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RESEARCH ARTICLE

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The effect of music listening style on music-induced analgesia

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ABSTRACT

Music listening may decrease pain via psychobiological mechanisms. Music listening style (MLS) influences music processing: Music empathizers (ME) focus on emotional aspects of music, whereas music systemizers (MS) focus on structural aspects, potentially affecting processes of music-induced analgesia. The effects of the MLS on music-induced analgesia might depend on the source of music selection (i.e. who selects the music) and gender. Different psychological mechanisms, such as stimulus-induced emotions and subjective stress, might mediate the effects of an empathizing versus systemizing MLS on pain. The purpose of this study was (a) to test how MLS influences pain during music listening, depending on the source of music selection and gender, and (b) to explore underlying psychological mechanisms. 61 participants (age: $M=24.23$, $SD=3.85$; four groups: male/female ME/MS) listened to stimuli (participant-selected/researcher-selected music/control) during cold pressor tests. Pain intensity, pain tolerance, and psychological mechanisms (stimulus-induced emotions, subjective stress) were repeatedly measured. Multilevel and mediation analyses were conducted. The MLS did not directly influence pain, but female ME were most pain sensitive with participant-selected music. Pain was tolerated longest for participant-selected music. The effect of MLS on pain intensity was not mediated by stimulus-induced emotions but by subjective stress. Our results indicate that music increases pain tolerance the most when participants select it. However, we found initial evidence that women scoring high on ME show increased pain when listening to their self-selected music. We also found initial evidence for the importance of subjective stress as a potential mechanism in the context of music-based pain management.

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KEYWORDS
Music listening style; music empathizing; music systemizing; pain; psychological mechanisms; emotions; subjective stress

Introduction

Music has become an important tool in pain management (Arnold et al., 2024; Browning, 2000; Lee et al., 2023). Previous studies have suggested that personality variables might influence music-induced analgesia (Howlin & Rooney, 2021; Nyakairu Doreen, 2024), such as the music listening style (MLS) (Kreutz et al., 2008; Linnemann et al., 2018), which indicates which aspects of music a person focuses on during music listening. While so-called music empathizers (ME) focus on emotional aspects, music systemizers (MS) focus on structural aspects (Kreutz et al., 2008) (for example items see S1). Given the different focus on specific aspects of music, it is conceivable that separate psychological processes might underpin music-induced analgesia in ME and MS, such as emotion regulation mechanisms or attention-related processes. While the effects of the MLS on pain have not yet been investigated, a study on cognitive agency in music interventions found increased pain tolerance in the context of music listening in individuals with higher trait empathy, which was also associated with higher emotional engagement with

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music (Howlin & Rooney, 2021). While this study has investigated individuals concerning their trait empathy toward other persons, it is conceivable that the analgesic effect of music may even be stronger in individuals who strongly empathize with the music itself. In line with this, if individuals generally empathize strongly with music (i.e. ME), one could assume that their emotional engagement with music might be strong, potentially serving as a major mechanism for the pain-reducing effects of music for these individuals and possibly associated with strong music-induced emotions. In this context, especially emotionally relevant music (i.e. music selected by participants) could be particularly pain-reducing for individuals who strongly empathize with music (ME). As any music contains structural elements, which MS focus on (Kreutz et al., 2008), MS might show stronger engagement with researcher-selected music than ME, associated with stronger pain reduction.

When investigating the effects of the MLS on pain during music listening, the source of music selection may be relevant, referring to the person who selects the music. In a previous study, a stronger preference for the music genre that participants listened to during a pain test was associated with a prolonged pain tolerance (Van der Valk Bouman et al., 2024). Similarly, previous research revealed stronger music-induced analgesia when participants had at least some control over the selection (Garza-Villarreal et al., 2017; Kühlmann et al., 2018; Vetter et al., 2015). In line with this, favorite participant-selected music reduced pain intensity more than researcher-selected relaxing music and more than silence in a study by Valevicius et al. (2023). In addition, liked music significantly lowered pain ratings to acute painful stimuli compared to disliked music and no music (Lu et al., 2023), and preferred music yielded higher pain thresholds than disliked music and lower perceived pain intensity during the stimulus (Timmerman et al., 2023). Furthermore, participants' pain threshold and pain tolerance were reported to be higher when listening to favorite music compared to unwind music and white noise (Colebaugh et al., 2023). It therefore seems that especially emotionally relevant (participant-selected) music has stronger pain-reducing effects than emotionally less relevant music. This effect might be especially strong for those who interpret music more emotionally (ME).

Furthermore, as gender effects were observed in the occurrence of music listening styles, these must also be taken into account when investigating the effects of MLS in the context of music-induced analgesia: Women are more often categorized as ME, and men more often as MS (Linnemann et al., 2018). While no gender differences emerged regarding music-induced analgesia during medical procedures (Kühlmann et al., 2018), a study on music presentation during experimentally-induced pain revealed different results: The increase in pain tolerance from a condition with no music presentation during experimentally-induced pain to a condition with preferred music during experimentally-induced pain was stronger in healthy women than in healthy men (Ghaffaripour et al., 2013). However, the MLS of the investigated persons in these studies is unclear. It is conceivable that an empathizing MLS, which is more prominent in women than in men (Linnemann et al., 2018) plays a role for the observed gender effects in the study by Ghaffaripour et al. (2013) rather than gender alone. In turn, it is necessary to consider possible gender effects when investigating MLS in the context of music-induced analgesia. To date, it is unclear whether pain responses of ME and MS indeed differ between participant-selected and researcher-selected music and whether these effects are gender-specific. Therefore, the present study aims to investigate the effects of the MLS on pain and whether they depend on influences of the source of music selection (i.e. who selects the music) and gender.

With regards to potential mechanisms, specific psychological processes have been suggested to underlie music-based analgesia, such as, for example, stimulus-induced emotions (Lunde et al., 2019) and subjective stress (Linnemann et al., 2015; Wuttke-Linnemann et al., 2020). After a closer look at the literature of music-induced analgesia in the context of the MLS, it becomes clear that there may be separate psychological processes underlying music-induced analgesia in ME and MS. So far, the underlying mechanisms of music-based analgesia in ME and MS are unclear. Following the aforementioned reasoning that ME may show higher emotional engagement with music in the context of music-based analgesia than MS, this would suggest that stronger emotions might be induced by music in ME than in MS, which in turn might be associated with a reduction in pain. It is therefore possible that listening to music could function particularly in ME as an important emotion regulation mechanism when pain occurs. Similarly, due to the focus on emotional aspects of music in ME, listening to specifically relaxing music could possibly reduce subjective stress more strongly in ME than in MS. It is still unclear and should be further

investigated whether music-induced emotions and subjective stress play a stronger mediating role in ME than in MS. Therefore, as a secondary question, the present study aims to investigate whether music-induced emotions and subjective stress play a stronger mediating role in ME than in MS.

This study investigates the role of the MLS for music-induced analgesia, potential influences of the source of music selection and gender, and potential underlying psychological mechanisms of the effects of the MLS on music-based analgesia (for detailed hypotheses see Table 1). We assume that (1) the effects of the MLS on pain depend on the source of music selection (i.e. who selects the music) and gender, and that (2) the effects of the MLS on pain are mediated by music-induced emotions and subjective stress.

Methods

Design

In the current experimental laboratory study examining the effects of MLS on pain responses, healthy ME and MS underwent three conditions (participant-selected music, researcher-selected music, sound of lapping water; randomized order) during a cold pressor test (CPT). Every participant underwent all three conditions, with each condition being presented on a different day (see Figure 1). Measurements took place between September 2014 and May 2016, and assessments were conducted between 11:30 and 18:00. This study is part of a larger project that received approval from the ethics committee of the University of Marburg (Department of Psychology, reference number 2014-25k). Two further manuscripts are currently published/ in preparation with one covering the effects of music listening on stress and mood responses (Maidhof et al., 2023) and the other manuscript targeting characteristics of music stimuli (Maidhof et al., In prep.). The study was conducted following the guidelines of the Declaration of Helsinki.

Participants

After the recruitment phase (for details see S2), participants were assessed for MLS using the Music-Empathizing-Music-Systematizing (ME-MS) Inventory. Eligibility criteria (for details see S3) were an empathizing or systemizing MLS, fluent German language skills, age 18–35 years, body mass index (BMI) < 30, no chronic physical disease (cardiovascular disease, arterial occlusive disease, Raynaud's syndrome, hearing impairment, severe visual impairment), no intake of pain medication, no illegal drug consumption, smoking < five cigarettes per week, no medication intake or treatment with neuroendocrine, autonomic or immunological impact (intake of oral contraceptives was no exclusion criterion), no current psychological disorder, no menstrual irregularities, no pregnancy, no breastfeeding, and no music-related profession. Participation was voluntary. All participants signed informed consent before participation. As compensation, each participant received either 40 Euros or course credit.

Sample size

The sample size was calculated using an online sample size calculator for hierarchical multiple regression (Soper, 2012), applying an anticipated effect size of $f^2 = .20$ (based on the effect size reported in a review

Table 1. Detailed hypotheses.

Research questions	Detailed hypotheses
1. How do MLS and gender modulate the effects of music listening on pain responses?	1. Music listening influences pain differently depending on the MLS. (a) ME will show lower pain intensity response and higher pain tolerance during a pain test when listening to PS favorite relaxing music compared to RS music and a control stimulus. MS will show lower pain intensity response and higher pain tolerance when listening to RS relaxing music compared to ME. (b) Male MS and female ME will show different pain responses compared to male ME and female MS, respectively.
2. Which psychological mechanisms underlie the observed effects?	2. In a secondary analysis, we will investigate which psychological mechanisms play a role in the observed effects of MLS on pain responses. We will explore how MLS influences pain responses via music-induced emotions and subjective stress.

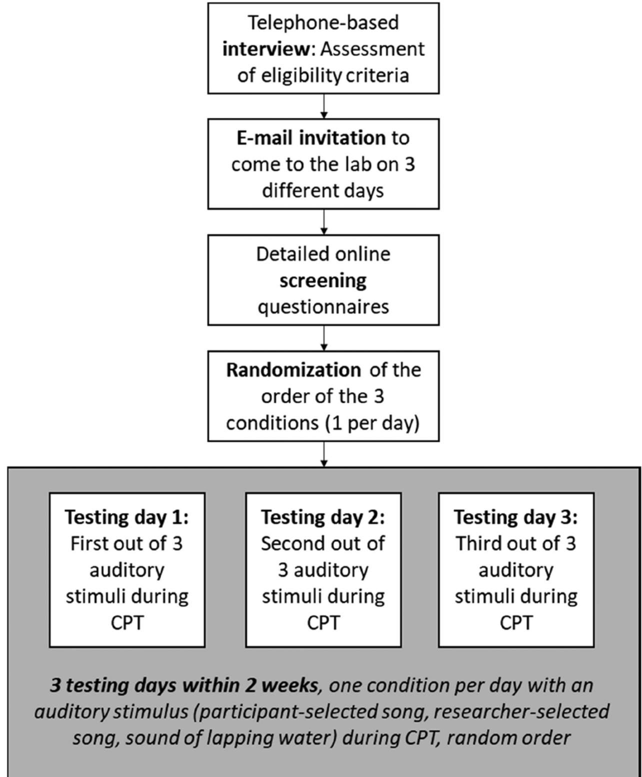

Figure 1. Overall procedure in the course of the study.
Note. CPT = cold pressor test.

for the effect of music on experimentally induced pain (Cepeda et al., 2006)), a power of .80, an alpha level of .05, and four predictors (*MLS, Gender, Time, Condition*), resulting in a minimum required sample size of 60. One additional participant (female ME) was recruited due to a data entry error. Data from this participant were later retained in the analysis to compensate for missing values of other participants, resulting in a total sample size of 61 participants (15 male ME, 16 female ME, 15 male MS, 15 female MS). Importantly, we decided on the sample size based on our main research question. Therefore, the findings of detailed underlying mechanisms need to be only interpreted cautiously as first insights into processes that previous research has widely neglected (see limitations).

Procedure

Participants first completed the ME-MS Inventory to determine their MLS. Those interested in the experimental study were contacted for further screening. A telephone-based interview was conducted to check general eligibility. Subsequently, participants received an e-mail with study details and a consent form. They were invited to come to the laboratory on three days within two weeks and bring self-selected music. The day before the first laboratory appointment, participants completed detailed online screening questionnaires. Female experimenters interacted with the participants in the laboratory. Participants were instructed not to eat in the laboratory, to only drink the water provided by the investigators, and were fitted with electrocardiography (ECG) electrodes. It needs to be noted that ECG data was collected in this project but not analyzed in the current paper. ECG data was analyzed in another paper that was published as part of the same project but with different hypotheses and a focus on the activity of stress-responsive systems (Maidhof et al., 2023). Each laboratory assessment started with a 30-minute baseline resting phase, followed by a saliva collection, stress ratings, and pain intensity ratings. Similar to ECG data, the analysis of saliva samples was not part of the current paper but part of another paper with different hypotheses and a focus on activity of stress-responsive systems (Maidhof et al., 2023). Subsequently, the CPT was introduced, which was described as a test to induce pain and stress. Directly

before the CPT, another saliva sample was collected and stress was rated again. The CPT involved immersing the dominant hand in cold water, while participants listened to one of the three acoustic stimuli. After the CPT, pain tolerance, pain intensity, and subjective stress were measured, and another saliva sample was collected. In the recovery period, both 20 minutes (rec 1) and 35 minutes (rec 2) after the start of the CPT, participants provided another saliva sample and rated subjective stress and pain intensity. This study is part of a larger-scale project that will result in several articles targeting different research questions. Additional questionnaires were therefore collected as part of the project, which are not relevant to this article. For an overview of the study procedures, see Figure 1 and supplement Figure F1.

Acoustic stimuli

Participants were instructed to bring a favorite relaxing song and an arousing song to the laboratory, but only the relaxing song was used as a stimulus. Intervention programs often aim to reduce the activity of stress-responsive systems (Nash & Thebarge, 2006) or increase parasympathetic activity in order to reduce pain (De Couck et al., 2014). As relaxing music appears to be more capable of downregulating the stress-responsive systems than stimulating music (Chanda & Levitin, 2013), we decided to use relaxing music for pain management in our study. In addition to relaxing music, participants were instructed to bring an arousing song for mainly two reasons, namely to disguise the study's intent and to reduce expectation effects. By bringing the two songs to the laboratory, the participants may have assumed that one purpose of the study was to compare relaxing to arousing music. If participants were only asked to bring one song, they may have guessed correctly that one purpose of the study was to compare participant-selected music to researcher-selected music. As a result, participants may have (unconsciously) acted in ways that would confirm what they assumed the researchers aimed to find. Asking the participants to bring an additional arousing song might mask the real hypotheses and reduce expectation effects at least to some extent. However, participants were informed about the true hypotheses of the study after their participation. Beside the relaxing participant-selected song, the other used stimuli were a researcher-selected relaxing song ("Carnelian" from New World Music's "An Introduction to Music to Relax, Inspire and Uplift You", Volume Three) and the sound of lapping water as a control stimulus ("Meeresrauschen" from Arnd Stein's "Naturgeräusche", Volume 1). The order of presentation was randomized. Participants were blinded regarding the stimulus that would be presented via headphones during the CPT on the three days. The acoustic stimuli were presented when the participant submerged his/ her hand into the water of the CPT and stopped when the hand was removed. All stimuli were normalized, and volume was individually adjusted on the first day in the laboratory based on each participant's preferences and was kept constant throughout. Accordingly, volume was the same between the conditions within one participant, and different between participants. For more details, see S4.

Measures

Patient Health Questionnaire

To screen participants' mental health, we used the German version of the Patient Health Questionnaire (PHQ-D; Löwe et al., 2002) before the laboratory assessments. This self-report questionnaire consists of 78 items assessing the most common mental disorders (Gräfe et al., 2004). Many of the items are filter questions and the majority of questions are only asked if the main criteria are fulfilled. Items are rated on two- to five-point scales. Internal consistency for the non-categorical scales of the PHQ-D lies between $\alpha = .79$ and .88 (Gräfe et al., 2004).

ME-MS inventory

To assess participants' MLS, we applied the German version of the self-report ME-MS Inventory (short version) (Linnemann et al., 2018), which comprises 18 items rated on a four-point scale (from "strongly agree" to "strongly disagree"; for example items see S1). Respondents are categorized as ME, MS, or Balanced based on cutoff scores. In the validation study by Linnemann et al. (2018), a confirmatory factor analysis revealed two factors, ME and MS (CFI = .87; GFI = .93), with reported adequate internal consistency ($\alpha_{ME} = .75$, $\alpha_{MS} = .78$).

Pain measures (dependent variables) and apparatus

Cold pressor test (CPT)

For the induction of pain and stress, we applied the CPT, a reliable and valid method to induce pain in laboratory experiments (Edens & Gil, 1995). In the CPT, participants were asked to place their dominant hand in cold water for as long as possible (at approximately 3 °C). If a participant's hand remained in the water for three minutes, he/ she was asked to immediately remove it to minimize cold-related health risks. A custom-made CPT was built for the study, consisting of a bucket filled with water and ice cubes at the bottom covered by a grid to keep the ice cubes in place. The water temperature was controlled with a thermometer. A pump was used to mix the water under the grid where the ice was located, with the water above the grid where the participant's hand was located. In this way, the pump mitigated the temperature increase over time. The advantages of the CPT compared to other experimental pain inductions include its high safety level, a high degree of participant control, and quick pain reduction when the hand is removed from the water (Edens & Gil, 1995).

Pain intensity

To investigate acute pain intensity, participants completed a visual analogue scale (VAS) at five time points during one testing day. Participants rated the item "I feel pain" on a 10-cm scale ranging from 0 (no pain at all) to 100 (maximum pain). VAS constitute a valid measure for the investigation of pain (Ferreira-Valente et al., 2011; Price et al., 1983).

Pain tolerance

Pain tolerance was measured using a stopwatch to record the amount of time (in seconds) for which the hand was immersed in the water during the CPT.

Psychological mechanisms

Stimulus-induced emotions

Stimulus-induced emotions were investigated once in each condition, assessed directly after the CPT. We investigated the two music-induced emotions of joy and anger, as both have been previously evaluated as important active emotions within music interventions (Davis & Mohammad, 2014). Specifically, we used single items ("Did the music/sound of lapping water evoke joy/anger?") rated on a five-point Likert scale ranging from 1 ("not at all") to 5 ("very much"). All items were carefully selected based on previous research (Davis & Mohammad, 2014; Mitchell et al., 2007) and on the consideration that in these cases, single items would provide an adequate assessment of the constructs (Allen et al., 2022).

Acute subjective stress

As a measure of acute subjective stress, participants rated the item "At this moment, I feel stressed" on a 10-cm VAS ranging from 0 (not at all stressed) to 100 (maximally stressed). The VAS is recommended as a useful tool for the assessment of stress due to its similarity with another validated measure of stress (Perceived Stress Scale, PSS), its discriminative sensitivity, observed correlations with similar constructs, and its quick and easy application (Lesage et al., 2012; Lesage & Berjot, 2011).

Statistical methods

Hypothesis 1 was investigated by mixed model analyses using the GAMLj module (Gallucci, 2019) in jamovi (The Jamovi Project, 2020) based on the program R (R Core Team, 2021). For each dependent variable, an individual model was tested. Hypothesis 1a was investigated by a three-way interaction using a mixed model with pain parameters as dependent variables, the two within-subject factors *Time* (five levels: baseline, anticipation, CPT, rec 1, rec 2) and *Condition* (three levels: participant-selected music, researcher-selected music, sound of lapping water), and the between-subject factor *MLS* (two levels: ME,

MS). Slopes of the predictors *Time* and *Condition* were allowed to vary across individuals. As we only investigated pain tolerance once per condition, *Time* was not considered a factor for pain tolerance. Regarding hypothesis 1b, the analysis was similar to hypothesis 1a, with the addition of *Gender* (two levels: male, female) as a between-subject factor. The analyses were based on the procedures described by Field (2013) and in the program instructions (Gallucci, 2019). The module handles missing values by including all assessed data (Gallucci, 2019). Post-hoc tests were conducted with Bonferroni correction.

Hypothesis 2 was investigated using mediation analyses conducted with the GLM mediation model included in the jAMM module (Gallucci, 2020) of jamovi. The module estimates mediation models using maximum likelihood regression. Pain intensity (assessed directly after the CPT) and pain tolerance were included as dependent variables and investigated in individual models. *MLS* was included as a factor, and stimulus-induced emotions and subjective stress were added as mediator variables. Subjective stress was assessed directly after the CPT.

For all analyses, p-values < .05 were considered as significant. For descriptive analyses and data preparation, SPSS (version 24.0) and Microsoft Excel were used. Outliers and extreme values were detected with box-and-whisker plots and were retained if they were not attributed to errors in data entry or recording. Test assumptions were investigated based on the procedure recommended in Field (2013).

Results

Study population

First, 3,356 individuals were screened online (1,194 men, 2,159 women, 3 not specified) regarding their MLS. Of these, 112 (9.4% of the men or 3.3% of all screened persons) were male ME, 492 (22.8% of the women or 14.7% of all screened persons) were female ME, 286 (24.0% of the men or 8.5% of all screened persons) were male MS, and 212 (9.8% of the women or 6.3% of all persons) were female MS. A total of 1,327 individuals (39.5% of all screened persons) stated an interest in participating in the laboratory-based study and provided contact information. The further screening procedure allowed us to filter at least 15 participants per group. A total of 69 persons identified as either ME or MS were asked to complete the PHQ screening questionnaire one day before their first day in the laboratory. Of these 69 persons, 8 persons (approximately 13%) were not included in the study due to their mental health assessment or for other reasons, such as lack of time. Recruitment was stopped when we reached 61 participants with a balanced distribution across the groups (15 male ME, 16 female ME, 15 male MS, 15 female MS). None of the 61 participants dropped out during the study. Fifty-seven participants completed the study within two weeks. Of the remaining four participants, one completed the study in four weeks, one in three weeks and two days, one in two weeks and two days, and one in two weeks and one day. Sample characteristics are presented in Table 2. All single cells (male ME, female ME, male MS, female MS) had similar values (p > .05). Gender differences emerged concerning age (p = .01) and BMI (p = .001): On average, the men were older (men: M = 25.43, SD = 4.03; women: M = 23.07, SD = 3.34) and had a higher BMI (men: M = 23.51; SD = 2.66; women: M = 21.14; SD = 2.35) than the women. The mean proportion of missing values lay at 8.78% (male ME: 11.06%, female ME: 6.85%, male MS: 7.39%, female MS: 10.08%). The handling of missing values was dependent on the statistical analysis and the options provided by the respective program (see statistical methods).

Mixed model analyses

Pain intensity

Pain intensity responses according to MLS, gender, and condition are depicted in Figure 2 (for detailed parameters of stepwise mixed models see supplement Table T1). The three-way interaction of *Time*, *Condition* and *MLS* was significant (F(22, 290.53) = 3.76; p < .001), with ME and MS reporting an increase in pain intensity from baseline to (the time point directly after the) CPT in all conditions, and from anticipation to CPT, followed by a decrease from CPT to the first recovery time point (rec 1; all p_b < .05). Furthermore, the decrease from CPT to the second recovery time point (rec 2) was significant in all

Table 2. Sample characteristics.

			ME (n=31)		MS (n=30)	
		Total sample (N=61)	Male ME (n=15)	Female ME (n=16)	Male MS (n=15)	Female MS (n=15)
Age (*SD*)		24.23 (3.85)	26.40 (3.83)	22.00 (2.53)	24.47 (4.12)	24.20 (3.78)
BMI (*SD*)		22.31 (2.76)	24.06 (2.47)	21.18 (2.35)	22.96 (2.81)	21.10 (2.43)
Marital status	Unmarried:	n=60	n=14	n=16	n=15	n=15
	Married:	n=1	n=1	n=0	n=0	n=0
	Divorced/living apart/widowed:	n=0	n=0	n=0	n=0	n=0
Current partnership	Yes:	n=26	n=4	n=6	n=6	n=10
	No:	n=35	n=11	n=10	n=9	n=5
Highest school education	No graduation/general school:	n=0	n=0	n=0	n=0	n=0
	Institute of applied sciences:	n=4	n=1	n=1	n=1	n=1
	High school:	n=55	n=13	n=14	n=14	n=14
	Other:	n=2	n=1	n=1	n=0	n=0
	Dropouts:	n=0	n=0	n=0	n=0	n=0
Highest professional education	Apprenticeship/similar operational training:	n=4	n=3	n=0	n=1	n=0
	University/college:	n=19	n=2	n=3	n=5	n=9
	Still in professional education:	n=22	n=7	n=6	n=6	n=3
	Other:	n=2	n=0	n=1	n=0	n=1
	None:	n=14	n=3	n=6	n=3	n=2
Current employment (amount)	Full time:	n=2	n=0	n=0	n=0	n=2
	At least half time:	n=4	n=2	n=0	n=2	n=0
	Less than half time:	n=13	n=5	n=4	n=3	n=1
	In education:	n=37	n=7	n=10	n=9	n=11
	Unemployed:	n=5	n=1	n=2	n=1	n=1
	Other:	n=0	n=0	n=0	n=0	n=0
Professional position	Worker:	n=1	n=0	n=0	n=0	n=1
	Employee:	n=9	n=4	n=1	n=3	n=1
	Civil servant:	n=0	n=0	n=0	n=0	n=0
	Self-employed:	n=2	n=1	n=0	n=0	n=1
	Other:	n=49	n=10	n=15	n=12	n=12
Income	< 1250€:	n=55	n=13	n=16	n=13	n=13
	1250–1750€:	n=3	n=2	n=0	n=1	n=0
	2250–3000€:	n=2	n=0	n=0	n=1	n=1
	> 5000€:	n=1	n=0	n=0	n=0	n=1
	Other:	n=0	n=0	n=0	n=0	n=0

Note. BMI = Body Mass Index; ME = Music Empathizers; MS = Music Systemizers; All single cells (male ME, female ME, male MS, female MS) had similar values ($p > .05$). Gender differed in age ($p = .01$) and BMI ($p = .001$).

groups and conditions, but the difference between rec 1 and rec 2 was not significant in any case. Post-hoc tests did not reveal any differences between MLS or between conditions (all $p_b > .05$).

The interaction effect of *Time*, *Condition*, *MLS,* and *Gender* was significant ($F(51, 241.96) = 1.84$; $p = .001$), with female ME reporting an increase from baseline to CPT in all conditions. With participant-selected music, female ME reported an additional increase from anticipation to CPT. Female ME reported a decrease in pain intensity from CPT to rec 1 in both music conditions and from CPT to rec 2 in all conditions. In contrast, there were no changes in pain intensity in any other group, except male MS. Specifically, male MS reported an increase from baseline to CPT and from anticipation to CPT, as well as a decrease in pain intensity from CPT to rec 1 and from CPT to rec 2 when listening to the sound of lapping water. Men and women did not differ in overall pain intensity responses over time ($F(4, 116.91) = .10$; $p = .98$). While the interaction effect of *Condition, Gender,* and *Time* was significant ($F(22, 289.76) = 3.39$; $p < .001$), Bonferroni-adjusted post-hoc tests revealed no differences between men and women over time in any condition. However, men and women differed in overall pain intensity ($F(1, 66.43) = 4.81$; $p = .03$), with women ($M = 7.23$; $SD = 15.59$) reporting lower pain intensity than men ($M = 9.41$; $SD = 16.07$; $Estimate = -1.882$; $SE = .86$).

Pain tolerance

Pain tolerance in the different groups is depicted in Figure 3 (for detailed parameters of stepwise mixed models see supplement Table T2). The interaction effect of *Condition* and *MLS* was not significant ($F(2, 117.19) = .30$; $p = .74$). Only the main effect of *Condition* was significant ($F(2, 117.19) = 8.33$; $p < .001$), with pain being tolerated for longer with participant-selected music than with lapping water ($p_b < .001$), and for longer with participant-selected music than with researcher-selected music ($p_b = .01$). No

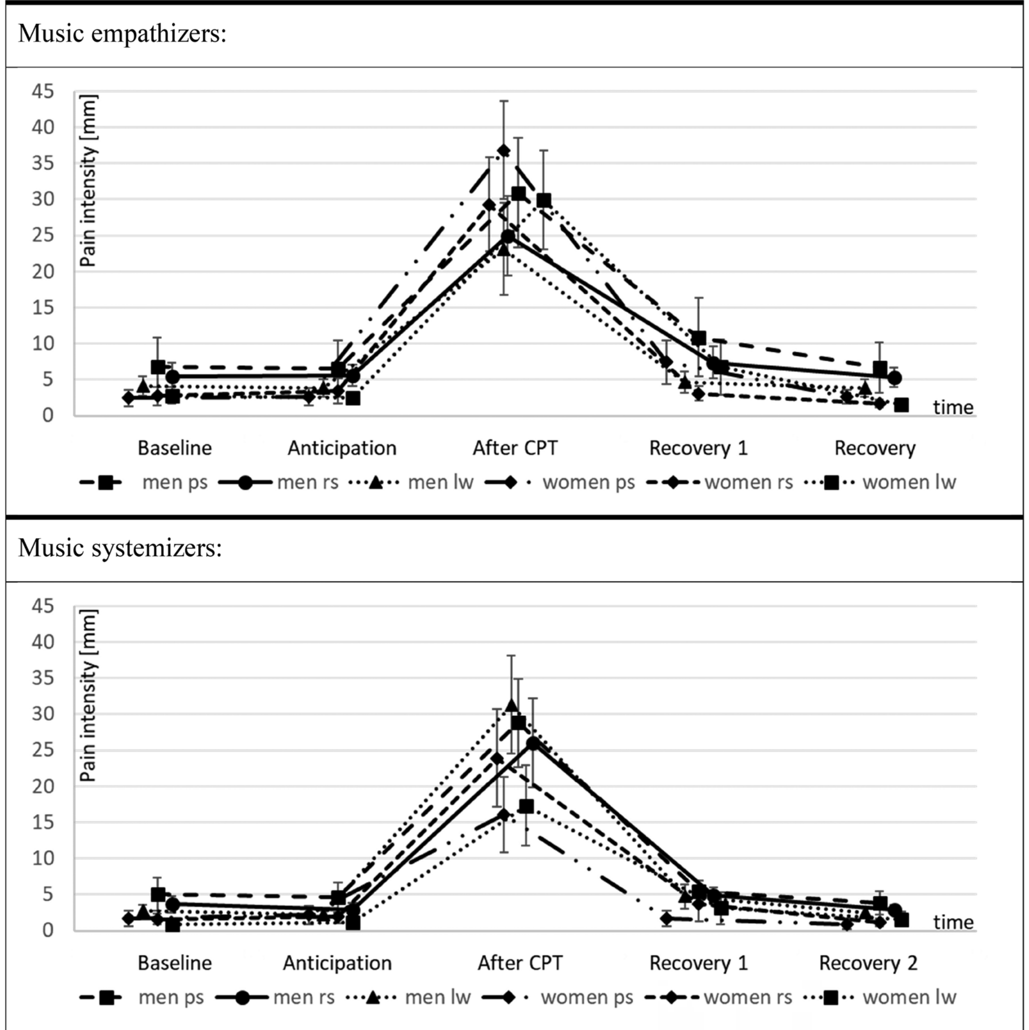

Figure 2. Changes in pain intensity over time for different MLS, gender, and conditions.
Note. ps = participant-selected music; rs = researcher-selected music; lw = sound of lapping water; CPT = cold pressor test; MLS = music listening styles.

significant difference emerged between researcher-selected music and the sound of lapping water (p_b > .99). The interaction effect of *Condition, MLS,* and *Gender* was not significant (F(7, 112.26) = .75; p = .68). Men and women did not differ in pain tolerance (F(1, 58.00) = .80; p = .33). The interaction effect of *Condition* and *Gender* was not significant (F(2, 117.20) = .16; p = .85).

Mediation analyses regarding psychological mechanisms

Stimulus-induced emotions

Neither stimulus-induced joy nor anger mediated the effects of the MLS on pain: Stimulus-induced emotions of joy (indirect effect: β = .002, z = .39, p = .69, effect of MLS on joy: β = −.06, z=−.83, p = .41; effect of joy on pain intensity: β = −.03, z=−.45, p = .65; direct effect of MLS on pain intensity: β = .12, z=1.60, p = .11; total effect: β = .12, z=1.66, p = .10) and anger (indirect effect: β = .002, z = .36, p = .72, effect of MLS on anger: β = −.08, z=−1.07, p = .29; effect of anger on pain intensity: β = −.03, z=−.38, p =.70) did not mediate the effects of MLS on pain intensity directly after the CPT. Stimulus-induced emotions of joy (indirect effect: β = .003, z=−.50, p = .61, effect of MLS on joy: β = −.06, z=−.83, p = .41; effect of joy on pain tolerance: β = .05, z = .63, p = .53; direct effect of MLS on pain tolerance: β = .03, z = .34, p = .73; total effect: β = .03, z = .42, p = .67) and anger (indirect effect: β = .01, z = .88, p = .38, effect of MLS on anger: β = −.08, z=−1.07, p = .29; effect of anger on pain tolerance: β = −.12, z=−1.57, p = .12) did also not mediate the effects of MLS on pain tolerance.

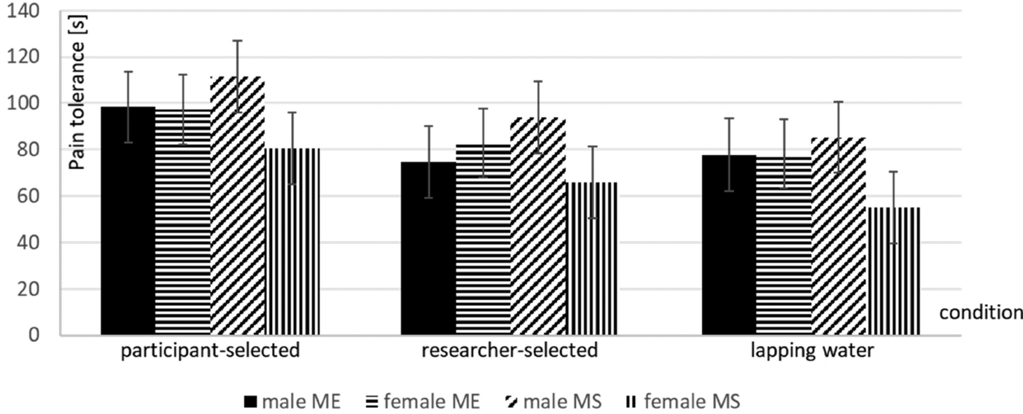

Figure 3. Differences in pain tolerance for different MLS, gender, and conditions.
Note. ME = music empathizers; MS = music systemizers; MLS = music listening styles. Pain tolerance was measured once per condition; CPT = cold pressor test.

Acute subjective stress

The effect of MLS on pain intensity directly after the CPT was mediated by acute subjective stress directly after the CPT (indirect effect: β = .06, z=2.14, p = .03, effect of MLS on subjective stress: β = .17, z=2.40, p = .02; effect of subjective stress on pain intensity: β = .33, z=4.77, p < .001; direct effect of MLS on pain intensity: β = .04, z = .53, p = .60; total effect: β = .11, z=1.46, p = .14). In detail, ME (M=17.48, SD=20.56) reported higher subjective stress directly after the CPT compared to MS (M=11.60, SD=12.26), and in turn, higher subjective stress directly after the CPT was associated with higher perceived pain intensity. The effect of MLS on pain tolerance was not mediated by subjective stress (indirect effect: β = .01, z = .90, p = .37, effect of MLS on subjective stress: β = .17, z=2.40, p = .02; effect of subjective stress on pain tolerance: β = .07, z = .97, p = .33; direct effect of MLS on pain tolerance: β = .01, z = .13, p = .90; total effect: β = .02, z = .30, p = .77).

Discussion

The impact of MLS and gender in the use of music as a tool for pain management, as well as underlying mechanisms, have not been sufficiently investigated so far. In this experiment, we tested whether ME and MS differ in music-induced pain reduction, and whether these effects vary by source of music selection and gender. We also explored, as a side question, stimulus-induced emotions and subjective stress as potential underlying mechanisms. Our findings suggest that ME and MS respond similarly to cold pressor pain, but MLS does influence pain intensity when combined with gender and the source of music selection. We identified first insights into the potential mechanism of subjective stress that might underlie the effects of MLS on pain.

The music listening style does not directly influence pain, but female music empathizers show highest pain intensity with participant-selected music; music selection source is crucial for pain tolerance

In contrast to our hypothesis, the MLS does not seem to directly influence pain with different auditory stimuli. However, female ME exhibit heightened pain intensity responses when an auditory stimulus is present, especially when they choose the music themselves. As female MS showed different responses, gender alone cannot explain music-induced pain modulation; rather, cognitive styles might play a role. Different explanations for increased pain intensity observed in female ME during listening to self-selected music seem possible, such as emotional vulnerability, cognitive-affective rumination, or emotional over-engagement: Related to that, the term “musical vulnerability” describes a person’s inherent and situational openness to being affected by the semantic and somatic properties of music (MacGregor, 2022). If women tend to focus on emotional aspects in music and then listen to music that has a strong

emotional meaning for them, it is conceivable that they may become emotionally more vulnerable and perceive any pain that occurs more intensely. It is also possible that such individuals may engage in cognitive-affective rumination about the music and its emotional meaning, which could possibly also be accompanied by rumination about the pain and a more intense perception of it. The emotional engagement with the emotionally meaningful music and the additional perception of pain might lead to emotional over-engagement, and potentially, emotionally less meaningful music would be more suitable for female ME in pain management. In line with this, it has been suggested that in persons with high emotional vulnerability, music may sometimes be highly distressing given its powerful capacity to access sad and traumatic memories (Bradt et al., 2015). Such processes should be further investigated in future studies. When discussing these possible considerations for the reasons of increased pain intensity in female ME when listening to their self-selected music, the small sample size should be kept in mind. It needs to be acknowledged that there is a heightened risk of Type I error due to multiple testing. Against this background and given that the finding was not theoretically anticipated, it may reflect a chance result rather than a reliable phenomenon. While our study provides initial evidence that female music empathizers show increased pain intensity when listening to their favorite self-selected relaxing music, further studies with larger samples are urgently needed to draw final conclusions about this effect and possible explanations for it.

As a side finding, we found similar pain intensity responses in men and women. However, women in our study reported lower pain intensity than men overall whereas pain tolerance did not differ according to gender. This contradicts studies suggesting greater pain sensitivity for women than for men (Bartley & Fillingim, 2013; Mogil, 2012), and a study revealing that women tolerated experimentally-induced pain with favorite music more than men (Ghaffaripour et al., 2013). It is possible that our results are attributable to the fact that female MS and male ME are overrepresented in our sample. As the studies by Bartley and Fillingim (2013), Mogil (2012), and Ghaffaripour et al. (2013) did not examine the MLS of the subjects, it is conceivable that their studies mainly examined female ME and male MS, which might have influenced the gender effects in their studies.

As another side finding, in our study, pain was tolerated for longest with participant-selected music. Similarly, another study had revealed the longest pain tolerance for participant-selected music compared to researcher-selected music and an auditory control (Mitchell & MacDonald, 2006). This is consistent with reports suggesting that some control over the music enhances pain-reducing effects (Garza-Villarreal et al., 2017; Kühlmann et al., 2018; Vetter et al., 2015).

Stimulus-induced emotions of joy and anger do not mediate the effects of the music listening style on pain while psychological stress is a mediator

In contrast to our hypotheses, the stimulus-induced emotions joy and anger did not mediate the effects of MLS on pain responses in our study. Even though ME place a greater focus on emotional aspects of music than MS (Kreutz et al., 2008), the modulation of the emotions joy and anger does not seem to be an important underlying mechanism of the effects of the MLS on pain responses. Rather, our results suggest that the modulation of subjective stress appears to be a more important psychological mechanism of the effects of MLS on pain than the modulation of joy or anger: The effect of MLS on pain intensity directly after the CPT was mediated by subjective stress directly after the CPT. Specifically, ME reported higher subjective stress directly after the CPT than MS, which was in turn associated with higher pain intensity. This indicates that how music is processed can influence pain intensity via subjective stress. Our findings support the suggestion that stress responses, and in our case subjective stress, may be an important mechanism when using music for health-related outcome, such as pain (Linnemann et al., 2015; Wuttke-Linnemann et al., 2020). As we found that the focus on emotional aspects of music was associated with higher subjective stress and, in turn, higher pain intensity when listening to music during pain perception, the question arises as to whether music should only be used cautiously in pain management in individuals with an emotional focus on music. Alternatively, one might conclude that subjective stress in the context of experiencing pain should be especially managed in persons who emotionally process music. It should also be noted that only the effects of MLS on pain intensity, but not on pain tolerance, were mediated by subjective stress. Beneficial effects of music on

pain intensity, but not on pain tolerance, have been reported by other researchers as well (Zhao & Chen, 2009), so this is not an unusual finding. However, when discussing the mechanisms, as discussed also in the previous section, the small sample size should be noted as a limitation. Our findings should therefore only be seen as an initial indicator that subjective stress may be an important modulator of the effects of MLS on pain. However, future studies should examine the effects with a larger sample before final conclusions can be drawn.

Our study reveals that the music selection source is an important predictor of pain tolerance. Our findings support the importance of individualized pain management programs and confirm the overall beneficial role of self-selecting music in pain management, although for female ME, music with less emotional content may be advisable.

Limitations

We decided on the sample size based on our main research question. To investigate the detailed underlying mechanisms, a larger sample size would have been more appropriate. Therefore, it is important to only cautiously interpret the respective findings as first insights into processes that previous research has widely neglected.

In addition, our sample is not representative of the population, as mental illnesses occur in the population and may be closely related to pain perception. For example, it has been reported that individuals with schizophrenia have elevated pain thresholds and tolerance, and depression and pain commonly co-occur (Onwumere et al., 2022). As we wanted to minimize confounding effects associated with mental illness, we decided to investigate only individuals with low scores on the PHQ. Our results do not allow any direct conclusions to be drawn about clinical samples, and it would be very important to conduct further studies in a clinical setting. Furthermore, the model parameters of the current findings indicate at least in part that the effects are relatively small. However, as the current stimulus presentation was not part of an elaborated intervention program, it can be assumed that our findings are particularly relevant and might even be enhanced in more elaborated intervention programs.

Given the highly individual perception of pain, within-subject designs are recommended in pain research (Gewandter et al., 2016). However, the within-subjects design carries the risk that participants might guess the different conditions, which might be associated with expectation effects and could potentially influence their responses. To reduce such expectation effects at least to some extent, participants were asked to bring an arousing song to the lab in addition to the relaxing song. We also randomized the order of the conditions so that the auditory stimulus of the last condition differed between participants. It cannot be ruled out that expectation effects may still have played a role. For example, the participants may have tried to endure the pain longer with their favorite music than in the other conditions. In a follow-up survey, we gave the participants the opportunity to tell us about such effects. No such effects were reported here. However, it cannot be ruled out that such effects may have unconsciously played a role. Before final conclusions can be drawn, it would be important to investigate similar research questions in a more natural setting, for example with Ecological Momentary Assessment (EMA) or Ecological Momentary Intervention (EMI) studies.

In addition, ambient temperature can influence pain perception at least to some extent (Strigo et al., 2000). The room temperature in our laboratory could not be controlled to the exact degree, which is a limitation of our study. However, the measurements took place in a building with thick brickwork, thus the room temperature was presumably less influenced by outside temperatures than in buildings with thinner walls. We have adjusted the room temperature to be as comfortable as possible in the different seasons through appropriate ventilation and heating behavior. Nevertheless, it cannot be ruled out that the room temperature had an influence on the perception of pain. As the measurements within the test subjects were taken at short intervals, we assume that the seasonal fluctuations in room temperature do not play a major role for the differences between the conditions within the individual subjects. However, to be certain that the room temperature does not influence the measurements, it would be necessary to use a laboratory in which the room temperature can be controlled to the exact degree.

Another limitation is the age of the data. Other studies have reported that the incidence of global mental health conditions such as anxiety and depression, as well as daily stress have increased over the

last years (Piao et al., 2024). It is therefore conceivable that the baseline level of stress is already higher today than it was in our study. To see similarly high peaks in the stress responses, the stressor might have to be higher today; for example, lower temperatures could be used for the water in the CPT. Related to this, a recent study reported that about 50% of the candidates were able to withstand the entire three minutes of the cold pressure test (Van der Valk Bouman et al., 2024), whereas in our study almost all candidates pulled their hand out of the water earlier. Future studies might consider using low temperatures of the CPT, for example, 0–1 degree, as it was used in the study by Fekete et al. (2022).

In addition, the gender of the experimenters may have an impact on pain perception. In previous research, males reported significantly less pain in front of a female experimenter than a male experimenter (Levine & De Simone, 1991), and, in another study, subjects tolerated pain longer when they were tested by an experimenter of the opposite sex (Kállai et al., 2004). It is possible that male subjects in our study would have shown higher pain with the presence of male experimenters compared to the presence of our all-female experimenters. We initially considered including male researchers in the data collection, but for practical reasons, it would have been very challenging to match the gender of study participants and researchers at each individual visit. We therefore decided to keep the gender of the researchers consistently female. However, the effects of MLS on pain when matching the experimenter's gender with the participant's gender should be investigated in future studies, especially with regard to possible interactions between gender and MLS.

To understand the differences between the most distinct MLS, we included participants with a clear categorization as either ME or MS. Persons with an MLS that is balanced between ME and MS were not investigated. Thus, no conclusions can be drawn regarding balanced MLS.

Future directions

As pain research aims to increase well-being in patients, investigations in clinical contexts are essential. Investigating balanced MLS would further illuminate the potential analgesic effects of music in a broader range of individuals. Additionally, it would be of interest to investigate the roles of MLS and gender for potential protective effects of music presentation before or after a painful and stressful event. While the current study investigates the potential management of pain during the presentation of a pain stimulus, it would be of high importance to investigate the potential prevention of pain by presenting music prior to the pain stimulus. Also, presenting music after presenting a pain stimulus might be of interest for future studies. These options would offer the advantage that music can be presented for a longer time than the presentation time of the pain stimulus, which is especially relevant given that music interventions with a duration of 20–30 minutes were associated with a larger decrease in pain scores than music interventions with a duration of less than 20 minutes (Richard-Lalonde et al., 2020). Moreover, the negative effects of music require further investigation. Finally, as music consists of audio features whose effects on human perception are mostly under-researched, more research on the potential effects of audio features is recommended (Martin-Saavedra et al., 2018).

Conclusions

Our results indicate that music for pain management increases pain tolerance the most when it is selected by participants. However, we found initial evidence that women scoring high on ME show increased pain when listening to their self-selected music. We also found initial evidence for the importance of subjective stress as a potential mechanism in the context of music-based pain management. Future studies should further investigate these effects to draw final conclusions. Understanding how music processing can influence pain is an important step toward improving individualized pain management and may inform the (further) development of guidelines and recommendations.

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Authors' contributions

Dr. Rosa M. Maidhof: contributor roles: data curation; formal analysis; funding acquisition; methodology; software; visualization; writing – original draft; Dr. Alexandra Wuttke: contributor roles: conceptualization; data curation; investigation; methodology; project administration; software; writing – review & editing; Mattes B. Kappert: contributor roles: data curation; formal analysis; investigation; methodology; project administration; software; writing – review & editing; Dr. Andreas R. Schwerdtfeger: contributor roles: methodology; software; validation; writing – review & editing; Dr. Gunter Kreutz: contributor roles: conceptualization; methodology; validation; writing – review & editing; Dr. Urs M. Nater: contributor roles: conceptualization; funding acquisition; methodology; resources; supervision; validation; writing – review & editing).

Open science policy and transparency statements

This study was not formally registered. The analysis plan was not formally pre-registered. De-identified data from this study are not available in a public archive. De-identified data from this study will be made available (as allowable according to institutional IRB standards) by emailing the corresponding author. Analytic code used to conduct the analyses presented in this study are not available in a public archive. They may be available by emailing the corresponding author. Materials used to conduct the study are not publically available. This article does not contain any studies with animals performed by any of the authors. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Disclosure statement

The authors declare that they have no conflict of interest.

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References

Allen, M. S., Iliescu, D., & Greiff, S. (2022). Single item measures in psychological science. *European Journal of Psychological Assessment*, *38*(1), 1–5. https://doi.org/10.1027/1015-5759/a000699

Arnold, C. A., Bagg, M. K., & Harvey, A. R. (2024). The psychophysiology of music-based interventions and the experience of pain. *Frontiers in Psychology*, *15*, 1361857. https://doi.org/10.3389/fpsyg.2024.1361857

Bartley, E. J., & Fillingim, R. B. (2013). Sex differences in pain: A brief review of clinical and experimental findings. *British Journal of Anaesthesia*, *111*(1), 52–58. https://doi.org/10.1093/bja/aet127

Bradt, J., Potvin, N., Kesslick, A., Shim, M., Radl, D., Schriver, E., Gracely, E. J., & Komarnicky-Kocher, L. T. (2015). The impact of music therapy versus music medicine on psychological outcomes and pain in cancer patients: A mixed methods study. *Supportive Care in Cancer: Official Journal of the Multinational Association of Supportive Care in Cancer*, *23*(5), 1261–1271. https://doi.org/10.1007/s00520-014-2478-7

Browning, C. A. (2000). Using music during childbirth. *Birth (Berkeley, Calif.)*, *27*(4), 272–276. https://doi.org/10.1046/j.1523-536x.2000.00272.x

Cepeda, M. S., Carr, D. B., Lau, J., & Alvarez, H. (2006). Music for pain relief. *Cochrane Database of Systematic Reviews*, *2*(2), CD004843. https://doi.org/10.1002/14651858.cd004843

Chanda, M. L., & Levitin, D. J. (2013). The neurochemistry of music. *Trends in Cognitive Sciences*, *17*(4), 179–193. https://doi.org/10.1016/j.tics.2013.02.007

Colebaugh, C. A., Wilson, J. M., Flowers, K. M., Overstreet, D., Wang, D., Edwards, R. R., Chai, P. R., & Schreiber, K. L. (2023). The impact of varied music applications on pain perception and situational pain catastrophizing. *Journal of Pain*, *24*(7), 1181–1192. https://doi.org/10.1016/j.jpain.2023.01.006

Davis, H., & Mohammad, S. M. (2014). Generating music from literature. In *Proceedings of the 3rd Workshop on Computational Linguistics for Literature (CLFL)* (pp. 1–10). Association for Computational Linguistics.

De Couck, M., Nijs, J., & Gidron, Y. (2014). You may need a nerve to treat pain: The neurobiological rationale for vagal nerve activation in pain management. *Clinical Journal of Pain*, *30*(12), 1099–1105. https://doi.org/10.1097/ajp.0000000000000071

Edens, J. L., & Gil, K. M. (1995). Experimental induction of pain: Utility in the study of clinical pain. *Behavior Therapy*, *26*(2), 197–216. https://doi.org/10.1016/s0005-7894(05)80102-9

Fekete, A., Maidhof, R. M., Specker, E., Nater, U. M., & Leder, H. (2022). Does art reduce pain and stress? A registered report protocol of investigating autonomic and endocrine markers of music, visual art, and multimodal aesthetic experience. *PloS One*, *17*(4), e0266545. https://doi.org/10.1371/journal.pone.0266545

Ferreira-Valente, M. A., Pais-Ribeiro, J. L., & Jensen, M. P. (2011). Validity of four pain intensity rating scales. *Pain*, *152*(10), 2399–2404. https://doi.org/10.1016/j.pain.2011.07.005

Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. Sage.

Gallucci, M. (2019). GAMLj: General analyses for linear models [jamovi module].

Gallucci, M. (2020). jAMM: jamovi advanced mediation models [jamovi module].

Garza-Villarreal, E. A., Pando, V., Vuust, P., & Parsons, C. (2017). Music-induced analgesia in chronic pain conditions: A systematic review and meta-analysis. *Pain Physician*, *20*(7), 597–610. https://doi.org/10.1101/105148

Gewandter, J. S., McDermott, M. P., McKeown, A., Hoang, K., Iwan, K., Kralovic, S., Rothstein, D., Gilron, I., Katz, N. P., Raja, S. N., Senn, S., Smith, S. M., Turk, D. C., & Dworkin, R. H. (2016). Reporting of cross-over clinical trials of analgesic treatments for chronic pain: Analgesic, anesthetic, and addiction clinical trial translations, innovations, opportunities, and networks systematic review and recommendations. *Pain*, *157*(11), 2544–2551. https://doi.org/10.1097/j.pain.0000000000000673

Ghaffaripour, S., Mahmoudi, H., Sahmeddini, M. A., Alipour, A., & Chohedri, A. (2013). Music can effectively reduce pain perception in women rather than men. *Pakistan Journal of Medical Sciences*, *29*(1), 128–131. https://doi.org/10.12669/pjms.291.2947

Gräfe, K., Zipfel, S., Herzog, W., & Löwe, B. (2004). Screening psychischer Störungen mit dem "Gesundheitsfragebogen für Patienten (PHQ-D)". *Diagnostica*, *50*(4), 171–181. https://doi.org/10.1026/0012-1924.50.4.171

Howlin, C., & Rooney, B. (2021). Cognitive agency in music interventions: Increased perceived control of music predicts increased pain tolerance. *European Journal of Pain (London, England)*, *25*(8), 1712–1722. https://doi.org/10.1002/ejp.1780

Kállai, I., Barke, A., & Voss, U. (2004). The effects of experimenter characteristics on pain reports in women and men. *Pain*, *112*(1–2), 142–147. https://doi.org/10.1016/j.pain.2004.08.008

Kreutz, G., Schubert, E., & Mitchell, L. A. (2008). Cognitive styles of music listening. *Music Perception*, *26*(1), 57–73. https://doi.org/10.1525/mp.2008.26.1.57

Kühlmann, A., De Rooij, A., Kroese, L., Van Dijk, M., Hunink, M., & Jeekel, J. (2018). Meta-analysis evaluating music interventions for anxiety and pain in surgery. *British Journal of Surgery*, *105*(7), 773–783. https://doi.org/10.1002/bjs.10853

Lee, H. Y., Nam, E. S., Chai, G. J., & Kim, D. M. (2023). Benefits of music intervention on anxiety, pain, and physiologic response in adults undergoing surgery: A systematic review and meta-analysis. *Asian Nursing Research*, *17*(3), 138–149. https://doi.org/10.1016/j.anr.2023.05.002

Lesage, F.-X., & Berjot, S. (2011). Validity of occupational stress assessment using a visual analogue scale. *Occupational Medicine (Oxford, England)*, *61*(6), 434–436. https://doi.org/10.1093/occmed/kqr037

Lesage, F.-X., Berjot, S., & Deschamps, F. (2012). Clinical stress assessment using a visual analogue scale. *Occupational Medicine (Oxford, England)*, *62*(8), 600–605. https://doi.org/10.1093/occmed/kqs140

Levine, F. M., & De Simone, L. L. (1991). The effects of experimenter gender on pain report in male and female subjects. *Pain*, *44*(1), 69–72. https://doi.org/10.1016/0304-3959(91)90149-R

Linnemann, A., Kappert, M. B., Fischer, S., Doerr, J. M., Strahler, J., & Nater, U. M. (2015). The effects of music listening on pain and stress in the daily life of patients with fibromyalgia syndrome. *Frontiers in Human Neuroscience*, *9*, 434. https://doi.org/10.3389/fnhum.2015.00434

Linnemann, A., Kreutz, G., Gollwitzer, M., & Nater, U. M. (2018). Validation of the German version of the music-empathizing-music-systemizing (MEMS) inventory (short version). *Frontiers in Behavioral Neuroscience*, *12*, 228. https://doi.org/10.3389/fnbeh.2018.00153

Löwe, B., Spitzer, R. L., Zipfel, S., & Herzog, W. (2002). *PHQ-D: Gesundheitsfragebogen für Patienten; Manual Komplettversion und Kurzform*. Pfizer GmbH.

Lu, X., Hou, X., Zhang, L., Li, H., Tu, Y., Shi, H., & Hu, L. (2023). The effect of background liked music on acute pain perception and its neural correlates. *Human Brain Mapping*, *44*(9), 3493–3505. https://doi.org/10.1002/hbm.26293

Lunde, S. J., Vuust, P., Garza-Villarreal, E. A., & Vase, L. (2019). Music-induced analgesia: How does music relieve pain? *Pain*, *160*(5), 989–993. https://doi.org/10.1097/j.pain.0000000000001452

MacGregor, E. H. (2022). Conceptualizing musical vulnerability. *Philosophy of Music Education Review*, *30*(1), 24–43. https://doi.org/10.2979/philmusieducrevi.30.1.03

Maidhof, R.M., Czedik-Eysenberg, I., Reuter, C., Nater, U.M. In prep. The role of audio features for music-based pain management.

Maidhof, R. M., Kappert, M. B., Wuttke, A., Schwerdtfeger, A. R., Kreutz, G., & Nater, U. M. (2023). Effects of participant-selected versus researcher-selected music on stress and mood – The role of gender. *Psychoneuroendocrinology*, *158*, 106381. https://doi.org/10.1016/j.psyneuen.2023.106381

Martin-Saavedra, J. S., Vergara-Mendez, L. D., & Talero-Gutiérrez, C. (2018). Music is an effective intervention for the management of pain: An umbrella review. *Complementary Therapies in Clinical Practice*, *32*, 103–114. https://doi.org/10.1016/j.ctcp.2018.06.003

Mitchell, L. A., & MacDonald, R. A. (2006). An experimental investigation of the effects of preferred and relaxing music listening on pain perception. *Journal of Music Therapy*, *43*(4), 295–316. https://doi.org/10.1093/jmt/43.4.295

Mitchell, L. A., MacDonald, R. A., Knussen, C., & Serpell, M. G. (2007). A survey investigation of the effects of music listening on chronic pain. *Psychology of Music*, *35*(1), 37–57. https://doi.org/10.1177/0305735607068887

Mogil, J. S. (2012). Sex differences in pain and pain inhibition: Multiple explanations of a controversial phenomenon. *Nature Reviews. Neuroscience*, *13*(12), 859–866. https://doi.org/10.1038/nrn3360

Nash, J. M., & Thebarge, R. W. (2006). Understanding psychological stress, its biological processes, and impact on primary headache. *Headache*, *46*(9), 1377–1386. https://doi.org/10.1111/j.1526-4610.2006.00580.x

Nyakairu Doreen, G. (2024). The role of music in pain management and healing. *Eurasian Experiment Journal of Scientific and Applied Research*, *6*(2), 5–9.

Onwumere, J., Stubbs, B., Stirling, M., Shiers, D., Gaughran, F., Rice, A. S., de, C., Williams, A. C., & Scott, W. (2022). Pain management in people with severe mental illness: An agenda for progress. *Pain*, *163*(9), 1653–1660. https://doi.org/10.1097/j.pain.0000000000002633

Piao, X., Xie, J., & Managi, S. (2024). Continuous worsening of population emotional stress globally: Universality and variations. *BMC Public Health*, *24*(1), 3576. https://doi.org/10.1186/s12889-024-20961-4

Price, D. D., McGrath, P. A., Rafii, A., & Buckingham, B. (1983). The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. *Pain*, *17*(1), 45–56. https://doi.org/10.1016/0304-3959(83)90126-4

R Core Team. (2021). *R: A language and environment for statistical computing [Software].*

Richard-Lalonde, M., Gélinas, C., Boitor, M., Gosselin, E., Feeley, N., Cossette, S., & Chlan, L. L. (2020). The effect of music on pain in the adult intensive care unit: A systematic review of randomized controlled trials. *Journal of Pain and Symptom Management*, *59*(6), 1304–1319.e6. e1306. https://doi.org/10.1016/j.jpainsymman.2019.12.359

Soper, D. (2012). *A-priori sample size calculator for hierarchical multiple regression*.

Strigo, I. A., Carli, F., & Bushnell, M. C. (2000). Effect of ambient temperature on human pain and temperature perception. *Anesthesiology*, *92*(3), 699–707. https://doi.org/10.1097/00000542-200003000-00014

The Jamovi Project. (2020). *Jamovi* [Software].

Timmerman, H., van Boekel, R. L., van de Linde, L. S., Bronkhorst, E. M., Vissers, K. C., van der Wal, S. E., & Steegers, M. A. (2023). The effect of preferred music versus disliked music on pain thresholds in healthy volunteers. An observational study. *PloS One*, *18*(1), e0280036. https://doi.org/10.1371/journal.pone.0280036

Valevicius, D., Lépine Lopez, A., Diushekeeva, A., Lee, A. C., & Roy, M. (2023). Emotional responses to favorite and relaxing music predict music-induced hypoalgesia. *Frontiers in Pain Research (Lausanne, Switzerland)*, *4*, 1210572. https://doi.org/10.3389/fpain.2023.1210572

Van der Valk Bouman, E. S., Becker, A. S., Schaap, J., Berghman, M., Oude Groeniger, J., Van Groeningen, M., Vandenberg, F., Geensen, R., Jeekel, J., & Klimek, M. (2024). The impact of different music genres on pain tolerance: Emphasizing the significance of individual music genre preferences. *Scientific Reports*, *14*(1), 21798. https://doi.org/10.1038/s41598-024-72882-2

Vetter, D., Barth, J., Uyulmaz, S., Uyulmaz, S., Vonlanthen, R., Belli, G., Montorsi, M., Bismuth, H., Witt, C. M., & Clavien, P.-A. (2015). Effects of art on surgical patients: A systematic review and meta-analysis. *Annals of Surgery*, *262*(5), 704–713. https://doi.org/10.1097/SLA.0000000000001480

Wuttke-Linnemann, A., Feneberg, A., & Nater, U. (2020). Music and health. In Gellman, M.D. (Ed.), *Encyclopedia of behavioral medicine*. Springer.

Zhao, H., & Chen, A. C. (2009). Both happy and sad melodies modulate tonic human heat pain. *Journal of Pain*, *10*(9), 953–960. https://doi.org/10.1016/j.jpain.2009.03.006