full list of favorite songs and genres).

Music and Pain Characteristics

Pressure Pain Threshold (PPT_h) and Tolerance (PPT_{ol})—Forearm pressure pain threshold (PPT_h) was significantly different between the three conditions ($\chi^2(2)=33.21$, $p<.001$). Specifically, post-hoc pairwise group comparisons revealed that participants had a significantly higher forearm PPT_h during the favorite music condition compared to both the white noise and Unwind conditions (Table 2). A similar pattern was found for forearm pressure pain tolerance (PPT_{ol}) ($\chi^2(2)=34.40$, $p<.001$), such that participants had a significantly higher PPT_{ol} during the favorite music condition compared to the white noise and Unwind conditions (Table 2). No significant difference was observed between the Unwind and white noise conditions for either forearm PPT_h or PPT_{ol}.

To gain further insight into how the exposure to music (favorite music or Unwind) vs. no music (white noise) played a role in pain processing, we explored the percent difference in pain processing between the favorite music vs. white noise conditions ((favorite music – white noise/white noise)*100), as well as the Unwind vs. white noise conditions ((Unwind–white noise/white noise)*100). Positive numbers indicated a decrease in pain sensitivity (higher PPT_h or PPT_{ol}). There was some variation among individuals, but when expressing decreased sensitivity in the two music conditions (favorite music and Unwind) compared to the white noise condition, favorite music appeared to impact participants' PPT_h and PPT_{ol} more consistently than Unwind (Figure 2).

Similarly, there was a significant difference in trapezius PPT_h ($\chi^2(2)=6.01$, $p=0.050$) and PPT_{ol} ($\chi^2(2)=9.07$, $p=.011$) across the three conditions, such that participants' trapezius PPT_h was higher during the favorite music condition compared to the white noise condition, and trapezius PPT_{ol} was higher during the favorite music condition compared to both the

Unwind and white noise conditions (Table 2). There was not a significant difference in trapezius PPT_h between the favorite music and Unwind condition. No significant differences in trapezius PPT_h or PPT_{ol} were observed between the Unwind and white noise conditions.

Heat Pain Threshold (HPT_h) and Offset Analgesia (OA)—We also observed a significant difference in heat pain threshold (HPT_h) across the three conditions ($\chi^2(2)=7.32$, $p=.026$). Post-hoc analyses revealed that participants' HPT_h was significantly higher during the favorite music condition compared to the Unwind and white noise conditions (Table 2). No significant difference in HPT_h between the Unwind and white noise conditions was observed.

We employed an offset analgesia (OA) paradigm, where pain at a temperature either before (T1) or after (T3) a more painful stimulus (T2) is compared, with the time at T3 typically showing a disproportionately greater decrease in pain perception (offset analgesia=T3-T1).⁴⁵ When analyzing pain ratings at these three timepoints, we observed that the initial heat pain ratings of participants' at T1 were significantly different among the three conditions ($\chi^2(2)=14.99$, $p<.001$), with lower pain ratings during the favorite music condition compared to the Unwind and white noise conditions. However, pain ratings at T3 were not significantly different across conditions ($p>.05$). Correspondingly, there was a significant difference in OA ($\chi^2(2)=10.02$, $p=.007$) across the three conditions, such there was significantly *less* OA in the favorite music condition compared to the Unwind and white noise conditions. No significant difference in OA was observed between the Unwind and white noise conditions (Figure 3).

Conditioned Pain Modulation (CPM)—Conditioned pain modulation (CPM) was determined by examining percentage change in trapezius PPT_h (test stimulus) comparing baseline PPT_h to the PPT_h in the presence of cold pain in the contralateral hand (conditioning stimulus). An increase in the PPT_h in the presence of the conditioning stimulus (cold water bath) indicates effective endogenous modulation of pain (i.e., pain inhibition). Table 2 highlights the mean percentage of change between the baseline and conditioned pain scores (calculated CPM), highlighting the fact that CPM was successfully induced by this QST protocol. However, there was no significant difference in CPM between the three conditions ($\chi^2(2)=1.58$, $p>.05$; Table 2).

Temporal Summation of Pain (TSP)—Temporal summation of pain (TSP) was successfully induced among participants by the QST protocol, with participants reporting more pain at the 10th stimulus compared to the single stimulus. However, TSP did not significantly differ across the three conditions ($\chi^2(2)=2.54$, $p>.05$; Table 2).

Music and Situational Pain Catastrophizing

There was a significant difference in situational pain catastrophizing across the three conditions ($\chi^2(2)=14.31$, $p<.001$). During the favorite music condition, participants rated their degree of catastrophic thinking about the pain they experienced in response to QST (SPCS score) significantly lower than catastrophizing during the Unwind and white noise

conditions (Table 2). No significant difference in situational pain catastrophizing was observed between the Unwind and white noise conditions.

Situational Pain Catastrophizing and Pain Sensitivity

We explored whether situational pain catastrophizing was related to pain sensitivity within each of the three conditions to determine whether catastrophizing may importantly be associated with pain processing. Interestingly, within each condition (white noise, Unwind, favorite music) situational catastrophizing reported in that condition was not significantly related to any pain outcome in that condition ($p > .05$; see Supplemental Table S3).

DISCUSSION

This QST, lab-based study of healthy adults investigated the modulatory role of different types of music, compared to white noise, on several aspects of pain processing and situational pain catastrophizing. Individuals had a broad range of musical tastes, with their favorite songs including a wide range of genres and artists, suggesting that it might be difficult to choose the perfect “one-size-fits-all” music intervention (see Supplemental Table S2 for complete song list and categorization by genre). The variation in music choice between participants, as well as sometimes within an individual’s favorite playlist, precluded our ability to assess the relative efficacy of any particular type of music. However, participants’ PPT_h, PPT_o, and HPT_h were significantly higher during the favorite music condition compared to both the Unwind and white noise conditions, indicating less pain sensitivity when listening to self-selected favorite music. Similarly, situational pain catastrophizing was significantly lower in the favorite music condition. Previous studies have shown variable analgesic benefits of music among participants.^{7, 22, 27, 31, 35, 38, 40} The current findings may add insight into the source of this variability, in that we observed a more profound response to one’s own personal favorite music than to a pre-selected relaxing music app with less choice and variety of music, or white noise. While it may be that some participants derived analgesic benefit in these conditions, favorite music resulted in an overall greater, more consistent effect on pain sensitivity, as well as negative pain-related thinking during pain testing.

Prior research has suggested that an individual’s music preference may be important to consider when exploring how music modulates pain processing, with certain songs evoking more or less enjoyment and effect, depending upon the individual.^{6, 31, 64} Evidence suggests that music may change both experimental and clinical pain compared to a control condition,^{13, 20, 27} including our previous work, which demonstrated increases in pain threshold and tolerance among individuals who listened to Unwind.^{5, 7} Previous research has shown that regardless of music type, participant choice has a significant greater analgesic effect than pre-selected music.²¹ The present work suggests that these effects appear more pronounced when individuals are allowed to choose their own preferred music.³¹ Although we did not directly manipulate the degree of choice, or isolate it as a factor, it is possible that the ability to choose and recognize one’s music during a painful, stressful experience may also provide a sense of control, which may be of particular importance when one is experiencing pain in a clinical context or situation which makes one feel powerless.

Thus, when considering best how to employ music as an adjunctive strategy to manage clinical pain, it seems likely that preference may maximize music's impact on pain threshold and tolerance. Music may also divert attention from painful stimuli by providing a more salient stimulus, in the form of memories, associations, and emotions that are evoked by their favorite song. Distraction and enhanced sensory engagement has previously been shown to effectively alter pain processing^{10, 50} and has frequently been postulated as a possible mechanism for music-induced reductions of pain.^{5, 10, 27, 28, 44, 49, 50, 56} Positive expectancy of an effect of music has been previously postulated as a possible mechanism,³⁷ although the addition of positive expectancy to favorite music did not necessarily augment the analgesic efficacy of favorite music.³² In the current study, to gather information on participant-selected favorite music, we exposed participants to knowledge of the research design, and likely induced some expectations in participants.

Interestingly, we found evidence of favorite music's impact on pain processing only for certain QST stimuli. Similar to previous reports, we observed reductions in PPTh and PPTol,⁷ as well as HPTH.⁴⁹ Of note, we did not observe differences in the degree of CPM or TSP across the three conditions. It is possible that, although we observed effective CPM and TSP using our QST methodology, these effects were relatively modest (mean 15% increase of PPTh with CPM, two point mean increase in pain for TSP), which, combined with the high degree of variability among participants, may have made group differences more difficult to discern. Potentially, a ceiling effect could have limited discernment of music's effect on CPM. If endogenous inhibitory capacity was maximally elicited by the conditioning stimulus in the CPM paradigm, it is possible that no additional inhibition by music was detectable. Alternatively, if music itself modulates central processing of pain, it may be replicative of the effect of these central pain modulatory processes.

We were also interested in assessing the impact of music on offset analgesia (OA), which consists of a disproportionate decrease in stimulus intensity after experience of a noxious stimulus.^{1, 26, 63} We observed effective OA, with a significantly lower pain rating at T3 compared to T1, and in this case we did observe group differences, with participants exhibiting less OA during the favorite music condition. One potential driver of this difference is the significantly lower starting point of pain at T1 in the favorite music condition, representing a floor effect (i.e., less overall potential for pain scores to be reduced at T3 compared to T1, resulting in overall less OA). Our OA protocol did not include a constant temperature control condition, in the interest of being cautious about total exposure and efficient timing to allow four rounds of testing (baseline + three conditions). Future research might probe whether a different impact of music on OA would be discernable if a condition-specific T1 temperature setting was used, or a constant temperature control was used, as prior research has indicated within- and across-stimulus measures may reflect different neural mechanisms.^{12, 62}

Pain catastrophizing is a negative psychological process which has an established association with worse clinical pain.^{2, 3, 15, 16, 41, 59} Our findings agree with previous reports that sensory engagement through music or other means can reduce pain catastrophizing and negative affect.^{9, 10} Importantly, these effects may extend to situational pain catastrophizing (i.e., catastrophic thinking about pain during the procedure of pain testing), since

participants reported lower SPCS scores during the favorite music condition. Similar to our previous study, we did not observe an impact of relaxing music (Unwind) on SPCS, compared to white noise.⁷ Although we did not observe a significant association between situational catastrophizing and pain sensitivity (see Supplemental Table S3), our design was not optimized to assess a mediational role of catastrophizing reduction in music's analgesic efficacy. This impact of favorite music on catastrophizing during a painful procedure (QST) may bode well for the efficacious application of music as an adjunct analgesic during painful clinical procedures, and in the perioperative or other acute care settings, particularly among individuals who have relatively greater catastrophizing.⁹

Limitations

When interpreting these findings, it is important to consider several limitations of this study. First, participants were not blinded to the music conditions or the researchers' interest in understanding the impact of music on pain. Second, while the current study aimed to compare the analgesic effect of two music conditions and a control condition, we did not investigate the mechanism(s) by which these effects were generated. For example, while participants were granted choice between five tracks during the Unwind app, and in the selection of their own self-described favorite music, choice and control were still limited to varying degrees. The playlist of favorite music was played in a random order during testing, removing agency in choice of the order of song selection, and due to time constraints, not all seven tracks were usually played during testing. We also did not ask participants to rate their enjoyment of the three conditions, precluding assessment of enjoyment as an important variable. Future studies designed to isolate music elements, expectation, distraction, choice, or psychosocial modulation are required to delineate the mechanism(s) of the analgesic effects of music. However, it seems likely that the mechanistic importance of any of these elements may be variably present in different individuals, just as music may be variably effective among individuals. Third, the duration of the beneficial impact of music on clinical pain and pain catastrophizing remains unknown, as these were brief and controlled applications of pain.

Finally, although ranging in age, study participants were predominantly highly educated, and White, limiting the generalizability of our findings. Future research examining the impact of music interventions on patients with acute procedural or chronic pain should include more diverse samples to increase generalizability and help determine whether this intervention could be used in practical clinical settings and to determine its relative efficacy among different individuals in different settings. Employing music interventions among chronic pain and surgical patients will allow assessment of the best and most efficacious application of music, as well as determine whether these findings generalize to clinical samples.

Future Directions

Previous studies have reported that music can reduce clinical pain,^{11, 22, 35, 36} is particularly beneficial as an adjunctive therapy in conjunction with pharmacological therapies for pain management, and may allow a decrease in opioid dose needed or reduce exposure to opioids. Indeed, prior research has demonstrated a decrease in opioid use with the addition of music.^{5, 14, 27, 43, 57} Additionally, music interventions are easy to implement and highly

accessible, whereas other behavioral interventions are often expensive, require more effort, and may not be as accessible to everyone. Future studies might further probe the potential of music personalization through making use of the vast array of music platforms and listening modalities. Although the present findings show benefits in healthy adults, future studies in patients with different types of chronic pain may allow assessment of the potential clinical benefit and give further insight about which aspects of nociception and psychological processing may be modulated by different types of music. Similarly, longitudinal studies, involving daily, at home use of music may extend the initial evidence presented here.

CONCLUSION

An individual's favorite music resulted in lower pain sensitivity compared to white noise and relaxing music (Unwind), most notably pressure pain threshold and tolerance and heat pain, as well as situational pain catastrophizing, in healthy volunteers. More research is necessary to explore whether the beneficial impact of preference of one's own favorite music extends to clinical settings or patients with chronic pain, and what mechanism(s) may explain the effects observed by favorite music.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Disclosures:

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Highlights

- Impact of music on pain processing was assessed using quantitative sensory testing (QST).
- Participants had lower pain sensitivity and less catastrophizing during their favorite music.
- Patient-selected favorite music may be an effective and low-risk adjuvant analgesic.

PERSPECTIVE:

This article presents evidence that participant-chosen favorite music can alter several aspects of nociceptive processing, including catastrophic thinking about pain, compared to white noise or relaxing music. Employing an individual's favorite music during episodic or procedural pain might represent a cost effective adjunctive analgesic strategy.

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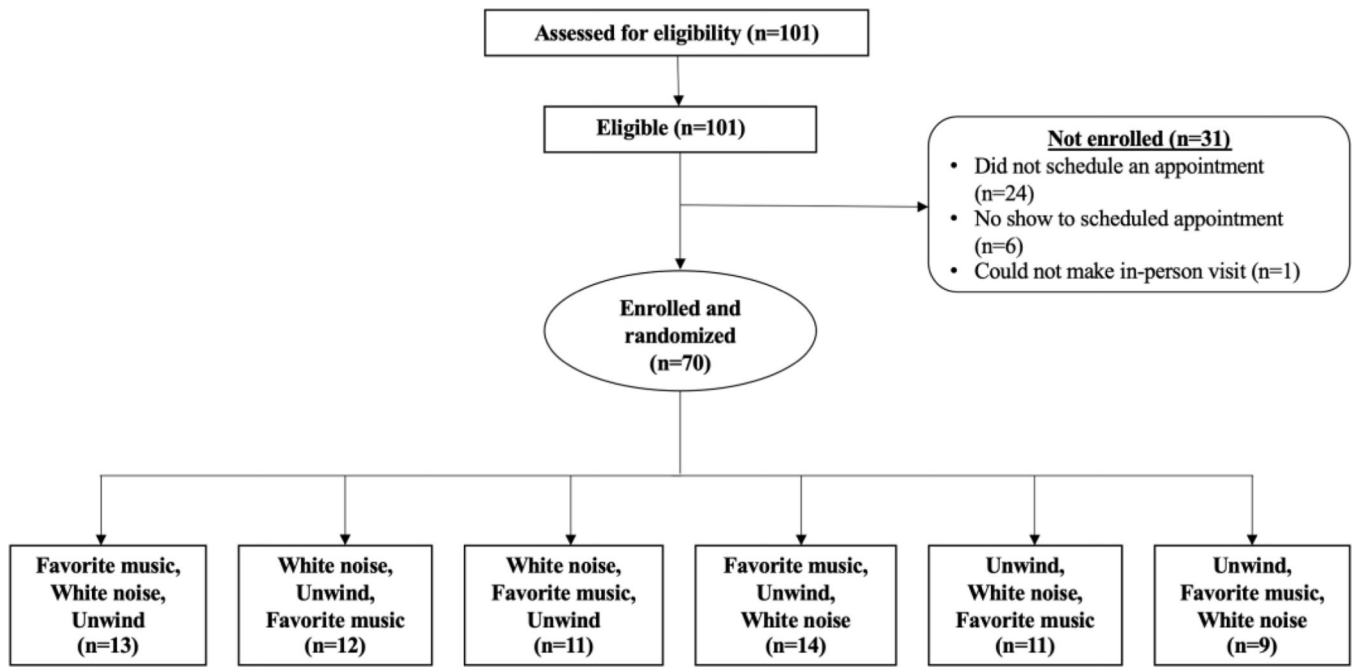


Figure 1. Study flow diagram.

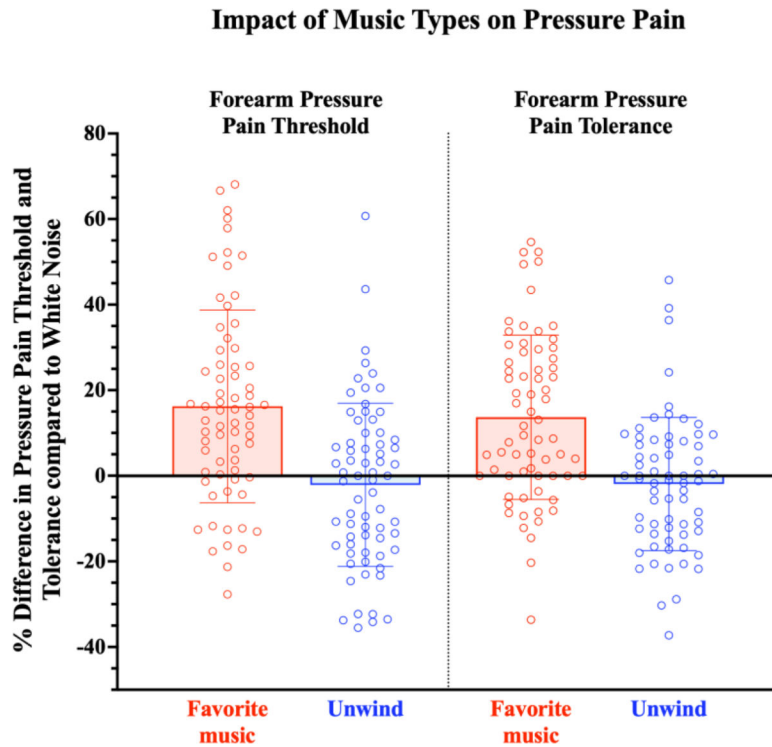


Figure 2. Percent difference in forearm pressure pain threshold (PPT_h) and tolerance (PPT_{ol}) when listening to favorite music and relaxing music (Unwind) compared to white noise. Participants reported a greater increase in PPT_h and PPT_{ol} during the favorite music condition compared to white noise (PPT_h mean change: 16% ± 23%; PPT_{ol} mean change: 14% ± 19%), indicating a *decrease* in pain sensitivity. Participants reported little change in PPT_h during the Unwind condition compared to white noise (PPT_h mean change: -2% ± 19%; PPT_{ol} mean change: -2% ± 16%). Percent difference in PPT_h during favorite music compared to white noise was calculated using the formula $((\text{favorite music} - \text{white noise}) / \text{white noise}) * 100$. Percent difference in PPT_h during the Unwind compared to white noise was calculated using the formula $((\text{Unwind} - \text{white noise}) / \text{white noise}) * 100$.

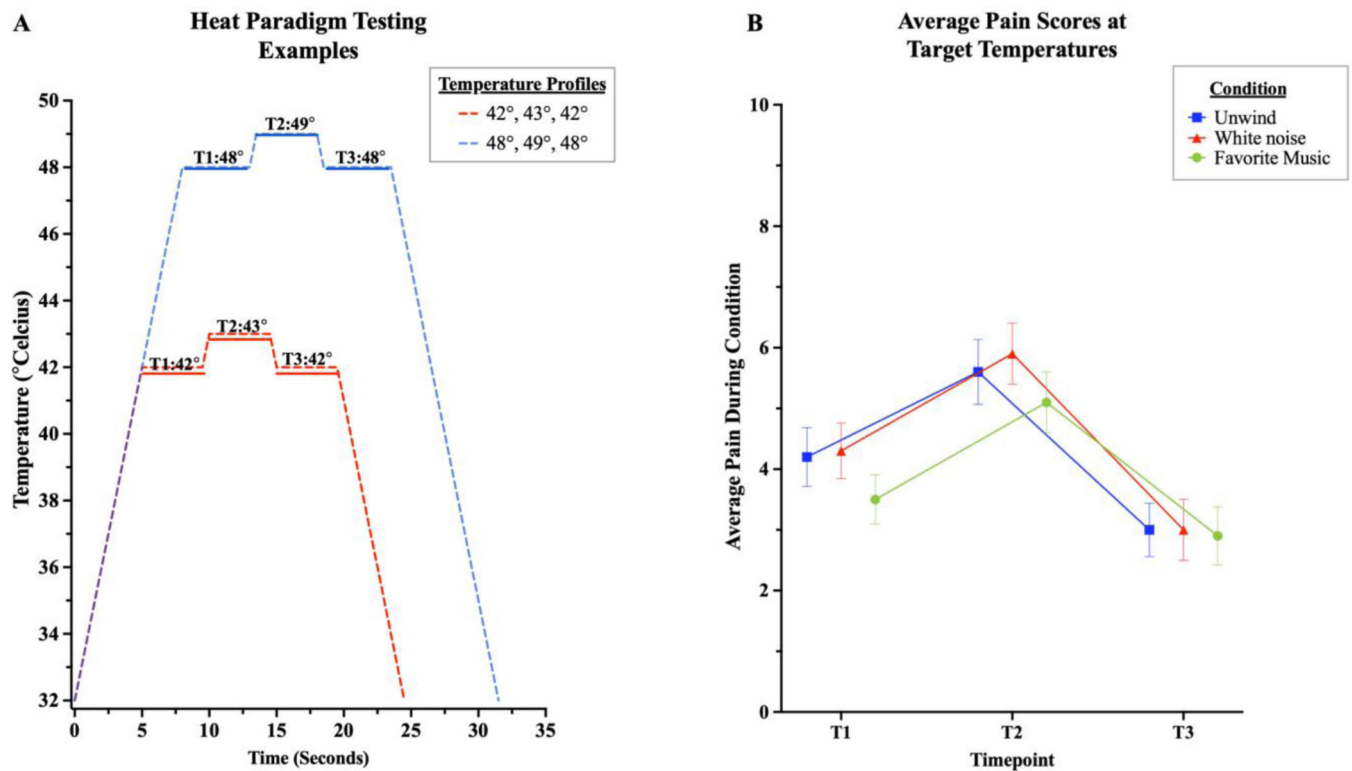


Figure 3. Offset analgesia (OA) paradigm.

A. The temperature profile used was tailored to each participant based on heat pain thresholds determined in the baseline run of QST, and identical temperature profile used across all three conditions. Example profiles are shown for participants with 5/10 heat pain thresholds closest to 43 and 49 on baseline testing. B. Average pain rating during the OA paradigm, shown across conditions. Pain ratings were significantly lower at T1 during the favorite music condition and were similar across the three conditions at T3. OA, calculated as difference in pain rating at T3-T1, was less during favorite music compared to the Unwind and white noise conditions.

Table 1.

Demographic characteristics

Variables	M (SD) or N (%)
Age (years)	35.0 (18.3)
Gender	
Male	23 (32.9%)
Female	47 (67.1%)
Race	
White	41 (58.6%)
Black	4 (5.7%)
Asian	16 (22.9%)
American Indian/Alaskan Native	1 (1.4%)
Other	5 (7.1%)
Prefer not to say	1 (1.4%)
More than one race	2 (2.9%)
Ethnicity	
Not Hispanic or Latino	59 (84.3%)
Hispanic or Latino	10 (14.3%)
Prefer not to say	1 (1.4%)
Marital Status	
Single, never married	46 (65.7%)
Married or in partnership	13 (18.6%)
Separated or divorced	5 (7.1%)
Together/living with partner	5 (7.1%)
Widowed	1 (1.4%)
Education	
High school/GED	2 (2.9%)
Some college	13 (18.6%)
Bachelor's degree	30 (42.9%)
Graduate/Professional degree	25 (35.7%)

Abbreviations: M=Mean; SD=Standard deviation; N=Number.

Table 2.

Pain and Catastrophizing Across Conditions

VARIABLES	UNWIND (U)		WHITE NOISE (WN)		FAVORITE MUSIC (FM)		P VALUE	EFFECT SIZE		
	M (SD)	M (SD)	M (SD)	M (SD)	FM VERSUS U	FM VERSUS WN		U VERSUS WN		
QST										
Forearm: pain pressure threshold ^{*, †} (lbs)	6.69 (3.70)	6.95 (3.78)	7.88 (3.98)	<.001	.43	.39	.11			
Forearm: pain pressure tolerance ^{*, †} (lbs)	9.81 (4.65)	10.08 (4.70)	11.11 (4.72)	<.001	.46	.40	.15			
Trapezius: pain pressure threshold ^{*, †} (lbs)	10.68 (4.47)	10.36 (4.49)	11.13 (4.82)	.050	.14	.22	.07			
Trapezius: pain pressure tolerance ^{*, †} (lbs)	13.85 (4.63)	13.70 (4.63)	14.48 (4.57)	.011	.28	.27	.02			
Heat pain threshold ^{*, †} (°C)	41.12 (2.87)	41.00 (3.30)	41.81 (3.25)	.026	.19	.20	.00			
Offset analgesia (T3-T1) ^{*, †} (change in NRS at T3-T1)	-1.20 (1.79)	-1.25 (1.82)	-0.60 (1.85)	.007	.24	.26	.00			
Offset analgesia: time 1 ^{*, †} (NRS)	4.16 (.96)	4.27 (1.89)	3.45 (1.65)	<.001	.28	.36	.03			
Offset analgesia: time 2 ^{*, †} (NRS)	5.58 (2.19)	5.87 (2.12)	5.09 (2.07)	<.001	.24	.35	.14			
Offset analgesia: time 3 (NRS)	2.96 (1.83)	3.01 (2.06)	2.85 (1.98)	.680	.08	.09	.02			
Conditioned pain modulation (% change from PPTH)	15.70% (24.62)	13.53% (25.76)	13.05% (20.37)	.453	.03	.09	.04			
Pinprick temporal summation (10th-baseline NRS)	2.53 (1.78)	2.43 (1.82)	2.32 (1.73)	.281	.07	.13	.06			
Psychosocial										
Situational pain catastrophizing ^{*, †} (range, 0–24)	1.31 (2.30)	1.61 (2.18)	0.87 (1.85)	<.001	.28	.21	.15			

Abbreviations: QST, quantitative sensory tests; NRS, numerical rating scale; PPTH, pressure pain threshold.

* Significant difference between the favorite music and white noise conditions ($P < .05$).

† Significant difference between the favorite music and Unwind conditions ($P < .05$). Higher scores for threshold and tolerance reflect lower pain sensitivity. Lower scores on offset analgesia reflect lower pain scores given at the designated temperatures. Higher scores of CPM reflect greater modulation of pain (less sensitive), and higher scores on pinprick temporal summation reflect greater pain amplification.