Randomized Trial

Modulation of Pain Perception Through Identifying Emotionally with Music Feedback During Physical Exercise for Patients with Chronic Pain: A Randomized Trial

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Background: The emotional modulation of pain can be achieved through interventions in the form of music, which may therefore be valuable in regulating emotions and perceived pain during physical activity.

Objectives: The present study aimed to investigate the effects of music feedback during physical exercise on chronic pain patients' emotional states, motivation, and pain levels during an acute clinic stay.

Study Design: A crossover design was used to test the effects of music feedback during an ergometer training (active condition) vs. music listening during an ergometer training (passive condition) on 43 patients with different chronic pain conditions during their acute clinical stay.

Setting: An acute clinic specializing in pain medicine.

Methods: Patients were recruited by clinical staff and randomly assigned to perform both conditions in different orders. The music was selected from 4 genres, and the same songs were used in the training sessions for both types of conditions.

Results: The results showed that patients' motivation to exercise was stronger during the active condition than during the passive condition, as measured by active engagement during the training interval ($t(39) = 3.013$, $P = 0.006$; 95% CI: 0.0104; .0529). Those findings matched with patients' individual ratings of their motivation. For both conditions, anxiety levels decreased significantly from baseline (active condition: $Z = -4.213$; $P < 0.001$; passive condition: $Z = -3.864$; $P < 0.001$). The pain levels did not differ between conditions ($Z = -0.137$, $P = 0.45$). Interestingly, the reported match/congruency of the patients' moods and emotions expressed by the chosen music pieces correlated with changes in pain perception ($r = -0.438$, $P = 0.007$), and the match of the patients' own emotional state with the music was significantly higher during the active condition (Mdn = 7.7) than during the passive condition (Mdn = 6.35; $Z = -3.429$; $P < 0.001$). No significant correlation between changes in pain intensity and changes in heart rate variability were observed ($r = 0.15$, $P = 0.952$).

Limitations: The rather heterogeneous patient sample limits specific conclusions about effects on certain pain conditions, and the focus on immediate effects precludes conclusions about long-term outcomes.

Conclusion: Music feedback during physical exercise may be beneficial in increasing motivation in patients with chronic pain. A stronger match of emotions expressed by music feedback and the patient's own emotional state seems to influence pain perception.

Key words: Music, music-feedback, emotion, chronic pain, physical activity, exercise, music-induced analgesia

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Pain is a common experience during hospital stays and often leads to significant distress, particularly when the pain persists and becomes chronic. In Europe, approximately 19% of adults experience moderate to severe chronic pain (1). Pain perception consists of 2 components: sensory pain, which provides information about the pain (e.g., location), and suffering pain, which is the individual's emotional response to it (2). As le Breton (3) states, "Pain is perceived and judged at the same time; we attach meaning and value to it, and it is never purely physiological."

Neuroscientific research has identified 3 major pain pathways. The lateral pathway, projecting to the somatosensory cortex, localizes noxious stimuli. The medial pathway, associated with emotional processing, projects to subcortical areas like the amygdala and periaqueductal gray (2). The inhibitory pathway projects to the prefrontal cortex and modulates pain suppression (2). Critically, the medial emotional pathway correlates strongly with pain disability (explaining up to 40% thereof), whereas pain intensity (associated with the lateral pathway) correlates only weakly (0-3%) (2). The transition from acute to chronic pain involves increased engagement of the medial and reward/learning pathways as well as decreased involvement of the lateral pathway (2,4-6).

Chronic pain is influenced significantly by emotional states and attention (7). Depression and anxiety can exacerbate pain perception (8), as can anger (9). Anger's impact on pain is linked to its regulation; suppression of anger is associated with higher pain levels (10). A study of patients' fibromyalgia diaries found that anger inhibition predicted higher pain, while anger expression predicted lower pain (11), highlighting the importance of emotional states and processing in chronic pain.

Emotions also influence pain-related behavior. Anger can arise from frustration (12), such as when chronic pain patients engage in recommended health behaviors (e.g., exercise) without immediate pain relief. This phenomenon can lead to increased pain perception and decreased adherence to such behaviors. Anxiety can induce fear of movement and avoidance, while depression can reduce motivation to engage in daily activities. These emotional influences on health behavior are critical, since resuming physical activity is vital for chronic pain patients' well-being and quality of life (13). The European Pain Federation (EFIC) recommends physical activity as a "generic treatment strategy" for several chronic pain conditions (14).

Physical activity, defined as any voluntary movement requiring the expenditure of energy (WHO fact sheet, 2021), is a key element of chronic pain management. Studies have demonstrated pain reduction following physical activity in patients with various chronic pain conditions, including fibromyalgia (15), chronic low back pain (11), and chronic neck pain (16). Mechanisms underlying these benefits include biological factors (e.g., endorphin release, reduced inflammation) and psychological/social factors (e.g., stress reduction, mood enhancement) (17).

However, chronic pain patients face numerous barriers to physical activity. Some studies report an absence of exercise-induced hypoalgesia, often seen in healthy individuals, and even observe short-term hyperalgesic effects (18). Chronic pain-related conditions like psychomotor slowing and stiffness contribute to exhaustion and fatigue (19). Consequently, exercise can be perceived by chronic pain patients as a threat, triggering negative emotions that hinder physical activity. These internal barriers include anxiety, avoidance, and psychological comorbidities (20), and the emotions that accompany these states can amplify pain, further reducing the likelihood of exercise. Chronic pain is generally associated with decreased physical activity (21). Qualitative research reveals that such factors as pleasure, self-efficacy, and autonomy can motivate patients to exercise despite their pain (20).

Emotional modulation of pain can be achieved through nonpharmacological interventions like music (7). Music interventions have been shown to reduce pain, anxiety, and depression in chronic pain patients (22) and to decrease their pain perception and use of analgesic medication (23). Music may therefore be valuable in regulating patients' emotions and perceived pain during physical activity. Combining physical activity with the active use of music via instant music feedback reduced acute pain in healthy individuals to a greater extent than did passive listening (24). The combination is also associated with decreased anxiety and increased exercise motivation in patients undergoing rehabilitation for chronic pain (25).

The present study investigates the effects of instant music feedback during exercise on chronic pain patients' emotion, motivation, and pain during acute care. We hypothesize that in comparison with passive music listening, music feedback will exert greater reductions on patients' pain perception and anxiety and increases on patients' motivation to exercise. We also explore the relationship between mood/emotion

congruence and pain perception as well as the correlation between pain perception changes and heart rate variability.

Methods

Patients

Forty-three patients (29 women, 14 men) with chronic pain conditions were recruited from the Centre for Pain Medicine in Berlin (Germany) based on medical recommendations for physical activity during their acute clinic stay (time period of recruitment: June to November 2024). Inclusion criteria were the presence of any chronic pain type and the ability to perform physical exercise. Exclusion criteria were the presence of a physical disability or contraindications to exercise. Patients were referred to the study by their treating physicians in the clinic. The study adhered to the Declaration of Helsinki and was approved by the ethics committees of the University of Leipzig and the German Medical Association (Berlin). All patients provided informed consent. The study protocol was pre-registered at the Open Science Framework (www.osf.io). The required sample size was computed a priori with G*Power 3.1 (Heinrich Heine Universität Düsseldorf), with effect size d = 0.45, alpha error probability of 0.05, and power of 0.8, resulting in a sample size of 43 patients and an estimated power of 0.803. The experiment was ended when the predefined sample size was reached. The mean age of the patients was 53.83 years (SD = 13.19; range = 24-80), and the average pain duration was 8.98 years (SD = 7.90). The patients' pain locations varied (Tables 1-3).

Experimental Design and Procedure

A clinical-experimental, randomized, controlled, crossover design was used (Fig. 1). All patients performed both the experimental (music feedback) and control (music listening) conditions in a randomized order, using simple randomization. While passive music listening involves the reception of auditory stimuli without direct influence over the musical output, our music-feedback intervention, utilizing Jymmin™ technology, introduced an active element in which patients' physical movements directly shaped the music they heard. This distinction is crucial, since the music feedback imbues the patient with a sense of agency and control over the musical experience, a factor largely absent in passive listening conditions. Patients were enrolled in the study by their treating physicians in the

Table 1. *Demographics of patient sample.*

Characteristic	n	%	Characteristic	n	%
Gender			**Nationality**		
Male	14	32.6	German	33	78.6
Female	29	67.4	Turkish	3	7.1
			Syrian	1	2.4
			Sudanese	1	2.4
			Polish	1	2.4
			Bosnian	1	2.4
			Serbian	1	2.4
			Taiwanese	1	2.4

Table 1 displays the demographics of the patient sample, including gender and nationality.
n = number of patients; % = percentage of patients.

Table 2. *Patients' descriptions of pain experiences on the day of admission to the clinic.*

Characteristic	n	%	Characteristic	n	%
Frequency of Pain			Main Pain Site (1)		
Constant pain with mild fluctuations	8	19.5	Back	22	52.4
Constant pain with severe fluctuations	18	43.9	Legs	8	19.1
Pain attacks, pain-free in between	2	4.9	Neck	3	7.1
Pain attacks, pain in between	13	31.7	Arms/Shoulder	4	9.5
Time Experiencing Pain			Head	3	7.1
<One year	5	11.9	Feet	4	9.5
One-3 years	9	21.4	Abdomen	1	2.4
4-6 years	9	21.4	Knee	6	14.3
7-9 years	4	9.5	Pelvis	5	11.9
10-20 years	8	19.1	Buttocks	3	7.1
>20 years	7	16.7	Whole body	9	21.4
	M	SD	Number of Pain Sites		
Pain-Related Emotions (Scale 0-6)			1	7	16.7
Pain-related depression	3.89	1.58	2-3	12	28.6
Pain-related anxiety	3.61	1.45	4-5	7	16.7
Pain-related anger	3.24	1.43	>5	16	38.0

(1) Patients could select more than one answer.
Table 2 displays how the patients described their pain experiences on the day of admission to the clinic.
n = number of patients; % = percentage of patients with corresponding symptoms; M = mean; SD = standard deviation.

Table 3. *Patients' information on their currently prescribed long-term and on-demand pain medications.*

Prescribed Pain Medication	n	%	Prescribed Pain Medication	n	%
Long-Term Pain Medication (1)			On-Demand Pain Medication (1)		
Opioids	13	37.1	Opioids	2	5.7
NSAIDs (nonsteroidal anti-inflammatory drugs)	7	20.0	NSAIDs (nonsteroidal anti-inflammatory drugs)	10	28.6
Metamizole	6	17.1	Metamizole	8	22.9
Antiepileptic drugs	8	22.9	Triptane	1	2.9
Antidepressants	7	20.0			
Muscle relaxants (tizanidine)	1	2.9			
Lidocaines	1	2.9			
Benzodiazepines	1	2.9			
No long-term pain medication	10	28.6			

(1) Patients could select more than one answer.
Table 3 displays the patients' information on the long-term and on-demand pain medication for which they had prescriptions at the time of admission to the clinic. Note: for n = 8 patients, there is no information on the prescribed pain medication.
n = number of patients; % = percentage of patients.

clinic and were then randomly assigned to one condition order by the experimenter. Behavioral and physiological data were collected at baseline and after each condition order to test the following hypotheses:

- H1 (confirmative): Pain perception (including pain intensity and pain unpleasantness) shows a greater reduction after the training with music feedback than after the training with music listening.
- H2 (confirmative): Anxiety levels show a greater reduction after the training with music feedback than they do after the training with music listening.
- H3 (confirmative): Motivation to exercise is stronger during the training with music feedback than during the training with music listening, as measured by active engagement during the training intervals.
- H1 (explorative): A reported match/congruency of current mood and emotion transferred by a chosen music piece correlates with changes in pain perception.
- H2 (explorative): Changes in pain perception correlate with changes in heart rate variability as a measure of emotional processing.

The behavioral/psychological assessment included the following measures and was presented to patients in the order displayed below:

Behavioral/Psychological Measures

Emotional State/Mood: The German Current Mood Scale (Dalbert, 2002) was used to assess patients' current moods (sadness, hopelessness, fatigue, anger, positive mood). Cronbach's alpha is reported as 0.83-0.94.

Anxiety

The state anxiety portion of the State-Trait Anxiety Inventory (STAI; Laux et al, 1981) was used. Internal consistency is reported as $\alpha = 0.90$.

Pain

Pain intensity and unpleasantness were assessed using a 100 mm visual analog scale (VAS) before, during, and after each exercise session.

Subjective Measures

Three self-constructed questions assessed motivation ("How strongly were you motivated during the physical training?"), agency ("How strongly did you have the impression to control the music yourself?"), and emotional match ("How well did the chosen music piece match with your own current emotional state?"). Responses were given on a 0-100 mm VAS.

Physiological Measures

Heart rate variability (HRV) is a commonly used measure of stress reactivity and has been argued to signal better emotional processing (26). In the present study, HRV was measured using the BioHarness 3.0 (Zephyr Technology Corporation). The device recorded patients' ECG, heart rate, and RR intervals. RR interval data was downloaded using BioHarness Log Downloader software (Zephyr Technology Corporation). HRV time-domain measures (R-R interval, SDNN, mean HR) were analyzed using Kubios software version 1.1 (Biosignal Analysis and Medical Imaging Group). ECG was recorded for 5 minutes, allowing for a reliable recording of a minimum-minute analysis window (27).

After baseline assessment, patients chose music from 4 genres (classical, world, blues, German folk). In the music-feedback condition, patients created music remixes using Jymmin™ while exercising on an ergometer. In the music-listening condition, they listened passively to the same music, also while exercising on an ergometer. Music was delivered via loudspeakers at a consistent, individually adjusted volume. The duration

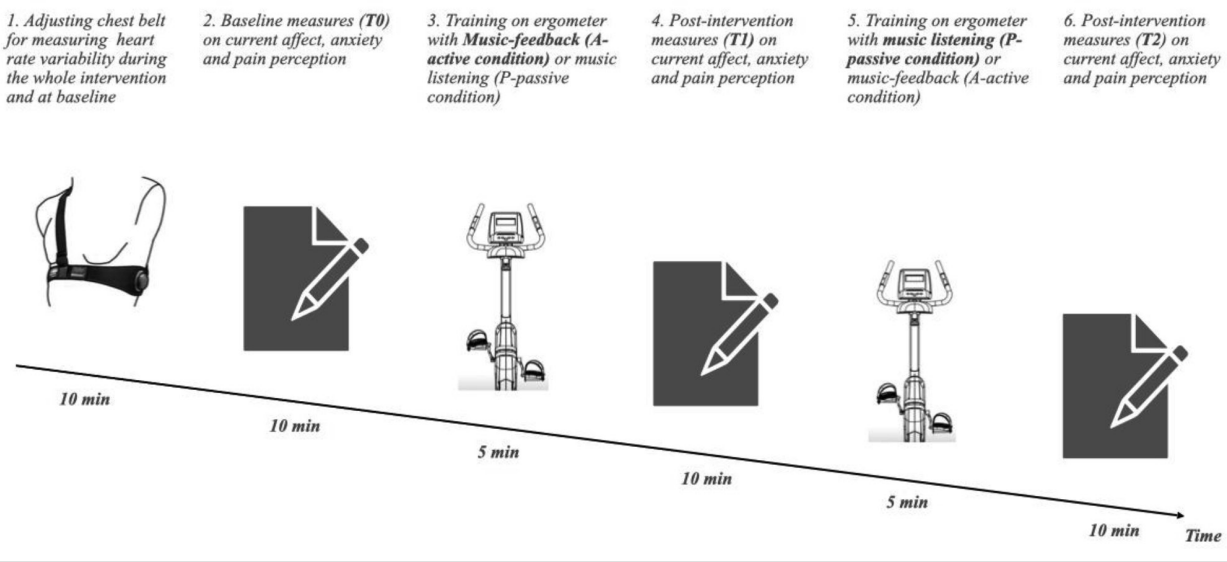


Fig. 1. *Schematic representation of timeline of experimental procedure for each patient.*

and type of physical exercise had been chosen by the cooperating doctor and physiotherapists as best fit the needs of the patient group and was set to 5 minutes of ergometer (THERA-Trainer) training with patients' legs for each condition. Patients trained independently after they were introduced to the ergometer. Meters driven during the 5-minute training intervals were recorded as objective measures of motivation.

Data Analysis

All data were first assessed for normality. Transformations were used to approximate normal distributions where necessary (e.g., log transformation). Nonparametric tests were used for ordinal data (pain, anxiety, mood, subjective motivation). A parametric t-test was used to analyze meters driven. Spearman's correlations were used for exploratory hypothesis testing (H1-H2 explorative, see above). Data analyses were performed for n = 42, since one patient could perform only one condition due to a starting migraine attack prior to the experiment.

Results

The current study investigated the effects of music feedback during physical exercise on emotions, motivation, and pain in patients with chronic pain conditions during an acute clinic stay. The first hypothesis (H1 confirmative), that pain perception was more greatly reduced after the training with music feedback (experimental condition) than after the training with music listening (control condition), could not be confirmed. Results showed no difference between baseline pain levels and pain levels after the physical training ($Z = -0.137$, $P = 0.45$ [one-tailed]). Furthermore, during the physical training, similar levels of pain intensity ($n = 42$; $Z = -1.368$, $P = 0.85$ [one-tailed]) and pain unpleasantness ($Z = -0.244$, $P = 0.40$ [one-tailed]) were reported for both the experimental and the control condition (Table 4). Note that the order of the conditions had no effect on the levels of pain intensity ($Z = -0.582$, $P = 0.561$) or on unpleasantness ($Z = -1.289$, $P = 0.197$).

For the second hypothesis (H2 confirmative), results showed that anxiety levels were significantly reduced after both the training with music feedback (active condition vs. baseline: $Z = -4.213$, $P < 0.001$) and the training with music listening (passive vs. baseline: $Z = -3.864$, $P < 0.001$) in comparison to baseline anxiety levels. The experimental condition showed no stronger reduction in anxiety levels (active vs passive: $Z = -1.606$, $P = 0.054$ [one-tailed]) (Fig. 2).

Results regarding the third hypothesis (H3 confirmative), that motivation to exercise was stronger during the training with music feedback than during the training with music listening, as measured by active engagement during the training interval, confirmed that hypothesis. During the ergometer training with music feedback, patients drove a significantly greater distance (more meters) in the 5-minute time window

than during the ergometer training with passive music listening (t(39) = 3.013, *P* = 0.006 [Bonferroni-corrected]; 95% CI: 0.01040; 0.05289; Cohen's d = 0.66 [medium effect]). The order in which patients undertook these 2 forms of training had no significant effect (Fig. 3). Additionally, patients' subjective reports on their motivation to exercise (on a VAS of 0-100 mm) also differed significantly. During the active condition (Mdn = 8.2; Var = 6.452) patients showed a significantly higher motivation to exercise than they did during the passive condition (Mdn = 7.25; Var = 8.17), with Z = -2.294, *P* = 0.033 (Bonferroni-corrected).

Table 4. *Displays descriptive statistics on patients' pain levels at baseline during and after each physical exercise condition, as measured on a visual analog scale (VAS) (100 mm). Medians (Mdn), variances (Var), and minimum and maximum values (min-max) are reported.*

Pain Measurement	Baseline Assessment (During Rest) (n = 42) (Mdn, Var; min-max)	Active Condition (Mdn, Var; min-max)	Passive Condition (Mdn, Var; min-max)
Pain intensity (VAS) before and after each training	4.05, 3.75; 1.0-9.0	3.40, 4.70; 0- 8.5	3.20, 3.20; 0- 8.6
Pain intensity during training (VAS)	-	2.70, 6.12; 0 - 8.4	3.10, 4.94; 0.1- 8.0
Pain unpleasantness during training (VAS)	-	2.30, 6.05; 0- 8.5	2.50, 5.14; 0.1- 9.0

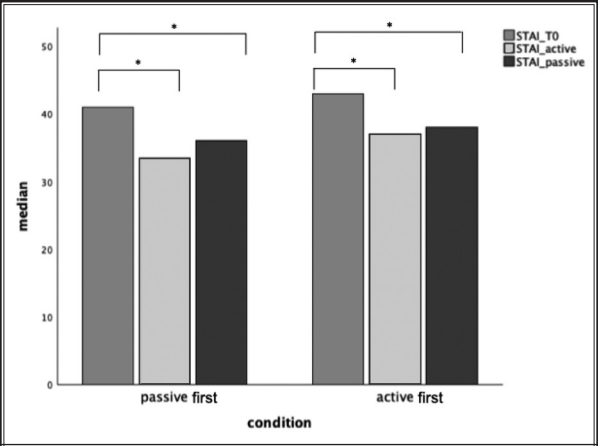


Fig. 2. *After each condition, anxiety levels were reduced significantly (*) from their baseline counterparts, as measured on the State-Trait-Anxiety-Inventory (STAI). Whether patients undertook the passive condition or the active condition first had no effect. The active and passive conditions did not differ significantly from each other.*

Exploratively, it was investigated if a reported match/congruency of current mood and emotion transferred by the chosen music pieces correlated with changes in patients' pain perception. Results indicated a significant correlation of differences observed in pain perception between the active and passive conditions as well as differences in the reported emotional matching of music pieces between those conditions (Spearman's correlation: r = -0.438, *P* = 0.007). Interestingly, the match of the patients' own emotional states with the music played while exercising was significantly higher during the active music-feedback condition (Mdn = 7.7) than during the music-listening condition (Mdn = 6.35; Z = -3.429; *P* < 0.001; Fig. 4). A second explorative hypothesis investigated if changes in pain perception correlated positively with changes in heart rate variability as a measure of emotional processing. Results showed no significant correlation between changes in pain intensity (as measured on a VAS) and changes in heart rate variability for the active or passive conditions (SDNN; r = 0.15, *P* = 0.952).

During the pair of 5-minute interventions, a certain patient could perform only one condition due to the onset of a migraine attack prior to the experiment. No other adverse events occurred during or on the days after the experiment (as monitored by clinical staff).

Discussion

The present study investigated the effects of music on pain perception, emotional states, and motivation to exercise in patients with chronic pain conditions. We compared music listening (passive) to music feedback (active) during ergometer training, using a crossover design.

Effects on Pain Perception

No significant differences in pain perception (intensity or unpleasantness) were found between the music-feedback and music-listening conditions. Neither condition altered pain perception from baseline. This result may be due to a lack of exercise-induced hypoalgesia in chronic pain patients (18). While exercise reliably induces hypoalgesia in pain-free individuals, results are mixed in chronic pain populations, with some studies even reporting hyperalgesic effects (18). Therefore, the effects of physical exercise on patients' current pain levels might have influenced the effects

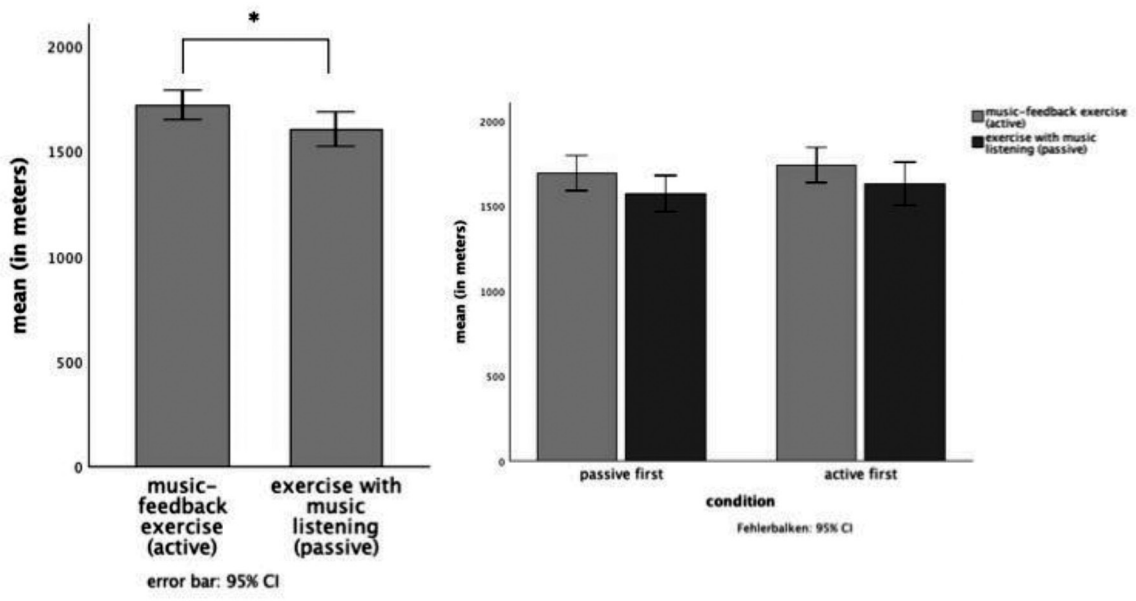


Fig. 3. *The distance (in meters) driven during the 5 minutes of ergometer training was significantly (*) higher during the active condition than during the passive condition. Whether patients undertook the active condition or the passive condition first had no significant effect.*

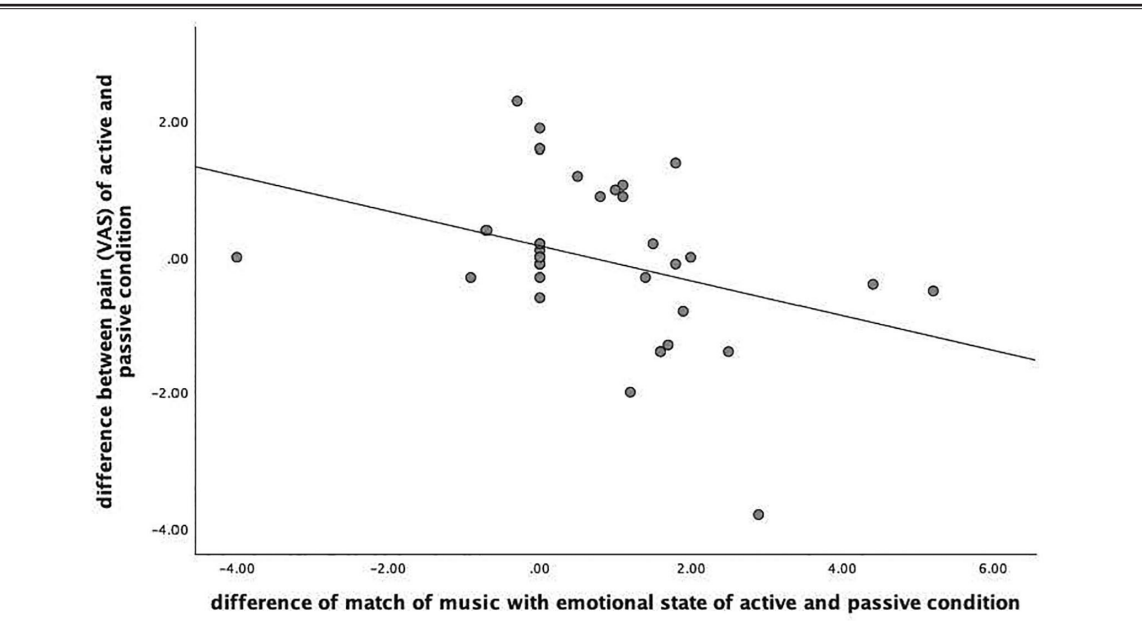


Fig. 4. *Spearman's correlation of differences in pain perception (active/passive condition) and differences in emotional matching of music (active/passive condition) reveals a significant correlation.*

of the musical interventions. Interestingly, research on painful vs. pain-free exercise in patients with chronic musculoskeletal pain shows short-term benefits associated with painful exercise but no long-term differences (28). Thus, pain during exercise may not negate its benefits (28), though it can exert a negative impact

on motivation (29). Decreasing the threat value of pain and movement is crucial for promoting regular physical activity in patients with chronic pain conditions (18).

Effects on Motivation

Despite similar pain levels between the 2 types of training, motivation was significantly higher in the music-feedback condition. Both subjective and objective measures confirmed this observation. Patients covered ~200 more meters on the ergometer with music feedback and reported greater motivation than they did during the passive music condition. Those effects were independent of condition order. These findings suggest that pain that occurred during the music-feedback condition was less disabling in terms of the amplitude of physical engagement. Enhancing physical activity motivation is crucial for chronic pain patients, since "physical activity should be the primary intervention for individuals living with chronic pain" (14). Importantly, increased activity with music feedback did not worsen pain, addressing a common fear among chronic pain patients. While both conditions reduced anxiety, the music-feedback condition did not show a stronger effect than the music-listening condition, differing from the results of previous research (25). These differences may be due to variations in study designs, such as exercise type, pain severity, and training duration.

Factors Influencing Motivation

Why were patients more motivated with music feedback despite experiencing similar pain and anxiety levels between the 2 conditions? Music feedback may enhance self-efficacy and autonomy, 2 factors that have been described as motives for patients with chronic pain to engage in physical activity (29). That patients could make their own efforts audible through music feedback might have had a modulating effect on the sense of self-efficacy. Patients "created" music despite their pain, potentially strengthening their belief in their competence to perform health-related behaviors despite barriers. A novelty effect may also contribute to increased motivation during music-feedback exercise. The novelty effect with the use of new technologies is the initial positive response, which may not persist over time (30). Although a study on Fitbit devices used by healthy individuals found a novelty period of ~3 months (30), different mechanisms may be relevant for chronic pain patients. For example, avoidance behavior could be diminished by initiating physical engagement. Repeated experiences of physical activity without worsened pain could gradually reduce patients' avoidance and fear of movement (similar to exposure therapy for patients with chronic pain, for example [31]), regardless of the novelty effect. The possibility that the novelty effect might add to increased motivation would therefore be beneficial for chronic pain patients' long-term motivation to engage in physical activity, especially given the previous evidence from the study on Fitbit devices that the novelty effect could be sustained for several months.

Relevance of Emotional Match of Music and the Individual's Emotional State

We explored the relationship between pain perception differences and the perceived emotional match of the music. Music feedback led to a greater match between music and patients' emotional state, which correlated negatively with pain intensity. Although the music was the same in both conditions, the ability to influence it in the music-feedback condition could have enhanced the sense of emotional matching. This possibility may be due to a perceived match between movement/arousal and musical properties, making the experience more personalized. The concept of floating intentionality (32) describes the phenomenon—the meanings of musical pieces are interpreted individually by listeners, experienced as personal to them and at the same time as "immediate and direct." This concept applies also to passive music listening, but the effect may be increased by a stronger sense of synchrony between the music and the patient's own movements/arousal, which might have led to an even stronger experience of intentionality matching in the music-feedback condition. Furthermore, studies suggest that music can imitate emotionally driven movement (33). We hypothesize that musical agency may further increase the experience of floating intentionality. Personalized, expressively "played" music may correspond more strongly to individuals' current experiences. For example, cycling speed may determine the perceived arousal of musical emotions. The "aesthetic positivity bias" (34) towards self-created music may further enhance identification with the music. Ambiguity in musical meaning may enhance the matching experience, allowing for diverse interpretations based on the individual's own emotional state; e.g., cycling at high speed with music feedback may be perceived as "imitating" running away when patients perceive a high level of default fear, while cycling at high speed with music feedback

may be perceived as "imitating" running through a meadow when patients are in a happy state. This interpretation adds to our understanding of how active music interventions in which patients control a music outcome have been argued to be efficient at modulating psychological parameters, also through mood/emotional states (35). We also explored whether music feedback enhanced the quality of emotional processing via increased heart rate variability (HRV). However, no differences in HRV were found between the conditions or in comparison with baseline.

Limitations

The patient sample in the current study was typical for a clinic designed to treat acute pain disorders and was chosen to ensure a high external validity. However, the heterogeneous patient sample limits specific conclusions about effects on certain pain conditions. The focus on immediate effects precludes conclusions about long-term outcomes, and the inclusion of music in both conditions prevents the direct comparison of exercise with and without music.

Conclusions

Music feedback during exercise reduced the disabling effects of pain on physical engagement in chronic pain patients and enhanced their engagement and motivation. However, the immediate effects on pain perception were not significant. Music feedback created a greater match between music and patients' emotional states, which correlated negatively with pain intensity. Both music conditions reduced anxiety. Because music listening is easily implemented and low-cost, it should be considered during physical exercise for patients with chronic pain conditions. Future research should investigate the long-term effects of music interventions during exercise. Long-term changes in emotional processing (e.g., HRV) may emerge with regular music-feedback training.

Author Contributions

LS, CE, MS, and TF contributed to the conception or design of the study. LS, AW, and JG handled the data collection, and LS proceeded to the data analysis and interpretation in addition to drafting the article. Later, LS, CE, MS, and TF undertook the critical revision of the paper. Lastly, all authors were responsible for the final approval of the version to be published.

Conflict of Interest

One of the authors (TF) and the Max Planck Institute for Innovation and Competition are shareholders in Jymmin, a Max Planck Institute for Human Cognitive and Brain Sciences spinoff that has developed the professional music feedback product implemented in the rehabilitation ergometer applied in the current research Other authors certify that he or she, or a member of his or her immediate family, has no commercial association (i.e., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

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